Electricity and Magnetism Activities

Ball in a Capacitor

Apparatus

huge parallel plate capacitor (two large metal plates mounted parallel to each other so that they can slide closer or further apart), van de Graaff generator or some other means of charging the capacitor, table tennis ball coated in conductive paint or wrapped in aluminium foil and suspended on a thread from a retort stand

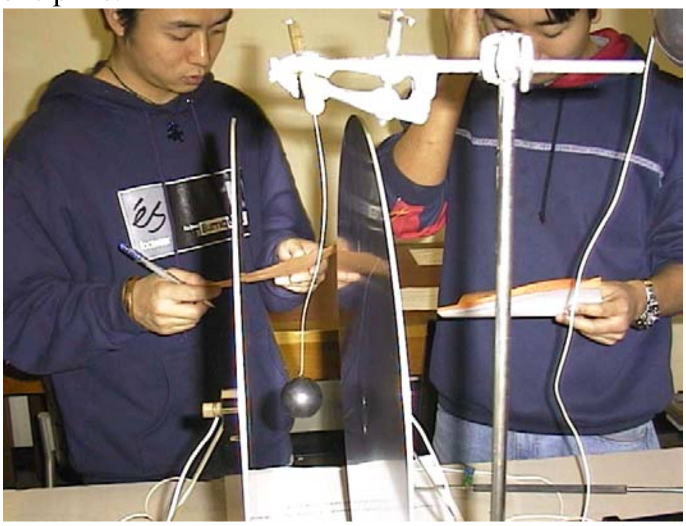
Action

The students hang the ball between the capacitor plates and observe the balls behaviour when the capacitor is charged. They can experiment with hanging the ball at different heights and moving the plates to different separations. If the ball is covered in foil they can remove the foil and see what effect this has.

The Physics

Charge separation occurs on the surface of the coating on the ball, positive charges are attracted towards the negative plate and negative charges are attracted towards the positive plate. The ball with not be perfectly spherical, nor is it likely to be precisely halfway between the plates, hence the attraction towards one plate will be slightly greater than the attraction towards the other. The ball will accelerate and swing to touch one plate. When it touches the plate, charge transfer occurs and the ball becomes charged the same way as the plate. It is then repelled by this plate and attracted by the other plate. It swings across to the other plate, where it becomes oppositely charged. It then bounces back and forth between the plates. Removing the foil prevents or greatly slows the transfer of charge, so the ball will still be attracted to one plate, but will then only bounce extremely slowly or stick to the one plate.

Students at the University of New South Wales puzzling over the ball in the capacitor.



Accompanying sheet

Ball in a Capacitor

Hang the ball between the capacitor plates.

Charge up the capacitor.
What do you observe?
Why is this happening?
Sketch the field lines for the capacitor.

Batteries I

Apparatus

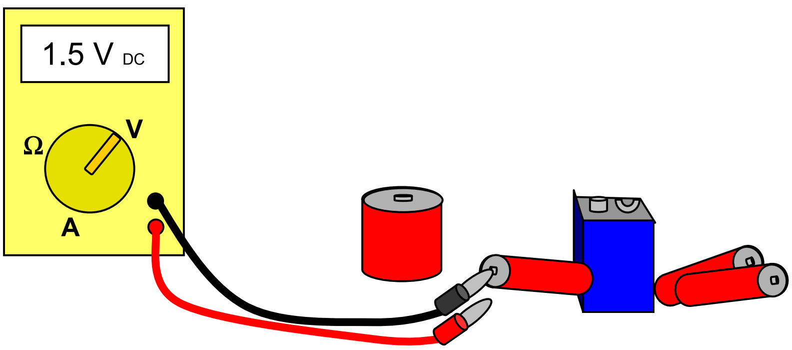
selection of different batteries, voltmeter

Action

The students examine the different batteries and describe how energy is stored in them. They can measure the potential difference across the terminals of the different batteries using the voltmeter.

The Physics

A battery [or cell] is a source of energy in electric circuits – a device for providing an electric current. This is done through the potential energy stored in the chemical bonds of the materials that make up the battery. Electrochemical cells are the simplest type of cell capable of producing an *emf.* They consist of two different metal plates [Zn and Cu] immersed in an electrolyte [sulfuric acid solution]. In chemical cells work is done by the disintegration of zinc or lead in acid. The copper plate loses electrons and becomes deficient in electrons, and this causes more electrons to flow via the conducting circuit from the zinc plate. Hence there is a current in the external circuit carried by electrons flowing from zinc to copper and a current in the cell carried by hydrogen ions flowing from zinc to copper. In a Dry Cell the electrolyte is a moist paste instead of a liquid solution. It has a carbon rod down the centre, which replaces one of the metals. The other electrode is in the zinc surrounding the paste. The cell is then covered with an insulating material. Rechargeable batteries are recharged with the negative terminals of the charger and battery connected to each other. This forces the current to run backward through the battery, reversing the chemical reactions.



Accompanying sheet

Batteries I

Observe the different batteries.

Use the voltmeter to measure the potential difference across the terminals of some of the batteries.
Does the size of the battery relate to the potential difference?

How is energy stored in the batteries?

Batteries II

Apparatus

selection of different batteries, voltmeter, wires and resistors

Action

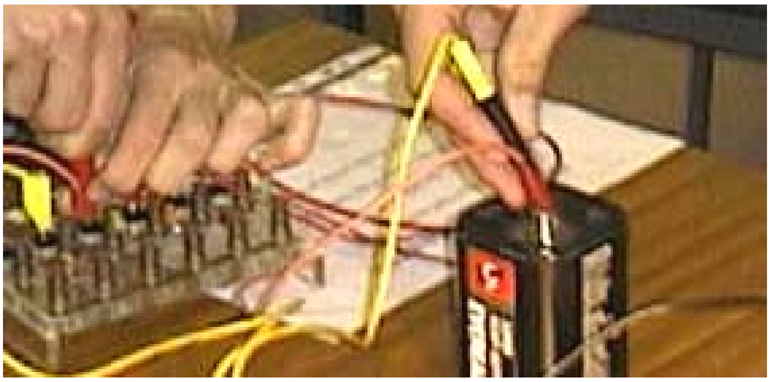
The students examine the circuit and determine which way the current is flowing. They can then measure the changes in potential across different components.

The Physics

The electrons move in the opposite direction to conventional current (flow of positive charges). The electrons gain potential energy as they move through the potential difference supplied by the battery, and lose potential energy as they pass through the resistors. The role of the battery is to supply energy to the electrons, it is a source of *emf*.

The person responsible for naming positive and negative charge was Benjamin Franklin who did not know that the charge carriers in a metal are really negatively charged electrons. So we are stuck with the notion of conventional current which we imagine to be a flow of positive charge, out of a battery's positive terminal, through a conducting path, and into its negative terminal. Some people like to be more realistic and imagine the actual flow of electrons in the opposite direction. Provided either convention is kept constant in calculating variables in a circuit, you will obtain the correct answer.
The battery provides an electrical potential difference which causes a current to flow.

A battery being connected to different globes and resistors.



Accompanying sheet

Batteries II

Examine the circuits containing the batteries.
In which direction is the current flowing in each circuit?
In which direction are the electrons moving?

Describe the changes in potential energy of the electrons as they move around the circuit.
What is the role of the battery?

Charged Rods

Apparatus

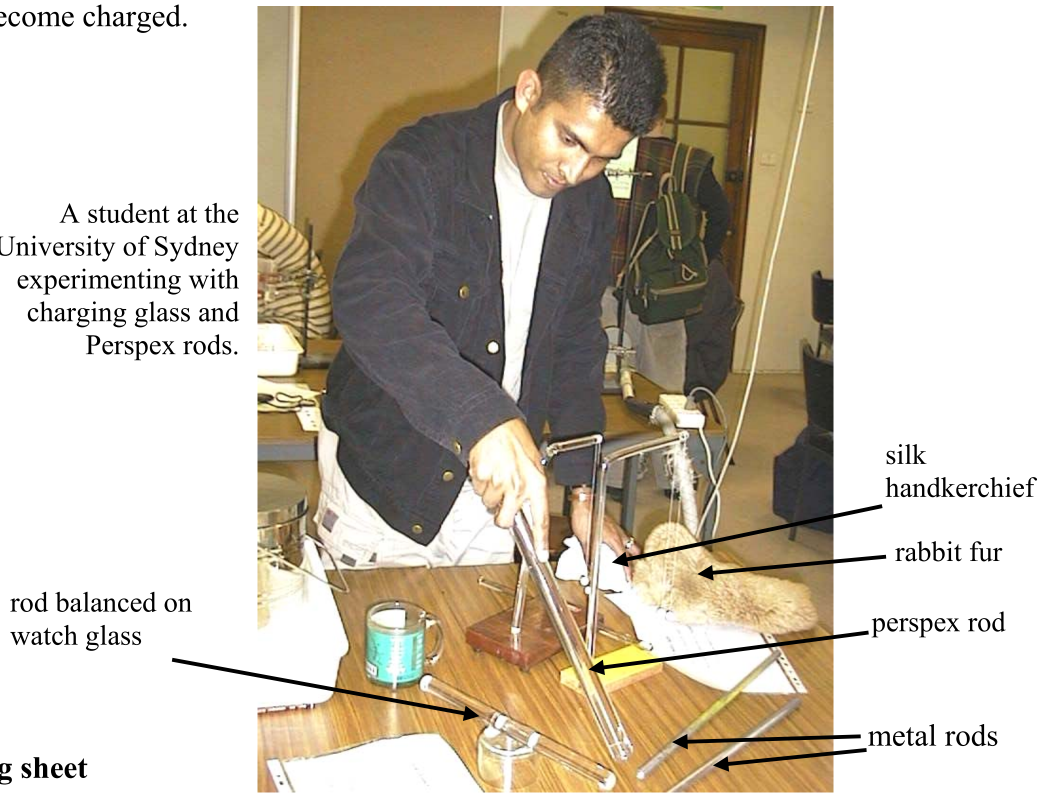
perspex, glass and metal rods, silk and fur for rubbing, petrie dish and watch glass, small lumps of blu-tack.

Action

The students charge a rod by rubbing it and balance it on the watch glass. They then charge a second rod, and by bringing the end of it near the first rod they can accelerate the rod balanced on the glass, causing it to spin. They should also try to charge the metal rod.

The Physics

The rods are charged by electrons moving to or from them from the fur or silk. The glass and Perspex rods will become charged, and can be used to show electrostatic force at a distance (an electric field). The metal rod is a conductor, and excess charge on the metal will flow to the person charging the rod and to earth so it will not become charged.



A student at the University of Sydney experimenting with charging glass and Perspex rods.

Accompanying sheet

> **Charged Rods**
>
> Charge up the rods using different materials.
> How do the items get charged?
>
> Balance a charged rod on a watch glass.
> How can you accelerate it without touching or blowing on it?
>
> Could you charge a metal rod in the same way?
> How would the charge distribution differ?

Charging Capacitors

Apparatus

range of large capacitors and resistors connected in series to a low voltage power supply, oscilloscope to view charging/discharging curves

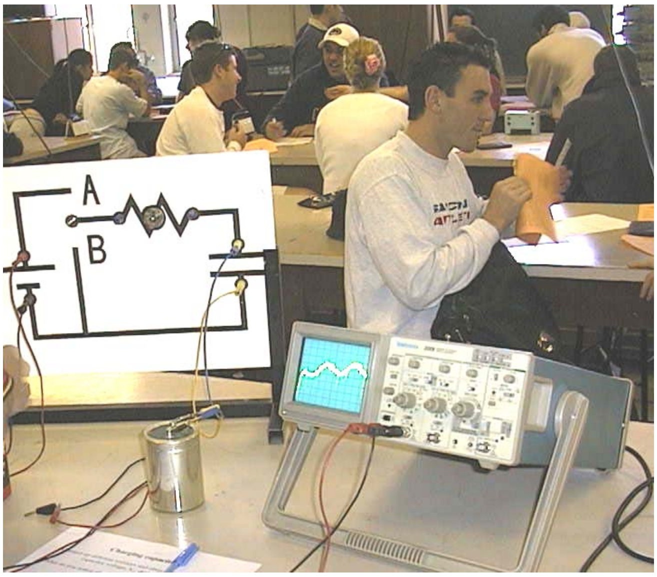
Note – depending on the students experience in connecting circuits, the circuits can be set up in advance or left for the students to connect.

