locktronics

Simplifying Electricity

Transformer construction and operation

CP1933

MATRIX

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Contents

Safety Issues

Transformers can be dangerous!

Take care!

Transformers can turn a relatively low voltage into a high voltage.

This can cause serious injury or even death.

Precautions:

- **Always used shrouded 4mm plugs and sockets!**
- **Do not touch exposed metal parts!**
- **Do not be tempted to “see what happens if…”!**
  Stick to the instructions given in the investigation.
- **If in doubt, ask the instructor!**

Introduction

Power supplies

In this course, several power supply voltages are used.

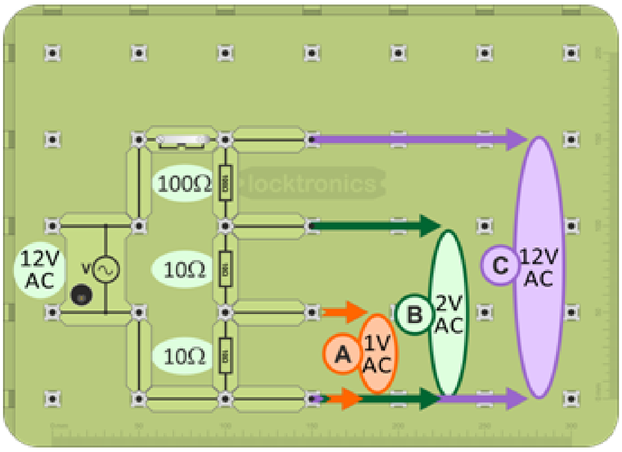
DC power supply:

- is obtained from the HP2666 plug-top power supply shown in the picture.
  (The inset shows it adjusted to give a 3V output.)

AC power supply:

- is obtained from the HP3728 plug-top power supply. The circuit shown in the layout opposite gives a choice of three voltages:
  - **A** - around 1V;
  - **B** - around 2V;
  - **C** - around 12V.

  (The voltage values are approximate because they depend on the current delivered.)



Caution!

The resistors can get very hot.

Do not touch them!

The role of transformers

Traditionally, electricity is generated as alternating current (AC). This means that it can be generated at a convenient voltage, then transformed and distributed around the country at a higher voltage. Finally, it is transformed back to a voltage usable for home or industry.

The benefit - higher distribution voltages require lower currents for the same power transfer. Lower currents reduce energy losses caused by the resistance of cables used to transmit the power.

The task of changing the voltage up and then down again is carried out by voltage transformer, usually known simply as a transformer, in a unit known as a substation.

Worksheet 1

Magnetic vs magnetised

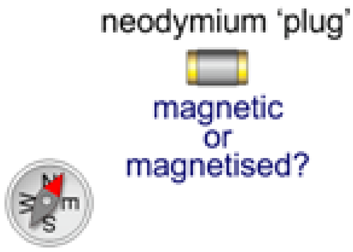
A material which has the ability to become a magnet is called ‘magnetic’.

A material which is a magnet is called ‘magnetised’.

The Earth is both magnetic and magnetised!
Its magnetic field has a profound effect on electrically-charged particles ejected from the Sun, causing the ‘Northern Lights’, (and ’Southern Lights’).

Over to you:

- Take one of the neodymium ‘plugs’ from the Lenz’s law kit and place it on a sheet of paper.
- Position the plotting compass nearby and notice which way the compass needle points.
- Move the compass to other positions around the ‘plug’ and- notice its behaviour.
- Next, swap for the other neodymium ‘plug’ and repeat the procedure.
- Answer the questions in the Student Handbook about the different behaviour of the compass for the two ‘plugs’.



The vocabulary of magnetism:

Magnetic - Made of a substance which can become a magnet. It is **attracted** to a magnet.

Magnetised - A magnet - it can both **attract** and **repel** another magnet.

Magnetic field - Magnets can move objects without touching them!
Any magnetic material nearby is **attracted** to the magnet.
A second magnet nearby is both **attracted** and **repelled** by the first .
To help us to visualise this, we picture the magnet as surrounded by an invisible magnetic field.

Magnetic pole - A point at which the magnetic force is strongest.

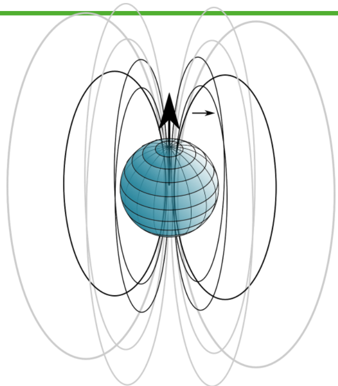
Magnetic flux - A magnetic field can be mapped as a set of ‘lines of force’ or magnetic flux lines, surrounding the magnet. Where the magnetic force is strong, these are tightly packed. Where it is weaker, they are more widely spaced. We talk about a flux line as the path taken by a free north pole as a result of the forces exerted on it by the magnet.

Worksheet 2

Electromagnetic?

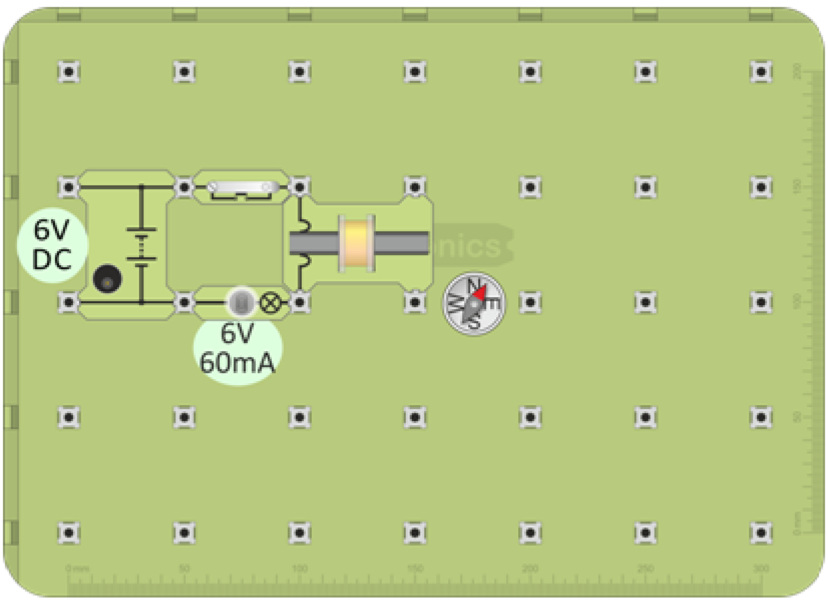
All magnetic effects result from the behaviour of electrons, tiny particles found in all atoms. Whenever they move, they create tiny magnetic effects. Under the right circumstances, these can add up to make an overall observable magnetic field.

One of the pioneers of electromagnetism, James Clerk Maxwell, showed, nearly two hundred years ago, that when a piece of metal moves inside a magnetic field, a voltage is induced in it.



Over to you:

- Set up the circuit shown in the layout below.
- Connect a DC power supply, set to deliver 6V, and turn it on. Do not press the push switch yet. The purpose of the lamp is to indicate when a current is present.
- Move the plotting compass around the baseboard. It will respond to the Earth's magnetic field and any other magnetic field nearby.
- Now press and hold down the push switch.
- Once again, move the plotting compass around the baseboard. The ferrite core intensifies the magnetic field produced by the electric current.
- Answer the questions in the Student Handbook about how the behaviour of the compass changes when the switch is pressed.



Challenge:

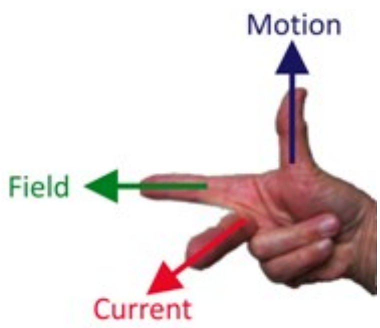
What happens when you reverse the current by turning the power supply carrier upside down?

Worksheet 3

Generating electricity - 1

The principle of the transformer is developed over the next three worksheets, via four steps.

It starts with an important result from the work of Michael Faraday, early in the 19th century, that when a piece of metal moves inside a magnetic field, a voltage is induced in it.

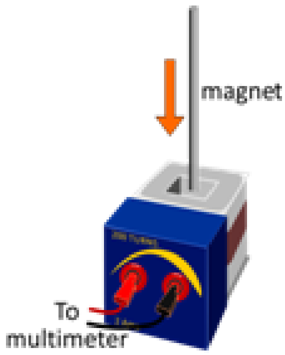


When this movement is at right-angles to the magnetic field, the resulting current flows at right-angles to both the magnetic field and the motion. This is illustrated in 'the right-hand rule' created by Ambrose Fleming in the late 19th century.

The first two steps in understanding transformers are covered in this worksheet.

Over to you:

Step 1 - Moving the magnet:



- Set up the arrangement shown opposite, using the 200 turn coil.
- Connect a multimeter, set to read DC voltages up to 200mV.
- Plunge the magnet into the coil, and then pull it out.
- Watch the multimeter as you do so.

Challenge:

What is the effect of using a different coil, having more turns?
What effect does the speed at which you move the magnet have on the result?

- Answer the questions in the Student Handbook.

Step 2 - Moving the coil:

- Next, move the 200 turn coil over the stationary magnet, while watching the multimeter.