Action

The students connect up the circuit to the oscilloscope and the power supply. They should observe the charging curve for the RC circuit. They then connect a different resistor and observe the effect on the charging time. If multiple capacitors (or a variable capacitor) are available they can also experiment with varying the capacitance.

The Physics

The voltage across the capacitor increases during the charging phase such that $V(t) = V_0(1 - e^{\frac{-t}{RC}})$. The larger the capacitance or the resistance, the greater the time constant, *RC*, and the longer it takes for the capacitor to charge. Many students find a fluid analogy helpful – the bigger the bucket or the narrower the hose to fill it, the longer it takes to fill.



An RC circuit hooked up to an oscilloscope at the University of New South Wales for an Industrial Design workshop.

Accompanying sheet

Charging Capacitors

Connect up different resistors
and observe the effect on the capacitor voltage, V_c, during charging.

What do you notice about the rate of charging with different resistors in the circuit?

Suppose instead that we kept the resistor fixed and changed the capacitor
would this produce a similar result?

Confused Bubbles

Apparatus

van de Graaff generator, bubble mix, loop for blowing bubbles

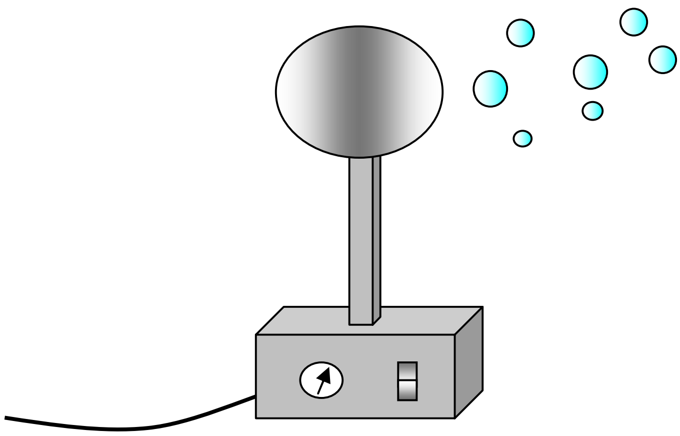
Action

The students blow bubbles towards the generator and watch what they do. Note that students can become easily distracted and spend too much time playing with the bubble mix, so this demonstration needs to be carefully supervised.

The Physics

The bubbles are initially uncharged. As they float near the van de Graaf generator, which is positively charged, there will be charge separation on the bubbles. Negative charges will be attracted towards the generator and move to the closer side of the bubble. Positive charges will be repelled and move to the opposite side. The bubbles will be attracted to the generator and accelerate towards because of this charge separation, even though the bubbles are still neutral. If a stream of bubbles is blown towards the generator other behaviour may be observed. If a bubble breaks in midair it may spray charged particles on to other bubbles. Those behind the burst bubble may be sprayed with positive charge and become net positively charged. These bubbles will then be repelled from the generator.

Note- this demonstration works best when a slow stream of large bubbles is blown towards but slightly to one side of the generator.



Accompanying sheet

Confused Bubbles

Blow some bubbles towards the generator.

Are the bubbles initially charged?
What do the bubbles do?
Why do they behave like this?

Current, Potential and Resistance - a Fluid Model

Apparatus

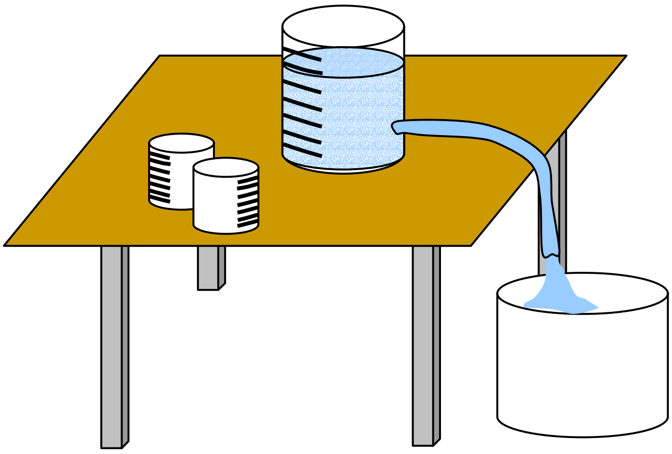
large container with hole at the bottom, beakers, bucket, flexible plastic tubing, paper towels for cleaning up afterwards

Action

The students put water into the large container and allow it to flow out. They should identify the changes in energy of the water as it flows through the system. They can change the resistance, and hence the current, by squeezing the tubing. They can change the gravitational potential energy of the water in the container by raising or lowering the container, and observe the effect this has on the current. The current can be measured by measuring the amount of water that flows out of the tube and into a beaker in a given time, or by using a flow meter if available.

The Physics

The energy of the water is determined by the height of the large container. This gravitational potential energy is converted to kinetic energy of the water when it is allowed to flow. Squeezing the tube is analogous to increasing the resistance in a circuit, which decreases the current. The difference in gravitational potential (proportional to the height) between the water in the container and the end of the pipe is analogous to the potential difference or *emf* provided by a battery, and increasing this height difference will increase the current flow.



Accompanying sheet

Current, Potential and Resistance - a Fluid Model

How can you measure the current here?

How does changing the gravitational potential change the current?

How can you change the resistance?
What effect does increasing the resistance have?

Current- Voltage Characteristics

Apparatus

low voltage variable power supply, voltmeter, ammeter, resistor, low voltage globe

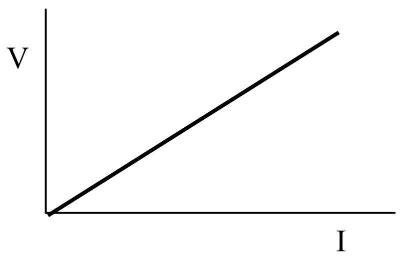
Action

The students measure current through and voltage across the resistor and then the globe for several voltages of the power supply. They should sketch the current as a function of voltage for both the globe and the resistor.

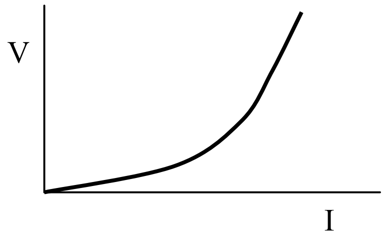
The Physics

The temperature of the filament in the globe increases very quickly as the current increases. The resistance increases with temperature, hence the I-V plot for the globe is curved. This is a useful demonstration as many students assume that all devices have a linear current-voltage curve.

resistor



globe



Students at the University of Sydney measuring the current voltage characteristics of a resistor and a light globe.

Accompanying sheet

Current – Voltage Characteristics

Measure current through and voltage across the resistor for different voltages.

Repeat these measurements for the globe.

Sketch a graph of *I* vs *V* for a resistor and a globe.

What do you notice about the I-V characteristics of the resistor and the globe? How are they different?

Earth Connections

Apparatus

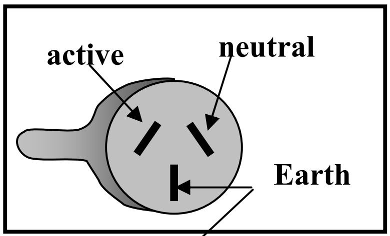
selection of appliances with and without earth connections, and a dismantled appliance showing where the earth lead connects; for example hair dryers, toasters, power drills

Action

The students examine the appliances and identify the earth connection. They should discuss the importance of correctly earthing appliances.

The Physics

The appliances with a third pin in their plug are earthed. The third wire is the earth connection, the other two pins are the live connections – the active and the neutral. If the earth is disconnected the appliance will usually still work, but will be unsafe to use. The earth connection usually provides a low resistance path from the casing of an appliance to the ground. If there is a short circuit and there is current flow to the case, the current will flow through the earth connection rather than through anyone touching the appliance.



Accompanying sheet

Earth Connections

Examine the appliances.
Which ones are properly Earthed? How can you tell?

What is the role of the Earth connection?
Why is it important that appliances be properly Earthed?

Electricity Generator

Apparatus

a coil which can be turned by hand, mounted between a pair of magnets, connected to an LED or low voltage globe

Note – this can be easily made by attaching a handle to a simple kit electric motor and replacing the battery with an LED or small 1.5 V globe.

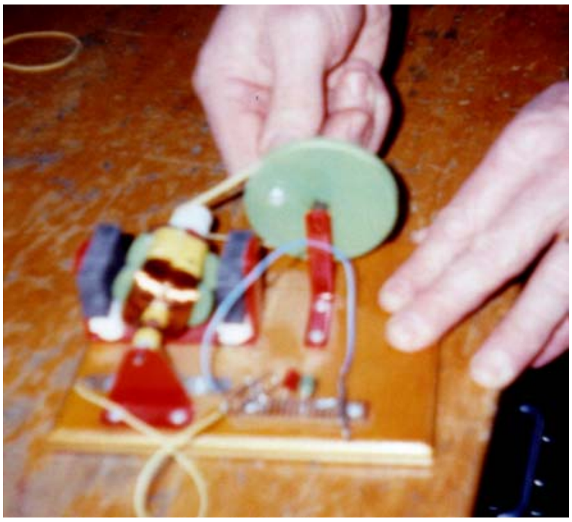
Action

The students turn the handle and watch the globe light up. They should compare this to an electric motor and discuss how this is similar and different.

The Physics

The generator is really just a motor in reverse. Rather than using a current in a magnetic field to produce a torque on a coil, it uses the motion of a coil in a magnetic field to induce a current in the coil. The induced *emf* in the coil is proportional to the rate of change of magnetic flux through the coil. As the coil rotates the magnetic flux oscillates, increasing and decreasing as the angle between the plane of the coil and the field changes. This induces an alternating current in the coil, which lights up the LED as the current flows in one direction only.

The motor converts electrical potential energy (from the battery) into kinetic energy, the generator converts kinetic energy into electrical potential energy.



Small hand driven generator used at Monash University.

Accompanying sheet

Electricity Generator

Turn the handle on the generator.

What is happening? Why?

How is this similar to the electric motor?
How is it different?

Electromagnetic Induction – 2 Coils of Wire and a Magnet

Apparatus

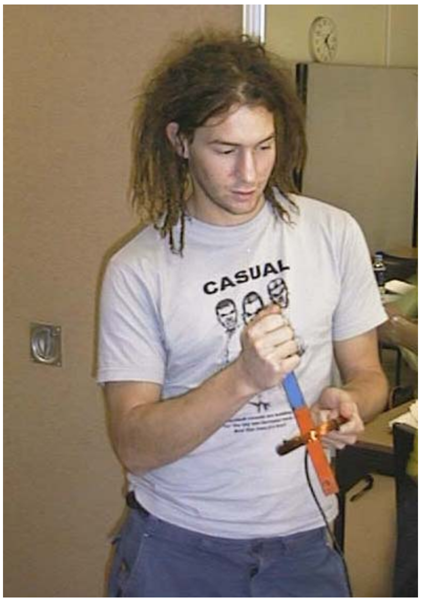
Power supply, current carrying coil, second coil connected to ammeter, bar magnet
If a centre-zero ammeter is not available it is worthwhile using the zero-adjust to move the needle's zero position well onto the scale.

Action

The students experiment with moving the coils relative to each other, and observing the induced current. They also experiment with moving the magnet in and out of the coil in different directions. They should investigate the effects of speed and direction of movement on the induced current.

The Physics

The direction of the current depends on the motion of the magnet relative to the loop and changes when the magnet is reversed. The magnitude of the current depends on the speed of the motion, number of turns of wire and the 'angle' between the loop and the magnet. It doesn't matter whether the coil or the magnet is moved, only the relative motion of the two is important (it was this observation that led Einstein to his theory of relativity).
A current carrying coil of wire has a magnetic field so there will be an induced current in a closed loop of wire which is moving relative to a current carrying coil. Moving the coil should produce exactly the same effect as moving the magnet.



A student at the University of Sydney experimenting with a magnet and a coil.

Accompanying sheet

Electromagnetic Induction – 2 Coils of Wire and a Magnet

Move the magnet in and out of the loop of wire with the ammeter.
Does the direction of the current depend on the motion of the magnet relative to the loop?
What happens if the magnet is reversed?
What happens if the loop is moved and the magnet is stationary?

Now repeat these observations using the current carrying coil instead of the magnet.

Electroscope and Electrophorus

Apparatus

Perspex plate, rubber gloves, metal plate with insulating handle, electroscope

Action

The students rub or slap the perspex plate with the rubber gloves which moves charge (by friction) onto the perspex plate. They then place the metal plate over the perspex plate which induces charge separation on the metal plate. The students then touch the upper surface of the metal plate with a finger, allowing the excess charge from the top surface to flow to Earth while leaving the excess charge on the bottom surface. This leaves the metal plate with a net charge. When they hold the metal plate with the insulating handle and bring it close to the electroscope the leaves will separate. They should note that they don't need to touch the electroscope for the leaves to separate.

The Physics

The charging is achieved by friction, with organic molecules being broken on the gloves and Perspex. The metal is a conductor so charges will easily separate and the excess charges flow through the persons finger (also a conductor) to Earth. When the charged metal plate is held near the electroscope it attracts opposite charges from the leaves towards the top cap, leaving the leaves charged. The leaves will have like charge and hence will repel each other and separate. The leaves will have the same sign charge as the plate. If the plate is touched to the electroscope some excess charge will move from the plate to the electroscope, and the leaves will again have like charge, and the same sign charge as the plate.

Accompanying sheet

Electroscope and Electrophorus

Slap the bottom plate with the rubber gloves.
Now put the upper (metal) plate on top of the lower plate.
Touch your finger to the upper surface of the metal plate.

Using the handle, hold the plate above the electroscope.
What is happening here? How does the plate become charged?

Energy Stored by a Capacitor

Apparatus

very large capacitor, battery, low voltage motor with fan or other attachment

Note – disposable cameras use capacitors to provide a quick burst of energy for the flash, these make an excellent example of the use of capacitors and a cheap additional display.

Action

The students connect the battery to the capacitor and allow it to charge. They then disconnect the battery and attach the capacitor to the motor. They should discuss how energy is stored in a capacitor, and how this can be used.

The Physics

The capacitor stores electrical potential energy $U = \frac{1}{2} CV^2$, in the form of stored charge and an electric field. Capacitors can make useful short term back up power supplies, and are used when a brief but rapid supply of energy is needed, for example in camera flashes.

Large capacitor with battery and motor.

Accompanying sheet

Energy Stored by a Capacitor

Connect the battery to the capacitor and allow it to charge up.
Now disconnect the battery and connect the motor to the capacitor.

How is energy stored in the capacitor?
Give an example of when this energy storage would be useful?

Equipotentials

Apparatus

low voltage power supply, electrodes (at least 2 plate or point electrodes), teledeltos (conducting) paper, voltmeter with probes

The electrodes are connected to the positive and negative terminals of the power supply and a sheet of teledeltos paper is placed over the electrodes.

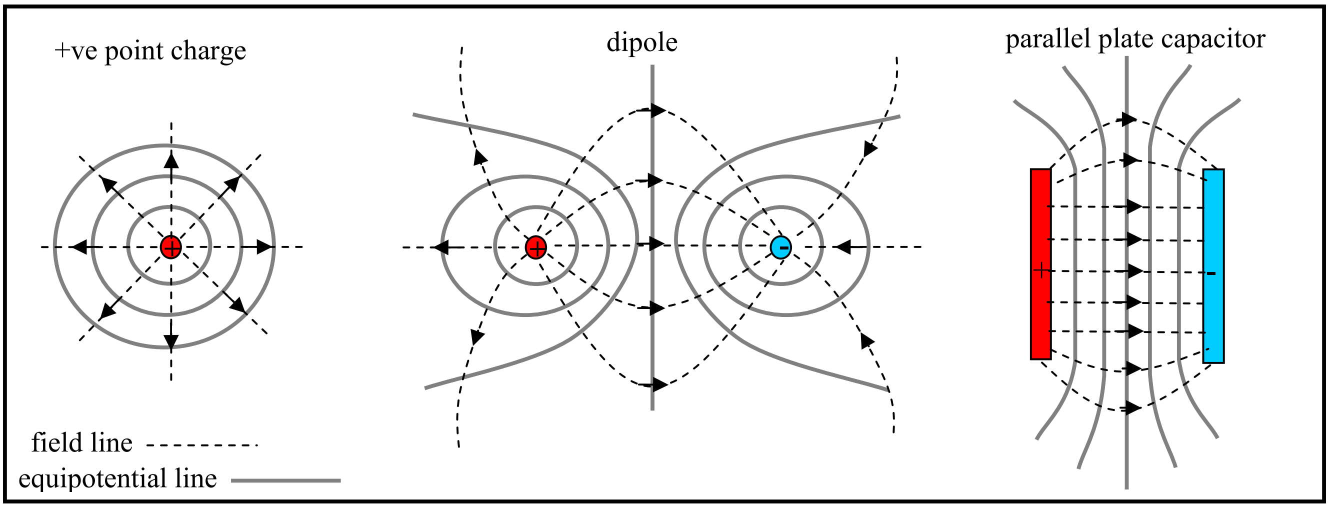
Action

One probe of the voltmeter should be connected to or held against a chosen reference point, for example one of the electrodes. The other probe is moved around the surface of the paper to find points of equipotential. The students should map out several lines of equipotential. They can then sketch the equipotential lines for the arrangement of electrodes and use these to draw field lines.

If other electrodes are available, for example plate electrodes, the students can investigate the potential between the plates of a parallel plate capacitor and other arrangements.

The Physics

Equipotentials are surfaces which have the same value of electric potential. Some examples are shown below. Field lines represent the magnitude and direction of forces. Field lines are perpendicular to equipotentials, so you can use equipotentials to draw field lines.



Accompanying sheet

Equipotentials

Use the probes to find lines which have the same potential all the way along them.

These are called equipotential lines.

How can you use these lines to draw field lines?

Faraday's Icepail

Apparatus

electroscope, large metal can, perspex or glass rod, fur to charge the rod, metal ball on an insulating stick to charge the can

Note: any means of charging the ball on the stick can be used.

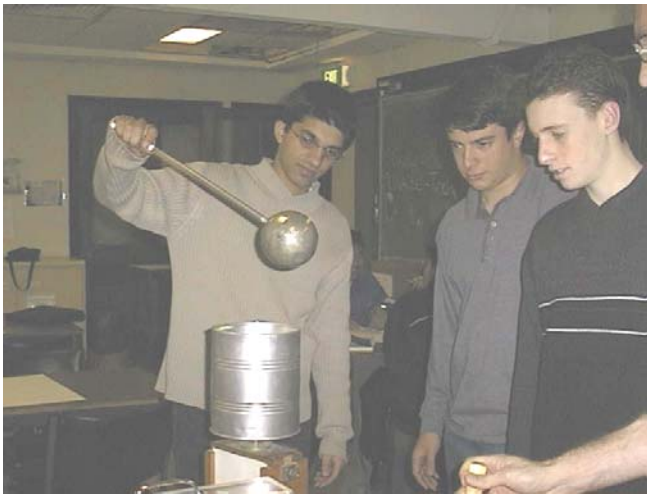
Action

The students charge up a rod and use it to charge up the metal ball on the stick. They then lower the ball into the can, which sits on top of the electroscope. They should observe the leaves of the electroscope separating. They then touch the ball to the bottom of the inside of the can. The can should now be charged, and the leaves stay separated when the ball is removed. The students should remove the can from the electroscope, discharge it (for example by Earthing via a finger) and check whether the ball retains any excess charge.

The Physics

When the ball is touched to the inner surface all its excess charge is transferred to the container and appears on the outer wall of the container. All the charge is transferred because when the ball is in contact with the container they act as a single conductor. The electric field within a conductor is zero, and if you draw a Gaussian surface inside the conductor it will contain zero charge because $E = 0$ everywhere on the surface. Hence the ball can contain no charge. When the ball is removed, they should see that it has no charge, thus confirming Gauss's law.

Students at the University of Sydney experimenting with Faraday's Icepail



Accompanying sheet

Faraday's Icepail

Charge the metallic ball.
Lower the ball into the pail without touching the walls.
What do you observe?

Touch the inner surface of the pail with the ball.
Now what do you observe?

Take the ball out of the pail.
How did the initially neutral pail become charged?
What has happened to the charge on the ball?

Flux

Apparatus

solar cell, desk lamp, ammeter

Action

The students hold the solar cell under the lamp and observe how the voltage varies as the angle and position of the solar cell is changed. They should relate the current to the flux of photons incident on the solar cell. (Note- students should be cautioned not to put the solar cell too close to the light as it may melt.)

The Physics

The current is directly proportional to the flux of photons incident on the solar panel. This will be a maximum when the surface of the panel is perpendicular to the direction of the flow of photons, and a minimum when it is parallel. The flux can also be increased by moving the solar cell closer to the light.

Students at the University of Sydney measuring the current output of a solar cell for different orientations of the cell relative to the light source.

Accompanying sheet

Flux

Hold the solar panel in front of the light.

How can you orient the panel to maximise the flux?

How can you orient the panel to minimise the flux?

If the orientation were kept constant,
how would the flux change if you doubled the area of the panel?

Gauss' Law

Apparatus

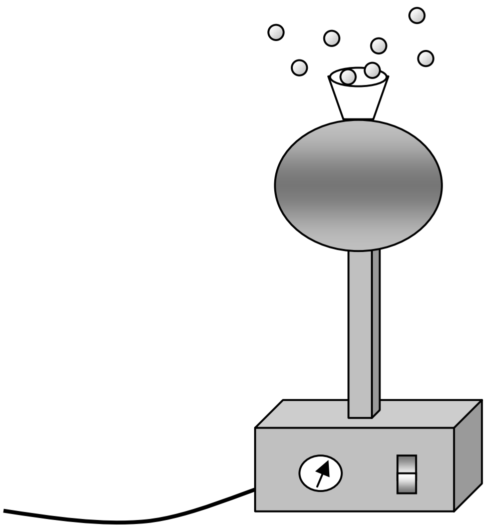
van de Graaff generator, metal can, plastic or foam cup, large polystyrene beads
Note- large beads that can be easily found and picked up are best, small ones can be very messy.

Action

The students place the metal can on the generator and fill it with beads. They then turn on the generator. They repeat this with the plastic or foam cup. They should then pick up the beads and put them back in the cup.

The Physics

When the generator is turned on the metal can becomes charged. On a conductor all the charge goes to the outside of the conductor. There is zero field inside and so the balls inside do not become charged. The metal can is a Faraday cage. When the plastic cup is placed on the generator, the balls fly out. The plastic is an insulator, so the charge does not flow easily to the outer surface. There is an electric field inside the cup. The balls inside become charged and repel each other, and they are light enough to fly apart and out of the container.



Accompanying sheet

Gauss' Law

Fill the metal can with polystyrene balls and place it on the generator.
Now turn the generator on. Explain what happens.

Remove the metal can and replace it with the plastic one.
Explain what happens this time when you turn the generator on.

Please pick up the balls and put them away when you are done!