Challenge:

What is the effect of using a different coil, having more turns?

- Answer the remaining questions in the Student Handbook.

Worksheet 4
Generating electricity - 2

'Electricity' is the result of the flow of electrons. It comes in two 'flavours', **DC** (direct current) and **AC** (alternating current), compared in the table.

DC	AC
one power supply terminal is always positive, the other negative	terminals change polarity repeatedly - one positive, the other negative and then they swap
'one-way traffic' - current always flows the same way around the circuit	'two-way traffic' - current flows clockwise, then anti-clockwise around the circuit
cannot be used with transformers	can be used with transformers

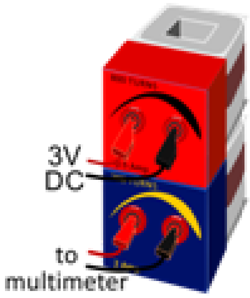
A huge advantage of generating electricity as AC is that it allows us to use transformers. These change the 'format' of the electricity supply, changing from high to low voltage, or the reverse, without losing much energy as heat in the process.

This worksheet takes the development of the

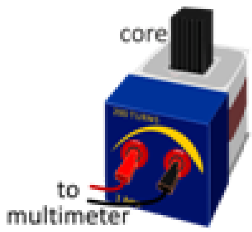
Over to you:

Step 3 - Electromagnet, not magnet:

- Now, replace the magnet with the 800 turn coil, connected to a **DC** power supply, set to 3V.
- Move this across the 200 turn coil connected to the multimeter, as in step 2.
- What is the effect on the multimeter?



- Place the second coil on top of the first.
- Switch the power on and off, by unplugging and reconnecting one wire to the coil.
- Watch the multimeter as you do so.



- Place a section of the core inside the lower coil, as shown in the diagram.
- Replace the second coil on top of the first.
- Switch the power on and off as before.
- Compare the effect with that observed without the core.

Challenge:

- Replace the 800 turn coil with the 3200 turn coil, connected to the 3V power supply. Repeat step 3 and compare the effect with that observed above.
- Replace the 200 turn coil with one having more turns and again, compare the effect.

- Answer the questions in the Student Handbook.

Worksheet 5
Mutual inductance

More vocabulary:

Induction - a voltage is generated when a changing magnetic field encounters a conductor.

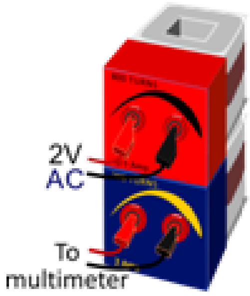
Self induction - a voltage is generated in a wire by a changing magnetic field caused by a current already flowing in that wire.

Mutual induction - a voltage is generated in one wire by a changing magnetic field caused by a current flowing in a wire in a different circuit.

Over to you:

Step 4 - AC not DC:

This time, the moving magnetic field is produced not by physically moving the magnet, or the coil, but by using a varying magnetic field generated by an alternating current. This produces a simple, but very inefficient, transformer.



- Disconnect the DC power supply from the second coil replace it with an AC supply of around 2V, obtained as shown in the introduction.
- Sit the second coil on top of the first.
- Set the multimeter to read AC voltages up to 200mV.
- Switch the AC supply on and off and watch the effect on the multimeter.
- Lower a ferrite core down the middle of the two coils, and notice the effect this has.

Caution!

The resistors can get very hot.

Do not touch them!

Challenge:

Explore what happens if you:

- separate the two coils;
- use a material like steel (a steel nail, for example) instead of ferrite for the core;
- connect the upper coil to a 1V AC supply, instead of 2V AC.

- Answer the questions in the Student Handbook.

Worksheet 6

Step it down

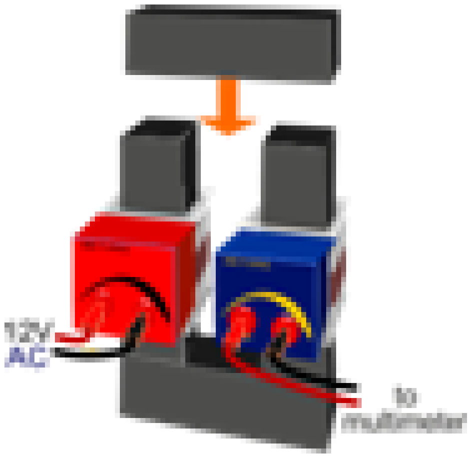
Most modern electronic devices work on a low voltage DC supply.

The first step in producing this is to step the AC supply voltage down to a lower level. This is accomplished using a step-down transformer, the subject of this investigation.

Then it is rectified, to turn AC into DC.