High Pass and Low Pass Filters

Apparatus

function generator, resistor, capacitor and 2 channel oscilloscope

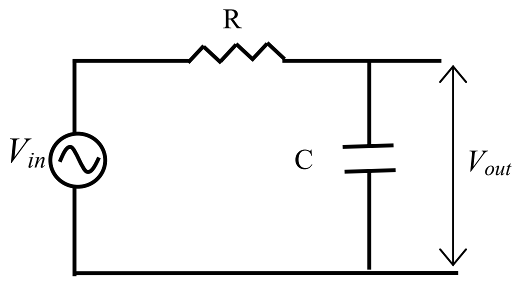
Action

The students vary the input frequency while observing both the input and output on the oscilloscope. They should identify one circuit arrangement as a high pass filter and the other as a low pass filter.

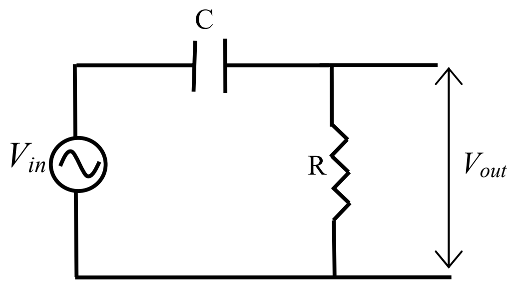
The Physics

The circuit on the left is a low pass filter. As the frequency changes, the reactance of the capacitor changes, hence V_C changes. When the frequency is low, the reactance is high, and most of the voltage is dropped across the capacitance rather than the resistance. Thus V_{out} will be high. We call this a low pass filter as low frequencies provide a significant output, but high frequencies do not.

The right hand circuit is a high pass filter. The output is taken across the resistor now. At high frequencies the reactance of the capacitor is low, so the voltage dropped across the capacitor is low while that across the resistor is high. Hence for a high pass filter we take V_{out} across the resistor.



low pass filter



high pass filter

Accompanying sheet

High Pass and Low Pass Filters

Observe both the input and output of the filter circuit on the oscilloscope.
Now vary the input frequency.
What happens to the output signal?
What sort of a filter is this, and how does it work?

Now try the other circuit.
What sort of filter is this one?

Jumping Rings

Apparatus

AC power supply, coil wrapped around a large ferrite core, solid and split metal rings

Note – it helps to have a momentary switch connecting the power supply to the core so it is not left turned on.

Action

The students place a ring over the core and switch on the power supply. They should observe that a solid ring will jump but a split ring or non-conducting ring will not. If the power supply is a large one, they can also hold the ring in place and feel it heating up.

The Physics

An AC coil with a long iron core produces an alternating magnetic flux, mostly in the region in and near the core. An *emf* is induced in a small conducting ring when it is slipped over the core and the power is turned on to the coil. If the ring is complete, a current is induced and the resulting magnetic force is sufficient to launch the ring several feet into the air. A split ring or a non-conductive ring will not jump because no current is induced.

Note – some safety warnings may be needed, such as do not stand over the apparatus. It is also best to have some clear space around the apparatus.

Students with the jumping rings at the University of Sydney.

Accompanying sheet

Jumping Rings.

Place a ring over the ferrite core.
Depress the switch to run a current through the coil.

What makes the ring jump?

What sort of ring won't jump? Why?

LC Oscillations

Apparatus

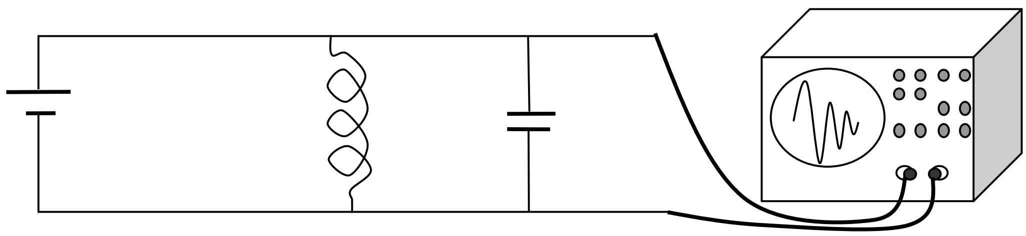
low voltage DC power supply, inductor, capacitor and oscilloscope

Action

The students close the switch to charge the circuit. They then open the switch and observe the oscillations. They should try to explain the origin of the oscillations, and why the oscillations die out.

The Physics

When the power supply is turned on the capacitor becomes charged. Energy is stored in the capacitor in the form of an electric field. Inductors store energy in the form of a magnetic field, due to current flow, so when the power supply is switched off and current ceases to flow the inductor stores no energy. As the capacitor discharges, the potential energy stored in the capacitor is transferred, causing a current flow through the inductor. When the capacitor is fully discharged it no longer stores any energy, and the current flow is a maximum through the inductor. The flow of current now reverses due to the back *emf* in the inductor and the capacitor is recharged by the inductor. This process repeats, and if the system had zero resistance would repeat indefinitely without energy loss. However there will be some resistance in the circuit due to the wires and the components themselves, hence the oscillations decrease in amplitude and gradually die away. Note that the frequency of oscillation depends only on the values of L and C, and hence the period of oscillation does not change in time, only the amplitude.
A helpful analogy to this circuit is an oscillating spring-mass system, in which energy is alternately converted between elastic potential energy (analogous to electric potential energy in the capacitor) and kinetic energy of the mass (energy of the moving charges in the inductor).



Accompanying sheet

LC Oscillations

Connect up the capacitors in parallel with the inductor,
the oscilloscope and the power supply.

What happens when the power supply is connected?

Now turn the power supply off.
Explain your observations.

How is energy stored in an inductor? How is it stored in a capacitor?

Magnetic Braking I – Damped Pendulums

Apparatus

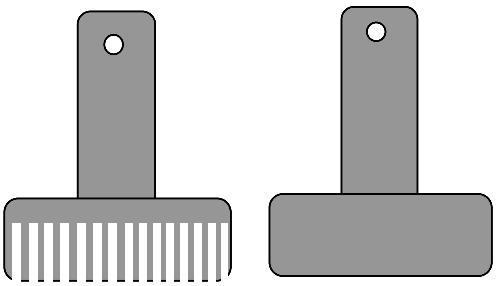
large horseshoe magnet or pair of magnets, pendulums made from complete and incomplete metal loops, pendulums made from complete sheets of aluminium or copper, and from sheets with slits

Action

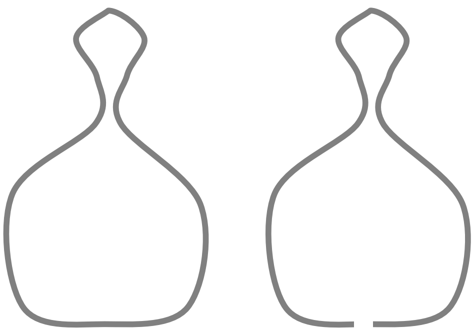
The students allow the different pendulums to swing between the magnetic poles and observe which ones are braked and which ones are not. They should try to predict in advance how the pendulums will behave and then compare their observations to their predictions.

The Physics

In all cases extensive swirls of currents, eddy currents, are induced in sheets and loops without slits and not in sheets or loops with slits. The induced currents experience a force due to the magnetic field from the magnets, which produces a force on the pendulum opposing the motion that causes them, braking the pendulums without slits.



Some simple pendulum designs



Students at the University of Sydney experimenting with a simple loop style pendulum in a magnetic field.

Accompanying sheet

> **Magnetic Braking I – Damped Pendulums**
>
> Which pendulums will swing freely and which will be damped by the magnetic field?
>
> Try the different pendulums and see what happens.
>
> Explain your observations.
> Were your predications correct?

Magnetic Braking II – Magnets in Pipes

Apparatus

copper pipe, copper pipe with slit along length, plastic pipe (all pipes should have similar diameters), small magnets which fit into pipes easily , retort stands and clamps to support the pipes
Rare earth magnets are good because they have a very strong magnetic field. It helps to put a cushion of some sort, e.g. a jumper, under the pipes so the magnets don't get lost or damaged.

Action

The students drop the magnets through the different pipes and compare the time taken to fall through.

The Physics

The movement of the magnet creates currents in the copper pipe, which produce magnetic fields, which act to oppose the motion which causes them, slowing the fall of the magnet. The plastic pipe is an insulator, so no current flows and hence the magnet is not braked. In the pipe with the slit there are still currents produced in vertical loops, but not in horizontal loops around the pipe as the slit prevents this. So the fall is slowed, but not as much as in the complete pipe.

Students the University of Sydney experimenting with magnets and a selection of copper and plastic pipes

Accompanying sheet

Magnetic Braking II – Magnets in Pipes

Predict what will happen as the magnet falls through the pipes.
What will happen in the pipe with the slit?

Drop the magnets through the pipes.
In which pipe is the magnet most slowed?
Were your predictions correct?

Magnetic Field around a Current Carrying Wire

Apparatus

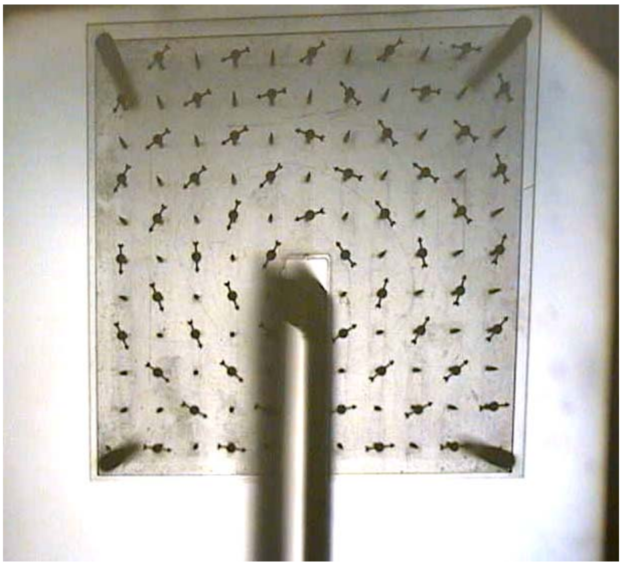
One current carrying wire, power supply, several compasses or large compass needles
This can also be done using iron filings and a high current.

Action

The students place the compasses or compass needles at various positions around the wire. They then turn the power supply on so that current runs through the wire. They should observe the deflection of the needles due to the current.

The Physics

A current produces a magnetic field. The magnetic field is perpendicular to the direction of the current and decreases linearly with distance from the current. The direction can be found pointing the right thumb in the direction of the current. The direction the fingers curl gives the direction of the field.



Accompanying sheet

Magnetic Field around a Current Carrying Wire

Turn on the power supply and observe what happens to the compass needles.

What happens when you change the direction of the current?

Draw a diagram showing the current and the field it produces.

Magnetic Force- the Pinch Effect

Apparatus

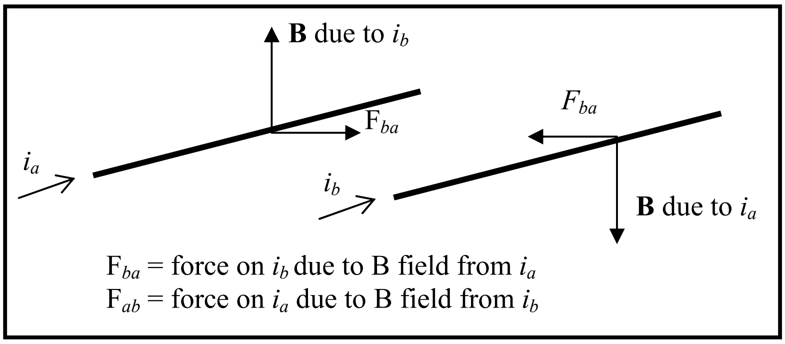
two long current carrying wires or strips of foil, mounted vertically and parallel to each other, power supply and connections

Action

The students turn the power supply on so that current runs through both wires in the same direction. They should observe the wires pinching in towards each other. If they change the connections so that the currents are anti-parallel they will see the wires move apart.

The Physics

Both currents produce a magnetic field. A current carrying wire in a magnetic field experiences a force proportional to the cross product of the current in the wire and the external field, $F \propto i \times B$. The force is perpendicular to both the field and the current, and the direction can be found using the right hand rule for cross products: curl your fingers from *i* towards *B* and your thumb points in the direction of *F*. The force will be towards the other wire when the currents are parallel, and away from it when the currents are anti-parallel.