Over to you:

- Build the transformer shown opposite. It uses a 800 turn coil as the primary, connected to 12V AC, and a 200 turn coil as the secondary, connected to a multimeter, set to read AC voltages.
- Switch on the AC supply.
- Measure the voltage, V_S, induced in the secondary coil, and record it in the table in the Student Handbook.
- Connect the multimeter to read the voltage, V_P, applied to the primary and record that in the table.
- Use your results to complete the first row of the table by calculating the value of 'V_P / V_S'
- Now replace the 800 turn coil with a 600 turn coil and repeat the procedure, completing the second row of the table in the process.



Caution!

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- Repeat the same procedure for each of the other pairs of coils listed in the table.

Challenge:

1. You wish to step down a 2VAC supply to 1V. Suggest what coils are needed to do this. Set up your design and test your prediction. Explain your choice of coils in the Student Handbook and give the test results obtained when you set up your design.

2. Build a step-down transformer using a 800 turn coil and a 400 turn coil.
Connect the primary coil to the 12VAC power supply and the secondary coil to a 6V 40mA lamp.
Measure:

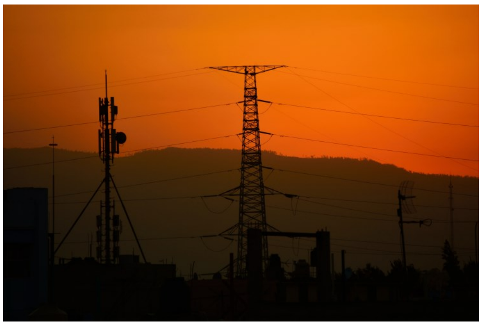
- the primary voltage, V_P and current, I_P;
- the secondary voltage, V_S and current, I_S.

Record your results in the Student Handbook.
Are they in line with your expectations? Give your comments in the Student Handbook.
Use them to work out the efficiency of the transformer by following the steps listed there.

Worksheet 7

Step it up

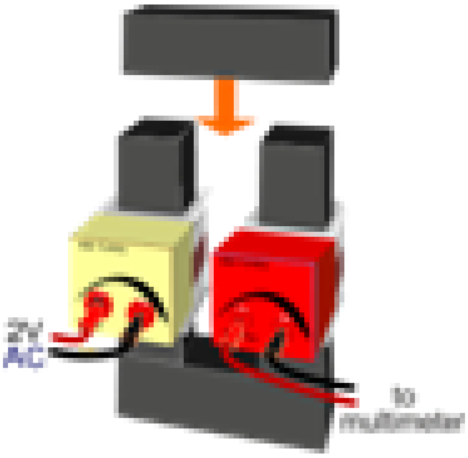
As the transmission voltage is increased, the current needed to deliver a given power level decreases. Heat is generated when an electric current flows through a cable. The bigger the current, the greater the quantity of heat generated. Using a high transmission voltage cuts down waste heat generation.



The electricity transmission grid in the UK contains thousands of kilometres of cable. To minimise energy losses caused by cable-heating, the grid uses a very high voltage, up to 400 kilovolts.
Transformers are used to step up the voltage from that generated in power stations.

Over to you:

- Build the step-up transformer, using a 400 turn coil as the primary, connected to 2V AC, and a 800 turn coil as the secondary, connected to a multimeter, set to read AC voltages. The test procedure is the same as for the step-down transformer.
- Switch on the AC supply.
- Measure the primary voltage, , V_P, and secondary voltage, V_S, and record them in the table in the Student Handbook.
- Use your results to complete the first row of the table by calculating 'V_P / V_S'
- Replace the 800 turn coil with a 1600 turn coil and repeat the procedure. Complete the second row of the table.
- Repeat the procedure for each of the other pairs of coils listed in the table.



Caution!

The resistors can get very hot.

Do not touch them!

Challenge:

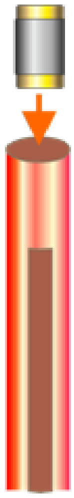
1. Predict what would happen if you replace the 2V AC supply with 1V AC for the transformer shown in the diagram. Then test your prediction. Comment on the outcome in the Student Handbook.
2. You need to step up a 1V AC supply to 4V. Suggest what coils are needed to do this.
   Set up your design and test your prediction. Explain your choice of coils in the Student Handbook and give the test results obtained when you set up your design.
3. Build a step-up transformer using a 600 turn coil and a 1600 turn coil.
   Connect the primary coil to the 2VAC power supply and the secondary coil to a 6V 40mA lamp.
   Take the measurements needed to work out the efficiency of the transformer by following the steps listed in the Student Handbook.
   Unscrew the bulb. What happens to the voltage readings?