A tutor at the University of Sydney demonstrating the pinch effect.

Accompanying sheet

magnetic force - the Pinch Effect

Turn on the power supply and observe what happens to the wires.

How can you make them repel instead of attracting?

Draw a diagram showing the field, current and forces on the wires.

Magnets and Magnetic Fields

Apparatus

selection of magnets, iron filings, perspex sheet

Action

The students place the sheet over the top of the magnets. They then sprinkle the iron filings on the perspex sheet. They should then sketch field lines for the magnets, and notice which field is similar to the Earth's magnetic field.

Note: the Perspex sheet is important because it keeps the filings from coming into direct contact with the magnets and sticking to them. When done the students can lift the sheet and pout the filings back into a container to be reused, this is much less messy than trying to remove them from a magnet.

The Physics

The iron filings are attracted to the poles of the magnet and tend to line up along field lines.
The Earth has a magnetic field like a bar magnet's, however what we call the north pole of the Earth is actually at the south magnetic pole.

A student at the University of New South Wales using iron filings to see the magnetic field around a bar magnet.

Accompanying sheet

Magnets and Magnetic Fields

Use the iron filings to investigate the field lines of the magnets.

How do these compare the field lines of the Earth?
Many animals such as pigeons and some fish have a magnetic sense which allows them to use the Earth's magnetic field to navigate.

Please keep the filings on the sheet, and the magnet underneath!

Measuring Voltage and Current

Apparatus

voltmeter, ammeter, simple circuit with resistor and power supply

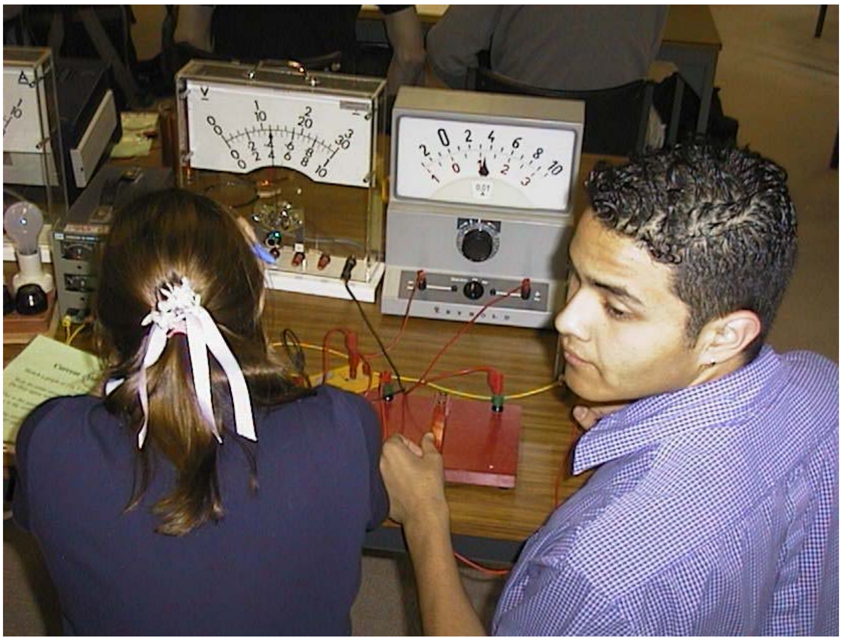
Action

The students can either set up the circuit to measure current and voltage, or the circuit can be set up for them in advance. The students connect up the voltmeter and ammeter to measure the current through the circuit and the voltage across the resistor, or observe and explain why they are set up the way they are.

The Physics

The ammeter measures the current, which is the number of charges per unit time passing through a given point on the circuit. To be able to count the charges, the ammeter must be part of the circuit hence it is connected in series. It must have a very low internal resistance so that it does not affect the current through the circuit.

The voltmeter is connected in parallel with the component, because it measures the difference in potential between two points i.e. the two sides of the component. It has a very high internal resistance so that very little current will flow through it, thus having little effect on the circuit.



Students at the University of Sydney attempting to measure voltage and current.

Accompanying sheet

Measuring Voltage and Current

Examine the simple circuit set up to measure current and voltage.
Why is the voltmeter connected in parallel with the resistor?
Why is the current meter connected up in series with the resistor.

Current meters have very low internal resistance.
Why do you think this is important?
Would you expect the voltmeter to have a high or low resistance? Why?

Measuring Voltages

Apparatus

voltmeter, batteries, low voltage power supplies, simple circuit with bare wires and resistor

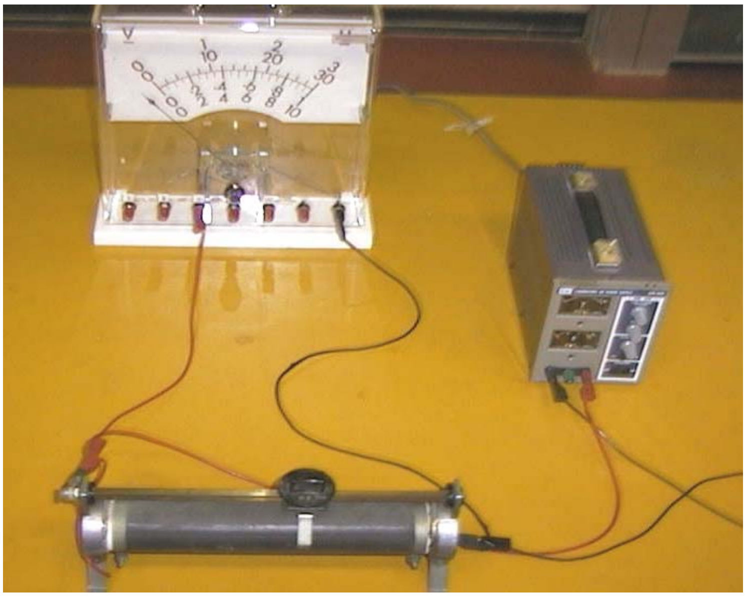
Action

The students can either set up the circuit to measure current and voltage, or the circuit can be set up for them in advance. The students measure the potential difference across the terminals of the batteries and/or power supplies. The students measure the potential difference across the resistor (a poor conductor) and across two points a similar distance apart on the wire. They should also consider why they measure potential difference by putting the probes at different points.

The Physics

All points on a conductor (the wire) will be at the same potential, hence the potential difference between two points on the wire is zero. The resistor is a poor conductor (approximately an insulator) and hence there will be a potential difference across the resistor.

The voltmeter is connected in parallel, because it measures the difference in potential between two points.



Accompanying sheet

Measuring Voltages

Use the voltmeter to measure the potential difference
across the terminals of the various batteries and power supplies.
Voltmeters are always connected in parallel
with the device you are measuring the voltage across.
Why is this the case?
Why do we often talk about "potential difference"
rather than simply potential?

Ohm's Law

Apparatus

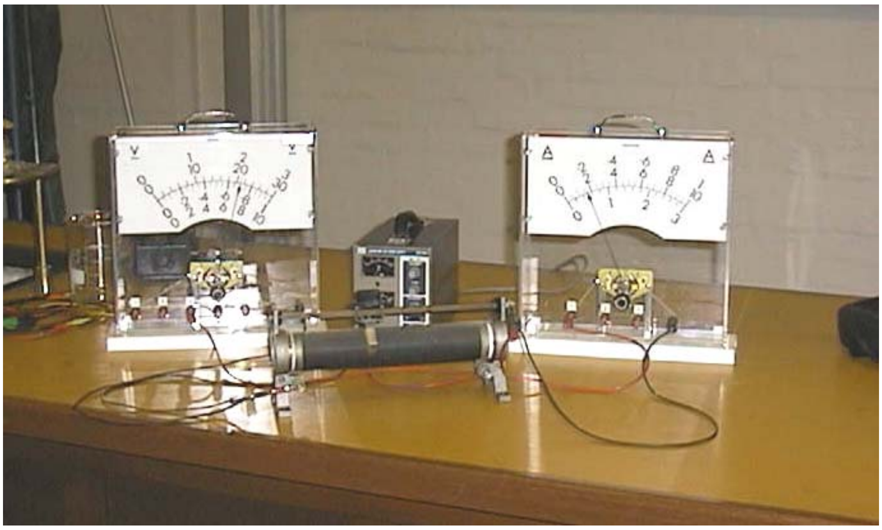
ammeter, variable voltage power supply, resistors, resistor colour code chart

Action

The students attach a resistor to the power supply and measure the current through the resistor for different voltages. They should calculate the resistance of the resistor, and then check their answer using the resistor colour code chart.

The Physics

The resistors obey Ohm's law, so the current through the resistor is $I=V/R$ where V is the voltage across the resistor and R is the resistance. The resistance, R, will be a constant for a resistor for large ranges of V. Note that this is not the case for many components, such as globes. The students may find small discrepancies in their calculated value for R and that read from the chart, this is a good opportunity for some comments on uncertainty, and it is worthwhile pointing out the "tolerance" of the resistors. There may also be a small difference due to resistance in the wires, inaccuracy and internal resistance of the power supply.



Accompanying sheet

Ohm's Law

Use the variable voltage supply and the current meter
to find the resistance of the mystery resistor.

Check your result with the resistor colour code provided.
Do they match?

Why might there be some difference?

Power Plants

Apparatus

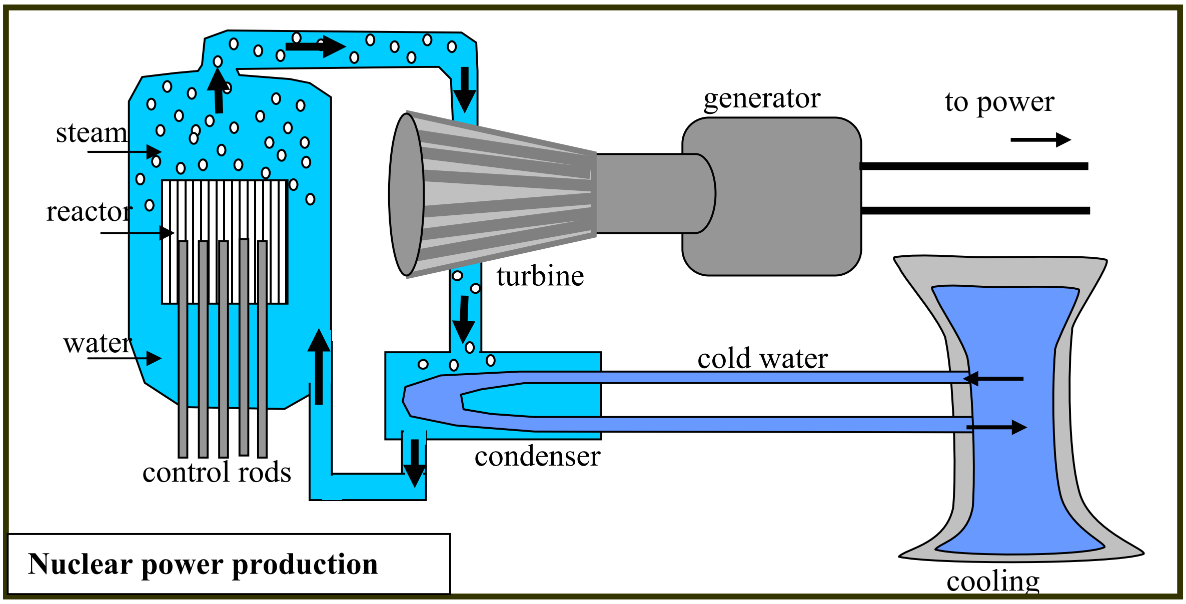
set of diagrams showing different means of electricity generation, see examples below and on next page

Action

The students examine the diagrams and find similarities between them. They should try to follow the energy conversions involved. They should also try to think of examples of electricity production which do *not* use a generator.