Worksheet 8
Eddy currents

Electromagnetic induction isn't choosy where it generates. We'd like it to concentrate on outputting electrical power from the second coil of the transformer. To improve that, we include a magnetic core to link the magnetic field created by the first coil with the second coil. Unfortunately, being metallic and sitting in the varying magnetic field, the core is also subject to an induced voltage. The currents that result are known as eddy currents.An important application of this effect, called the electromagnetic retarder, is used to slow down heavy vehicles without causing wear on the conventional friction brakes.

Over to you:

This investigation uses the Lenz's law kit - a copper tube and two neodymium plugs.



- Hold the copper tube in a vertical position.
- Drop the first 'plug' down the tube.
- Now drop the second one and compare its behaviour.
- In the Student Handbook, answer the question about the difference in the behaviour of the two.
- In Worksheet 1, you showed that one of these 'plugs' is magnetised and one is not. Which fell faster?
  In the Student Handbook, write down your answer.

What is going on?

When the magnetised plug falls through the copper tube, the moving magnetic field induces electric currents (eddy currents) in the copper.

These in turn generate magnetic fields (even though copper is not a magnetic material!).

These act to repel the magnetised plug, slowing its fall. This is an illustration of Lenz's law.

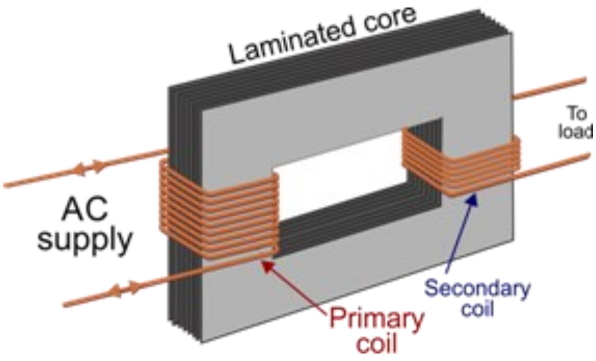
Transformers

An Overview

Overview

Structure of a transformer:

A basic transformer consists of two coils of insulated wire wound around a magnetic core.



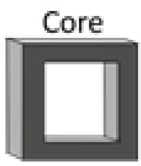
- The coils are electrically insulated from each other and from the magnetic core, but are exposed to the same magnetic fields.
- The coil connected to the AC supply is known as the ***primary*** coil.
- The coil connected to the load powered by the transformer is called the ***secondary*** coil.
-

The magnetic core is usually laminated - made of thin sheets of magnetic material glued together. Transformers can be divided into two broad types, depending on the position of the coils.

These are :

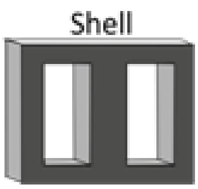
- **Core type**

  The core is a hollow rectangle. In its simplest form, the primary coil is wound on one side and the secondary on the other. Often, to improve efficiency, half of the primary coil, overlapped by half of the secondary coil is found on one side of the rectangle, with the same arrangement on the other side.



- **Shell type**

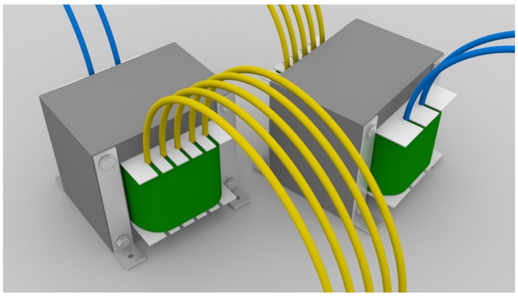
  The core has a centre leg. Both the primary and secondary windings are wound around it. It is more efficient than the core type because the magnetic field is more closely linked to the coils.



Overview

Operating principles:

When an electric current flows through the primary coil, it generates a magnetic field. This magnetises the transformer core. The secondary coil sits in the magnetic field of the core.



When the primary current is AC, the magnetic field varies. As the AC rises, falls and reverses, the magnetic field increases, falls and reverses in step with it. This moving magnetic field generates an alternating voltage in the secondary coil.

This effect is known as mutual induction.

The greater the number of turns in the primary, the stronger the magnetic field produced in the core.

The greater the number of turns in the secondary, the greater the voltage generated by the moving magnetic field in the core.

Depending on the relative number of turns on the primary and secondary coils, the transformer can increase or decrease the supply voltage.

It has no effect on the frequency of the supply.

It does not increase the energy delivered by the electricity supply - in fact it wastes energy. Rather, it changes the 'characteristics' of the energy.

In an *ideal* step-down transformer:

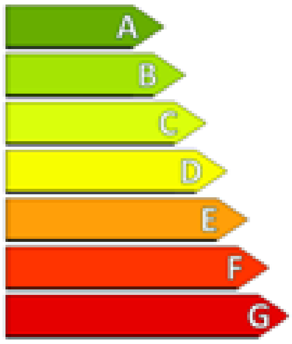
- the secondary coil generates a ***smaller*** voltage than that applied to the primary;
- the current in the primary coil is ***smaller*** than that flowing in the secondary.

In an *ideal* 'step-up' transformer,

- the secondary coil generates a ***higher*** voltage than that applied to the primary;
- the current in the primary coil is ***bigger*** than that flowing in the secondary.

Overview

Transformer efficiency:



Energy is wasted in a transformer.

If 100% efficient, then all the energy supplied to it, via the primary coil, would go into generating electricity in the secondary coil.

The main sources of this energy loss are:

- 'copper losses'
- 'iron losses'.

Copper losses:

are caused by the electrical resistance of the copper wire used to make the primary and secondary coils. Even though copper is an excellent conductor, it still has some resistance. In normal use, large currents flow in the coils , generating unwanted heat.

Iron losses:

originate in the core and result from two effects:

- **eddy currents**;
- **hysteresis**.

Eddy currents:

The core is made from an electrical conductor, often steel. It behaves like a single loop of wire and the changing magnetic field generated by the primary coil current induces a current in the core as well as in the secondary coil.

Known as **eddy currents**, these generate waste heat in the resistance of the core.
Laminating the core, (constructing it from thin sheets of steel, glued together, but insulated from each other,) increases the electrical resistance of the core and so reduces the size of the eddy currents. This reduces the wasted heat.

Hysteresis:

Magnetising the core involves aligning the magnetic effects of the atoms in it. This requires small quantities of energy. As the magnetic field builds, falls and reverses, in step with the alternating current in the primary coil, this continual alignment and realignment requires a significant amount of energy, which eventually is released as heat.

Transformers

Appendix
-
Electrical measurements with a multimeter

Appendix 1 -measuring DC voltage

The picture shows one form of multimeter. It has a wide range of uses, which varies from model to model - but usually includes measuring AC and DC voltage and current.

When using a multimeter, before you switch it on:

- take care to plug the probes into the correct sockets;
- select the correct range.

(‘Auto-ranging’ versions select the best range automatically.)

Voltage:

- is a measure of the force pushing the electrons around the circuit;
- measures energy lost or gained as an electron moves through part of a circuit;
- is measured with a voltmeter connected in parallel with the component.

The circuit symbol for a voltmeter is shown in the diagram.

Using a multimeter to measure voltage:

Multimeters can measure both AC and DC. The following symbols distinguish between them:

- Plug one wire into the black ‘**COM**’ socket.
- Plug another into the red ‘**V**’ socket.
- Select the 20V DC range by turning the dial to the ‘**20**’ mark next to the ‘ ⎓ ’ symbol.
(It is good practice to set the meter on a range that is much higher than the reading you are expecting. Then refine it by choosing a lower range to suit the voltage you find.)
- Plug the wires into the sockets at the ends of the component under investigation.
- Switch on the multimeter when you are ready to take a reading.
- A ‘**-**’ sign in front of the reading means that the meter wires are connected the wrong way round. Swap them over to get rid of it!

Appendix 2 -measuring DC current

When using a multimeter to measure current, plug the probes into the '**A**' and '**COM**' sockets, or equivalents.

Then select the correct range, either from the '**A~**' section, for AC current or the ' **A** ⎓ ' section, for DC current.

Finally, switch on.

Current:

- measures the number of electrons passing any point in the circuit each second;
- measures the rate of flow of electrical charge in the circuit;
- is measured with an ammeter connected in series with the component.

The circuit symbol for a ammeter is shown in the diagram.

Using a multimeter to measure current:

- Plug one wire into the black '**COM**' socket.
- Plug another into the red '**mA**' socket.
- Select the 200mA DC range by turning the dial to the '**200m**' mark next to the '**A** ⎓ ' symbol.
  (Again, it is best to set the meter on a higher range to begin with.
  Then choose a lower range to suit the current you find.)
- Break the circuit where you want to measure the current, by removing a link, and then plug the two multimeter leads in its place.
- Switch on the multimeter when you are ready to take a reading.

- **A possible problem:**
  The ammeter range is protected by a fuse located inside the body of the multimeter.
  This may have 'blown', in which case the ammeter will not work.
  Report any problems to your instructor so that it can be checked.

Appendix 3 -measuring resistance

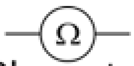
When using a multimeter to measure resistance, first remove the component from the circuit !

Once again, before you switch on:

- take care to plug the probes into the correct sockets, the ’**Ω**’ and ’**COM**’ sockets;
- select the correct range.

Resistance:

- is a hindrance to the flow of electrons around the circuit;
- removes energy from each electron as it moves through the resistor;
- converts this energy into heat;
- is measured in units called ’ohms’ (symbol - ’Ω’) or kilohms (kΩ), using an ohmmeter. (1 kilohm = 1 000 ohms.)