The Physics

Virtually all commercial electricity production uses a generator. Usually water, either as liquid or as steam, is used to drive a turbine which spins a coil in a generator to produce an *emf*. Examples include wind power, coal and other fossil fuel power plants, geothermal power and nuclear power plants. Solar cells *do not* use a generator, they use the photoelectric effect to produce a current. See the demonstration materials for the electricity generator for details on how the *emf* is produced.



Nuclear power production

Accompanying sheet

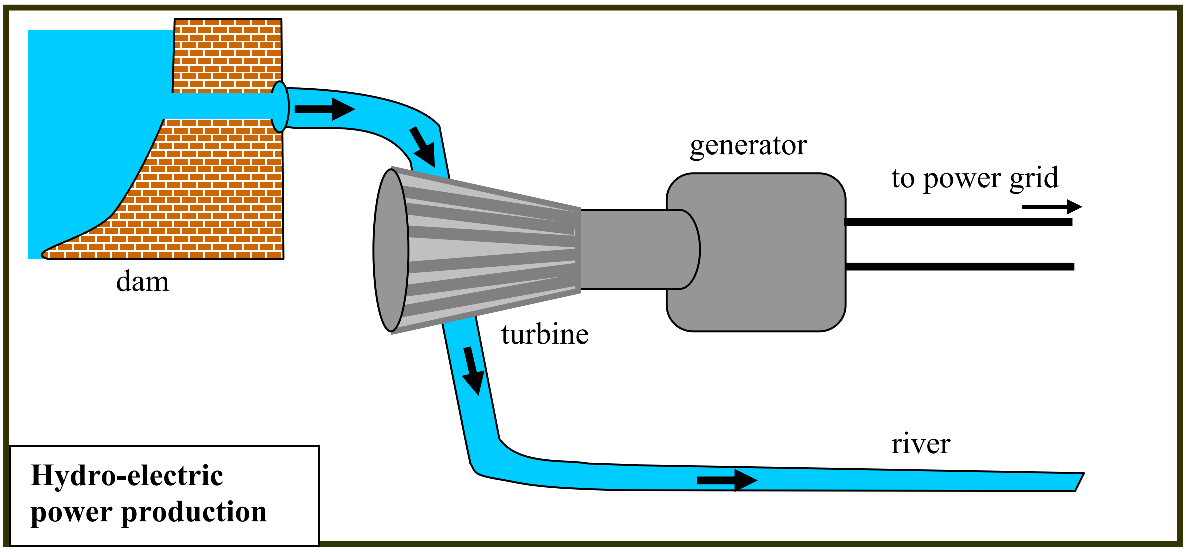
Power Plants

Compare the different means of generating electricity shown.
Which process or processes are used to produce electricity for your home?

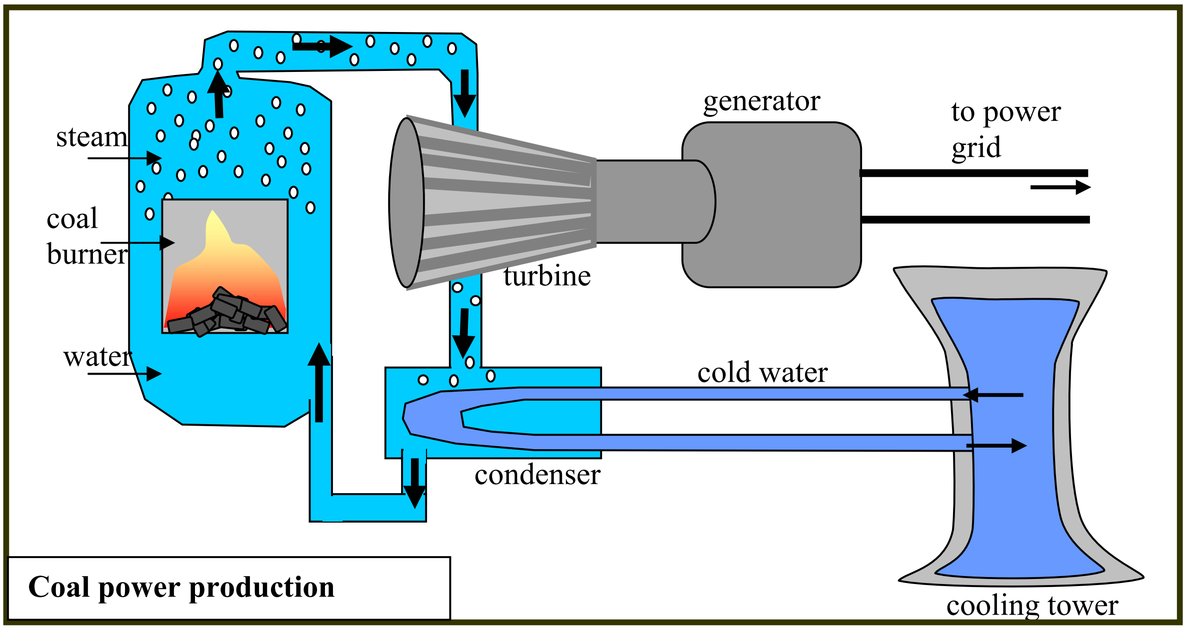
What do you notice is similar about all these processes?

Can you think of a means of generating electricity
which does not use a generator?

Power generation diagrams to go with Power Plants Activity.



Hydro-electric power production



Coal power production

Resistivity and Resistance

Apparatus

reels of copper and other wires of known length and diameter (for example complete reels of enameled copper wire in standard lengths), ohm-meter

Note – the reels need to be fairly long (several meters or more) to have substantial resistances, and if using enameled copper wire the wire may need to be sanded at the ends to expose the copper so that a probe can make electrical contact.

Action

The students measure the resistance of the lengths of wire. They should examine the effect of length, cross section and material on both the resistance and the resistivity, and distinguish between resistance and resistivity.

The Physics

Resistance increases with length, and decreases with cross section for a given material. Resistivity is a property of the material, and does not depend on shape or size.

Optometry students at the University of New South Wales preparing to measure the resistance of various types of wire.

Accompanying sheet

Resistivity and Resistance

Measure the resistance of the objects displayed.

How does the length of the object affect its resistance?
How does it affect resistivity?

Does the shape or size of its cross section have an affect?

Safety Switch and Fuses

Apparatus

a safety switch, selection of fuses including a few burnt out ones

Action

The students examine the switch and fuses and discuss the role and importance of these devices.

The Physics

Safety switches open, stopping current flow, when a sensor detects a surge in current. A surge in current usually indicates a short circuit, when the current increases due to a large drop in resistance. This may be due to the current passing through a low resistance human to flow to Earth rather than through relatively higher resistance circuitry. A fuse is made of a material, often a thin metal wire or strip, which heats ups and melts when a large enough current passes through it. This protects machinery and people from power surges, but cannot be reset the way a switch can be, the wire or entire fuse must be replaced.

Accompanying sheet

Safety Switch and Fuses

Examine the safety switch and fuses.

Explain how they work and the role they play in preventing power surges.

How can safety switches protect you from short circuits?

Series RLC Circuit

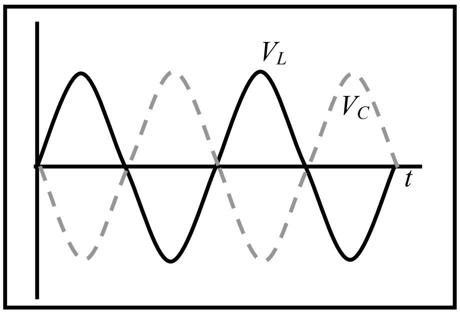
Apparatus

function generator, variable inductor, capacitor, low voltage globe, all wired in series

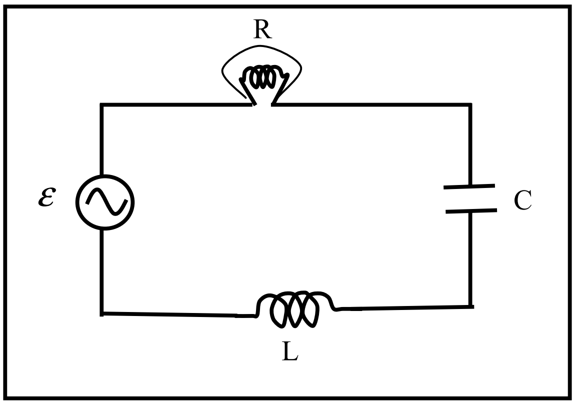
Action

The students vary the frequency of the input from the signal generator while observing the globe. At resonance the globe will be brightest. They then vary the inductance for a fixed input frequency and again look for resonance.

The Physics



The globe acts as a resistor, dissipating energy as heat and light. The voltages across the inductor and the capacitor depend on the reactance of the two components. The reactance, X, depends on the frequency, f: $X_C = 1/\ 2\pi fC$ and $X_L = 2\pi fL$.
When $X_c = X_L$, the total voltage drop across L and C is zero, since V_C and V_L are 180° out of phase and equal in magnitude, cancelling each other out – so $V_L + V_C = 0$, and all the voltage drop is across R. See diagram opposite.
So the impedance of the circuit = R, the resistance of the globe. The current will be a maximum and the bulb will glow most brightly. Varying the inductance, L, of the inductor until $X_c = X_L$ will lead to a similar effect. Note also that the voltage across the capacitor and inductor are always 180° out of phase.



Accompanying sheet

Series RLC Circuit

Vary the frequency of the input.
What happens to the globe? Why?

Now vary the inductance of the circuit.
Explain what happens.

Simple Electric Motor

Apparatus

a loop of enameled copper wire mounted between a pair of magnets, battery

Note - the wire loop needs to be sanded on one side only at each end to allow contact with the battery attachments. It should be sanded on the same side at each end so that as it spins it alternately makes and breaks contact. See diagram below.

Action

The students connect the coil to the battery, and if necessary give it a gentle push to get it started. They should discuss how it works, and why it doesn't stop as does the loop in the demonstration "torque on a current carrying coil in a magnetic field".

The Physics

The current experiences a force due to the external magnetic field from the magnets. On one side of the coil the force is upwards, on the other it is downwards, resulting in a torque on the coil (figure **a**). As the coil begins to rotate the forces will change direction such that of the current still flows they will point in the opposite direction and stop the motion of the coil (figure **b)**. Hence it is important that the current be stopped so that the force become zero. The coil will then continue to rotate, with no force other than friction opposing it, until it returns to its original position. It will then get another push to continue it spinning, and as long as the force due to the field on the current is greater than friction it will continue to spin.

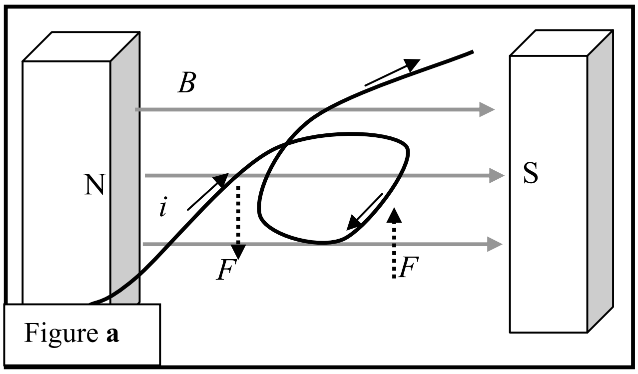


Figure **a**

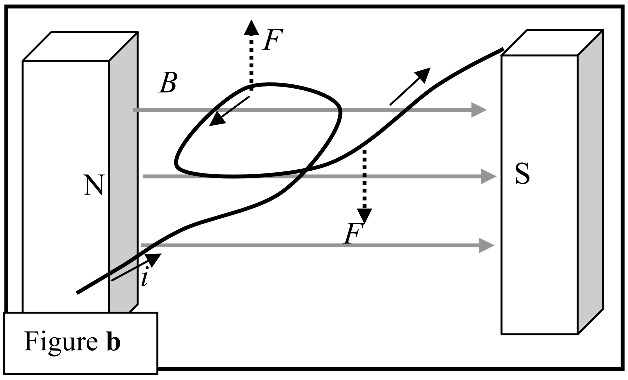


Figure **b**

Accompanying sheet

Simple Electric Motor

What makes the coil spin?