Ohmmeter

Using a multimeter to measure resistance:

- Plug one wire into the black ‘**COM**’ socket.
- Plug another into the red ‘**Ω**’ socket.
- Turn the dial to select a resistance range, such as 200kΩ.
  (Once again, it is good practice to set the meter on a range higher than the reading you are expecting and then refine it to a lower range.)
- Make sure that the component under investigation is not connected to any other.
- Plug the wires into the sockets at the ends of the component.
- Switch on the multimeter when you are ready to take a reading.

Transformers

Student Handbook

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For your records

The role of transformers

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The benefit is that higher distribution voltages require lower currents for the same power transfer. Lower current reduces energy losses caused by the resistance of the transmission cables.

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Magnetised - a magnet - it can both **attract** and **repel** another magnet.

Magnetic field - magnets can move objects without touching them!
Any magnetic material nearby is **attracted** to the magnet.
A second magnet nearby is both **attracted** and **repelled** by the first .
To help us to visualise this, we picture the magnet as surrounded by an invisible magnetic field.

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Magnetic flux - A magnetic field can be mapped as a set of 'lines of force' or magnetic flux lines, surrounding the magnet. Where the magnetic force is strong, these are tightly packed. Where it is weaker, they are more widely spaced. We talk about a flux line as the path taken by a free north pole as a result of the forces exerted on it by the magnet.

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Self induction - a voltage is generated in a wire by a changing magnetic field caused by a current already flowing in that wire.

Mutual induction - a voltage is generated in one wire by a changing magnetic field caused by a current flowing in a wire in a different circuit.

Worksheet 1 - Magnetic vs magnetised

Describe the behaviour of the plotting compass when placed near:

- the first neodymium plug:

....

....

....

....

....

....

- the second neodymium plug.

....

....

....

....

....

....

- How did you decide which of the plugs is magnetised?

....

....

....

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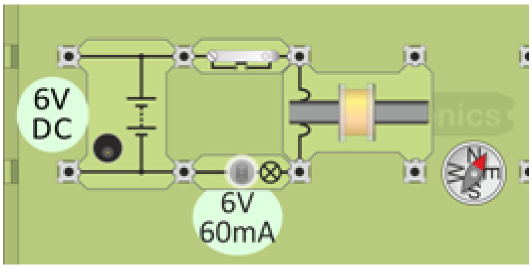
....

Worksheet 2 - Electromagnetic?

All magnetic effects result from the behaviour of electrons, tiny particles found in all atoms. Whenever they move, they create tiny magnetic effects. Under the right circumstances, these can add up to make an overall observable magnetic field.



Describe the behaviour of the plotting compass:

- before the switch is pressed:

....

....

....

....

- after the switch is pressed:

....

....

....

....

What is the effect of the ferrite core?

....

....

....

What happens when you reverse the current by turning the power supply carrier upside downe?

....

....

....

Worksheet 3 - Generating electricity - 1

Step 1 - Moving the magnet:

What happened when:

- you plunged the magnet into the coil:

………

………

- you pulled the magnet out of the coil:

………

………

What was the effect of:

- using a coil with more turns:

………

………

- moving the magnet faster:

………

………

Step 2 - Moving the coil:

What was the effect of:

- moving the coil over the magnet:

………

………

- using a coil with more turns:

………

………

Verdict:

The requirement is that a magnetic field moves over a conductor. The size of the voltage generated depends on the speed at which the magnetic field changes and the number of turns of wire over which it moves.

Worksheet 4 - Generating electricity - 2

'Electricity' is the result of the flow of electrons.

It comes in two 'flavours', **DC** (direct current) and **AC** (alternating current).

These are compared in the table.

DC	AC
one power supply terminal is always positive, the other negative	terminals change polarity repeatedly - one positive, the other negative and then they swap
'one-way traffic' - current always flows the same way around the circuit	'two-way traffic' - current flows clockwise, then anti-clockwise around the circuit
cannot be used with transformers	can be used with transformers

Step 3 - Electromagnet, not magnet:

What happened when you:

- moved the electromagnet over the coil;

....

....

....

- placed the electromagnet on the coil and switched on and off;

....

....

....

- added a ferrite core to the coil;

....

....

....

- used the 3200 turn coil as the electromagnet;

....

....

....

- replace the 200 turn coil with one having more turns ?

....

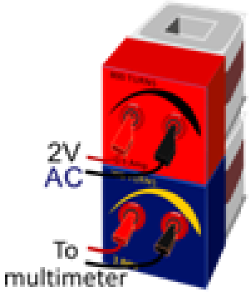
....

....

Worksheet 5 - Mutual inductance

Step 4 - AC not DC:

This time, the moving magnetic field is produced not by physically moving the magnet, or the coil, but by using a varying magnetic field generated by an alternating current.