Why doesn't it stop like the single loop in the magnetic field?

Simple Membrane Model – Resistors in Parallel

Apparatus

low voltage power supply, ammeter, voltmeter, simple membrane circuit (5 resistors and 5 switches, shown below)

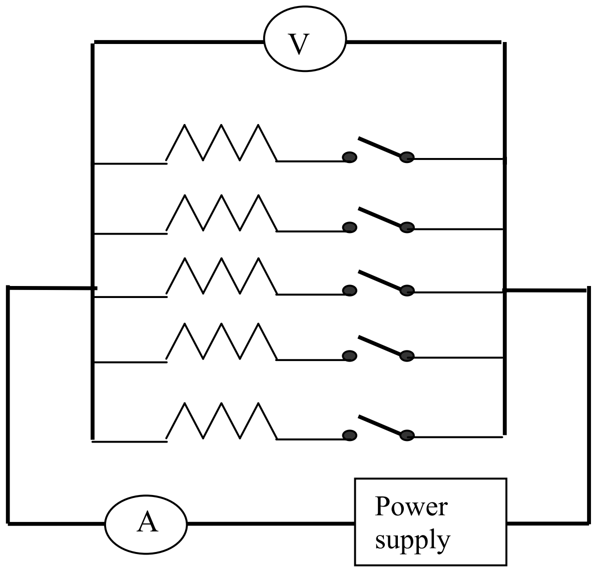
Action

The students connect the membrane circuit to the power supply and measure the voltage across the membrane and the current through the membrane with 0, 1, 2,…, 5 resistors in parallel.

The Physics

When resistors are connected in parallel the total resistance is less than any individual resistance. There are more paths for the current to flow along, and so the total current is greater. Resistance is the voltage divided by the current, $R = V/I$, so a larger current means a smaller resistance for a given voltage supply. This is a very simplified model of a cell membrane, but the basic configuration of channels which can be opened or closed in parallel across the membrane is correct.

The students should note that the voltage across the membrane does not change, but the current does. Time permitting, it is interesting to get them to plot resistance vs number of resistors connected, and note that the curve decreases with such that $R \propto 1/n$.



Accompanying sheet

Simple Membrane Model – Resistors in Parallel

Close one of the switches, leaving the rest open.
Measure the resistance of the membrane.

Close each of the switches,
and measure the resistance each time you add another resistor in parallel.

What is happening to the total resistance? Why?
What effect does this have on current flow across the membrane?

Solenoid

Apparatus

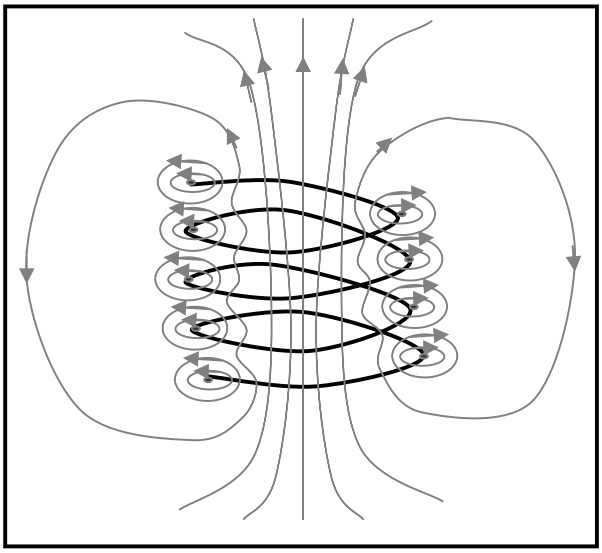
power supply, giant solenoid with no core (a large coil of wire), magnetic field meter with probe

Action

The students use the probe on the magnetic field meter to measure the magnetic field in and around the solenoid. They should try to sketch the field lines.

The Physics

The net magnetic field is the vector sum of the fields due to each loop. These fields tend to add inside the solenoid, and cancel between the loops. The resultant field inside the solenoid is approximately uniform, while that outside the solenoid is approximately zero. The smaller the radius compared to the length of the solenoid, the larger and more uniform the internal field. If the solenoid was infinitely long the field outside would be exactly zero.



Accompanying sheet

Solenoid

Draw a diagram showing the magnetic field in and around the solenoid.

Are there any points where the magnetic field is zero?

How does the magnetic field vary inside the solenoid?

Tape Charge

Apparatus

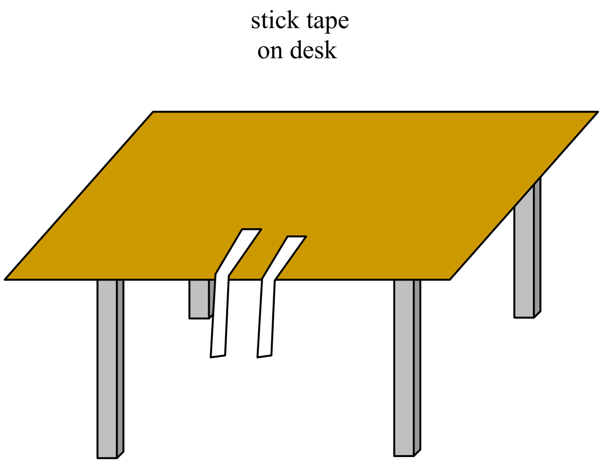
roll of sticky tape, the slightly opaque tape works best
It is worth experimenting with a few different types to find one that works well.

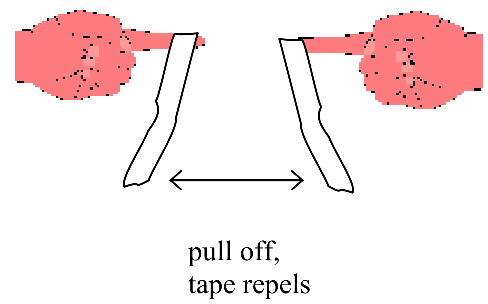
Action

The students stick two lengths of sticky tape, approximately 10 cm long, onto a desk *with the ends hanging off* (this is important for easy removal). They then peel the tape strips off, and hang them near each other. They can also stick two strips of tape together and then pull them apart and hang them close together.

The Physics

The sticky tape becomes charged when it is pulled off the desk. Large organic molecules, such as are involved in sticky tape or combs and hair or glass/plastic and cloth/fur, break easily and leave these items charged. The pieces have like charge and repel each other. This also explains why sometimes sticky tape curls up and sticks to your hand when you pull a long strip from a roll. Pieces which have been stuck to each other and pulled apart may have opposite charge, and hence attract rather than repel.





Accompanying sheet

> **Tape Charge**
>
> Stick two strips of tape on the desk,
> with one end of the tape hanging over the edge.
>
> Now peel them off.
>
> Hang them close to each other and see what happens.
> Explain your observations

Toaster Man – Resistors in Series

Apparatus

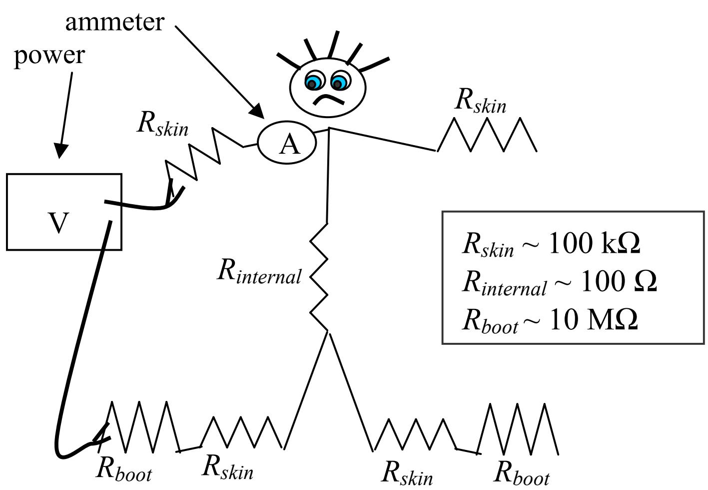
ammeter, low voltage power supply, "toaster man" circuit, leads with alligator clips

Action

The students measure the current through toaster man's heart for different positions of the power supply leads.

The Physics

The resistance of the current path is changed by connecting the power supply to different points. When the resistance is lower the current is higher and vice versa. This demonstrates the importance of insulation, for example wearing rubber soled shoes when working with high voltages. Small currents of only 10 mA can disrupt the heart beat and lead to fibrillation. This demonstration started as a demonstration on why poking knives into toasters is a bad idea, hence the name toaster man.



Students at the Australian Catholic University experimenting with "toaster man".

Accompanying sheet

Toaster Man

Connect the ammeter across toaster man's heart.

Attach one lead from the power supply to toaster man's hand.

What current flows when the other lead is connected to his boot?
What about when it is connected straight to his foot?

Torch – a Simple Circuit

Apparatus

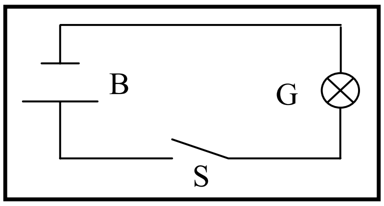
a few cheap torches that can be taken apart

Action

The students take the torches apart, identify the components and draw a circuit diagram for the torch. They should try to identify the current path.

The Physics

The torch is a very simple circuit, containing only three components; a switch, a globe and a battery. The components are connected in series. The battery stores energy as electric potential energy, which is converted to light and heat by the globe, when the switch is closed to connect the circuit.



For a current to flow and the torch to work there needs to be a complete circuit. In a metal cased torch the case itself often forms part of the circuit.

Optometry students at the University of New South Wales dismantling a torch.

Accompanying sheet

Torch – a Simple Circuit

Dismantle the torch and examine its components.

Draw a circuit diagram for the torch.
Is it a complete circuit?
Trace the flow of current in the torch.
Label each component and show its function.

When you have finished, please put the torch back together again.

Torque on a Current Carrying Coil in a Magnetic Field

Apparatus

horseshoe magnet or pair of bar magnets, loop of wire attached to power supply

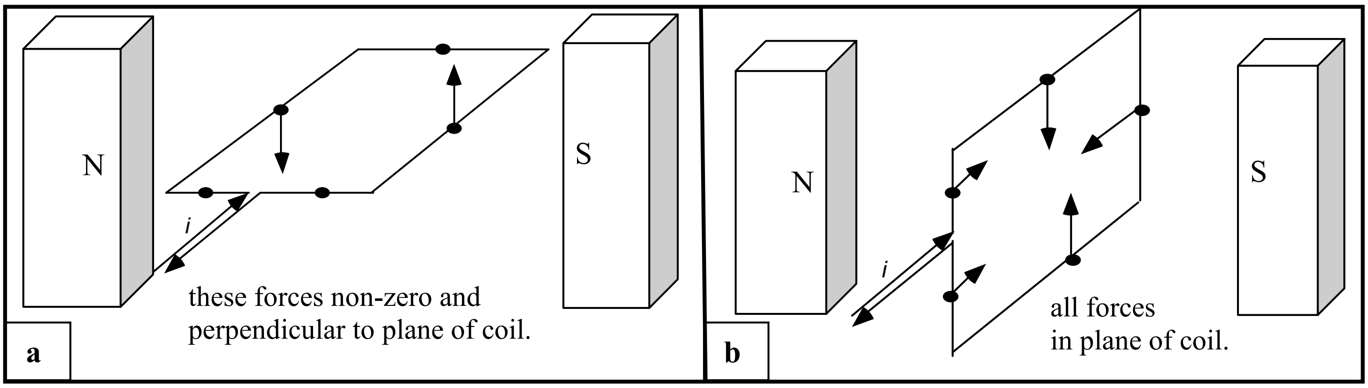
Action

The students turn on the power supply and experiment with placing the coil at different angles and observing its behaviour.

The Physics

The force is proportional to the cross product of the current in the wire and the external field, $F \propto i \times B$. When the coil is horizontal (figure **a**) the magnetic field is perpendicular to the current at the points shown and hence the force is a maximum, and itself perpendicular to both the current and the field. In this position the coil will begin to rotate when the power is switched on.

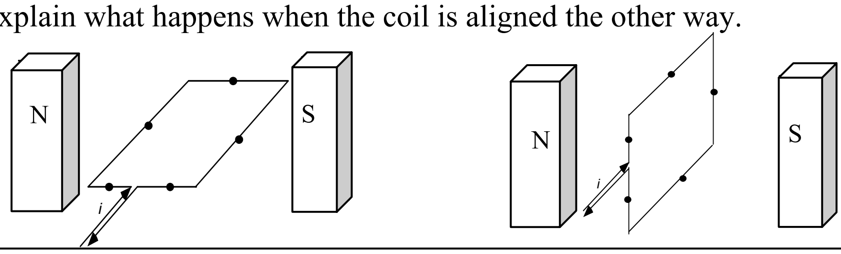
When the coil is vertical (figure **b**) the forces will be in the plane of the coil and in different directions. They will tend to cancel and the coil will not move in this position.



Accompanying sheet

Torque on a Current Carrying Coil in a Magnetic Field

Align the coil between the magnets and turn on the power supply.
Explain what happens.
Explain what happens when the coil is aligned the other way.



Tuning Circuit

Apparatus

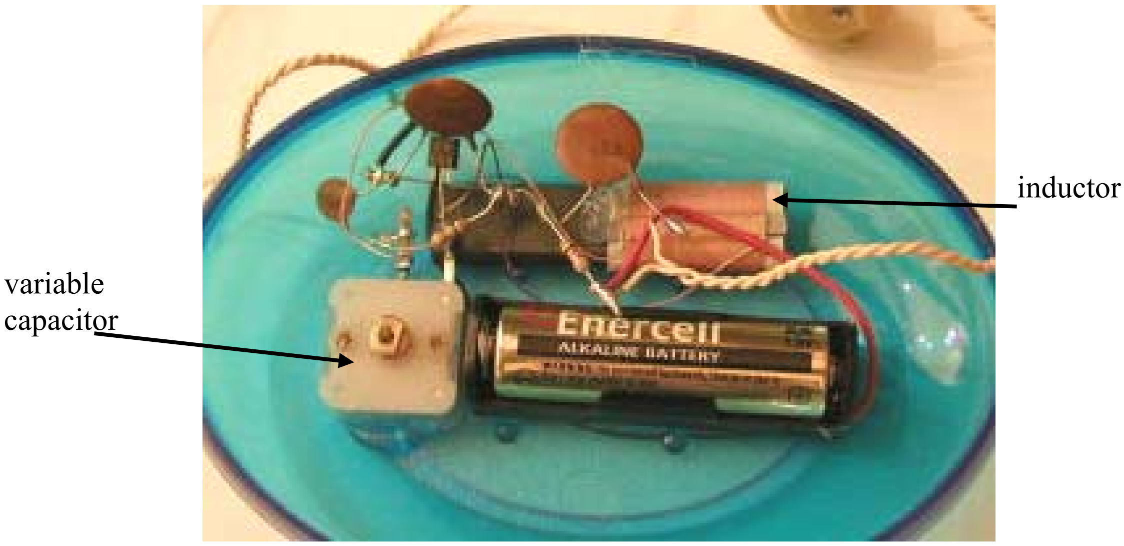
tuning circuit from a dismantled radio, with components visible

Action

The students examine the circuit and identify the main components. They should draw a diagram showing how the tuning circuit works.

The Physics

A tuning circuit consists of an inductor and a capacitor, usually in parallel.
Either the inductance of the inductor or the capacitance of the capacitor must be able to be varied. By varying either the capacitance or inductance the resonant frequency of the circuit is varied. When the resonant frequency matches an incoming signal, for example the carrier wave of your favourite radio station, then the circuit is tuned to that frequency and the radio program can be heard.



Accompanying sheet

Tuning Circuit

Examine the circuit and identify the main components.
How is this circuit tuned?

Draw a circuit diagram showing how it works.

van de Graaff Generator

Apparatus

van de Graaff generator, insulating block (e.g. polystyrene)

Action

The students take turns standing on a thick piece of polystyrene with a hand on the generator. If you have small numbers it's handy to bring a camera for this one, it makes good photos for open day, and if you have a digital camera you can email students photos of themselves later on.

The Physics

The generator charges you up to a very high voltage, which means a lot of extra charges. People's hair tends to stand up because the charges exert a repulsive force on each other, the hairs try to get as far away from each other as possible. The hairs also try to line up along field lines.

Note: make sure other students stay clear, and the student in contact with the generator doesn't take their hand off and on.

Student at University of Sydney attached to a van de Graaff generator.

Accompanying sheet

van de Graaff Generator

While the generator is turned off:
Stand on the block and place your hand on the generator.

Now get someone to turn it on.

What do you feel?
What can you see when someone is touching it?
Explain your observations.

van de Graaff Generator and Wig

Apparatus

van de Graaff generator , paper, string or hair "wig", sticky tape

A paper wig can be quickly made by cutting several pieces of scrap paper into strips, leaving a few inches uncut at the bottom so they can be stuck to the van de Graaff generator.

Action

The students attach the wig to the generator and turn it on. They may also want to experiment with holding strips of tape near the generator.

The Physics

The generator charges the wig to a very high voltage, which means a lot of extra charges. The hair stands up because the charges exert a repulsive force on each other and the hairs try to get as far away from each other as possible. The hairs also try to line up along field lines.

Note: this demonstration replaces the van de Graaff generator demonstration on the previous page if you do not wish students to touch the generator or if the students are uncomfortable with touching it.

Students at the University of New South Wales experimenting with a van de Graaff generator

Accompanying sheet

van de Graaff Generator and Wig

Put the wig on the generator.

Now turn it on.

Explain what happens to the wig.
What does this tell you about the field around the generator?

Variable Capacitor I – Giant Capacitor

Apparatus

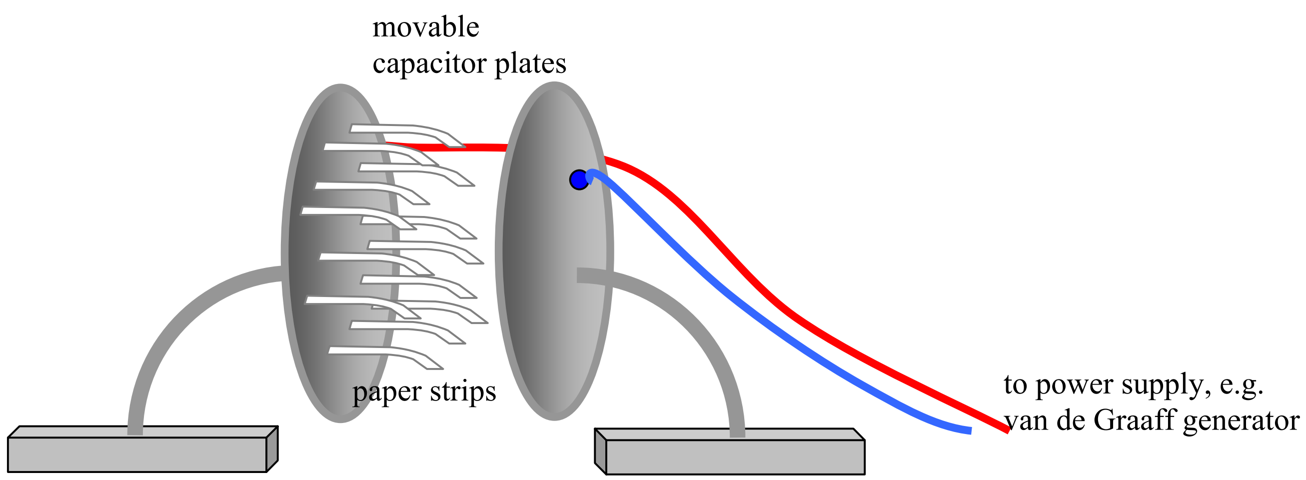
van de Graaff generator, large parallel plate capacitor with plates that slide towards or away from each other, thin strips of paper taped at one end to one plate of the capacitor

Action.

The students examine the capacitor and explain how the capacitance is varied. They then charge the capacitor and observe the behaviour of the paper strips, and sketch field lines for the electric field between the plates.

The Physics

The capacitance is inversely proportional to the separation of the plates, moving the plates closer together increases the capacitance. The paper strips lift and align with the field lines when the field is strong enough. The strips become charged by the plate to which they are attached, and are both repelled by this plate and attracted towards the opposite plate.



Accompanying sheet

Variable Capacitor I – Giant Capacitor

Examine this variable capacitor.
How can the capacitance be varied?

Charge up the capacitor.
What happens to the paper strips? Why?

Sketch the field lines for the electric field between the plates.

Variable Capacitor II – Tuning Capacitor

Apparatus

variable capacitor

Action.

The students examine the capacitor and explain how the capacitance is varied. They should describe and give examples of how such capacitors are used.

The Physics

The capacitor is a series of leaves. Rotating the "stem" rotates one set of leaves so that the area of overlap changes. This changes the value of the capacitor.

Variable capacitors can be used in tuning devices such as radios where dialing up the radio station is just twisting the "stem". The variable capacitor is part of the resonant circuit where maximum response to the transmitted signal depends on matching the resonant frequency of the circuit with the frequency of the signals carrier waves.

Accompanying sheet

Variable Capacitor II – Tuning Capacitor

Examine the variable capacitor.
How can the capacitance be varied?

Can you think of where these devices might be used?

Wheatstone Bridge

Apparatus

a Wheatstone bridge circuit (see below, with a variable resistor such as a decade box that the resistance can be read off), low voltage power supply, voltmeter, unknown resistor, resistor colour code chart Note – the bridge circuit can be wired in advance, or the students can wire it themselves, however this may take a long time.

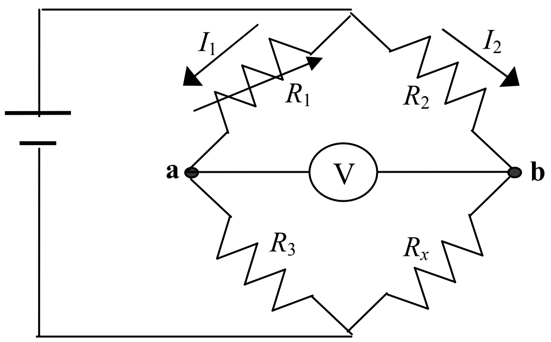
Action.

The students find an expression for the unknown resistor in terms of the known resistances when the bridge is balanced. They then balance the bridge by adjusting the variable resistor until there is no potential difference between points **a** and **b** - this is the balance condition (see diagram below). When the bridge is balanced they read off the value of the variable resistor, and find the value of the unknown resistor. If a resistor colour chart is available they can then check their measurement.

The Physics

When there is no potential difference between points **a** and **b** there is no current flow between these points. Hence all of current I_1 flows through R_1 and into R_3, and all of current I_2 flows through R_2 and into R_x. As there is no potential difference between points **a** and **b**, we also know that the potential difference across R_1, must be equal to the potential difference across R_2., i.e. that $V_1 = I_1 R_1 = I_2 R_2$. The potential differences across R_3 and into R_x must also be equal, giving $I_1 R_3 = I_2 R_x$. We can now divide the second equation by the first to give $R_3 / R_1 = R_x/R_2$, and rearrange to obtain an expression for R_x. : R_x. = $(R_2 R_3)/ R_1$.

Wheatstone bridges have many applications, for example they are used in many gauges where one element of the Wheatstone bridge is a resistance which varies with some physical property, such as temperature or stress. Hence they can be used to measure properties such as mass by measuring small changes in resistance.



Accompanying sheet

Wheatstone Bridge

Explain how this circuit works.

Find an expression for R_x, the unknown resistor, when the bridge is “balanced”.

Balance the bridge to find the value of the unknown resistor.
Use the chart to check your measurement.