What happened when you:

- switched the AC supply on and off ;

…

…

…

…

- lowered the ferrite core down the middle of the two coils;

…

…

…

- separated the two coils;

…

…

…

- used a different material for the core;

…

…

…

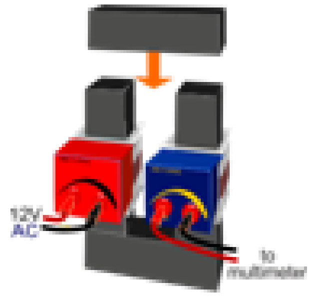
- connect the upper coil to a 1V AC supply, instead of 2V AC?

…

…

…

Worksheet 6 - Step it down



Most modern electronic devices work on a low voltage DC supply. The first stage is to step the AC supply voltage down to a lower level.
This is accomplished using a step-down transformer.

Number of turns on primary, N_P	Number of turns on secondary, N_S	Turns ratio N_P/N_S	Voltage applied to primary, V_P	Voltage applied to secondary, V_S	V_P/V_S
800	200	4			
600	200	3			
800	400	2			
1600	400	4			
1600	800	2			

1. To step down a 2VAC supply to 1V: Primary coil = ... turns
Secondary coil = ... turns

Reasons for choice:

....

....

Test results:

....

....

2. Step-down transformer using a 800 turn coil and a 400 turn coil.

Measurements:

Primary voltage **V_P** = ... Primary current **I_P** = ...

Secondary voltage **V_S** = ... Secondary current **I_S** = ...

Comments:

....

....

Power delivered to primary coil **P_P** = **V_P** x **I_P** = ...

Power delivered by secondary coil **P_S** = **V_S** x **I_S** = ...

Transformer efficiency **= P_S / P_P x 100%**

= ....

Worksheet 7- Step it up

Using a high transmission voltage reduces the current needed to deliver a given power level. In turn, this reduces unwanted heat generated in the cables.

The UK electricity transmission grid uses thousands of kilometres of cable. To minimise energy losses caused by cable-heating, step-up transformers raise the output from the power stations to very high voltages, up to 400 kilovolts.

Number of turns on primary, N_P	Number of turns on secondary, N_S	Turns ratio N_P/N_S	Voltage applied to primary, V_P	Voltage applied to secondary, V_S	V_P/V_S
400	800	0.5			
400	1600	0.25			
400	3200	0.13			
800	1600	0.5			
800	3200	0.25			

1. Comment on the behaviour of the original step-up transformer connected to a 1V AC supply.

……

……

2. To step up a 1VAC supply to 4V: Primary coil = ………………. turns

Secondary coil = ………………. turns

Reasons for choice:

……

……

Test results:

……

3. Step-up transformer using a 600 turn coil and a 1600 turn coil.

Measurements: Primary voltage V_P = ………………. Primary current I_P = ……………….

Secondary voltage V_S = ………………. Secondary current I_S= ……………….

Power delivered to primary coil P_P = V_P x I_P = ……………….

Power delivered by secondary coil P_S = V_S x I_S = ……………….

Transformer efficiency **= P_S / P_P x 100%**

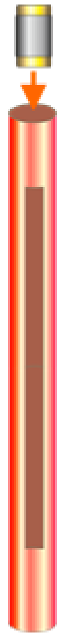
= ……………….

What happened when the bulb was unscrewed?

……

……

Worksheet 8 - Eddy currents



A changing magnetic field interacts with the electrons in a conductor to generate a voltage which can drive a current through the conductor. In the core of a transformer, these unwanted currents, known as eddy currents, waste energy by heating up the core.

How did the behaviour of the plugs differ when dropped into the copper tube?

……

……

……

……

……

……

How did you decide which plug was the magnet?

………

………

………

Which fell faster, the magnetised plug or the unmagnetised one?

………

What is going on?

When the magnetised plug falls through the copper tube, the moving magnetic field induces electric currents (eddy currents) in the copper.

These in turn generate magnetic fields (even though copper is not a magnetic material!)

These act to repel the magnetised plug, slowing its fall - an illustration of Lenz's law.

Eddy currents have their uses:

- in vehicle braking systems for trucks and trains;
- in machine tools to bring moving parts to a quick halt;
- in domestic induction hobs to heat metallic pans.

Transformers

Instructor Guide

About this course

Introduction

The course is essentially a practical one. The equipment makes it simple to construct and test circuits designed to encourage clear understanding of transformers. Where possible, practical implications and applications of the theory are highlighted to make the course more relevant to the students.

A Student Handbook is included to give students a concise record of their studies.

Aim

Transformers are devices for increasing or decreasing voltage and current. The transformer kit allows students to study not only how transformers work, but also study several other related properties.

Prior Knowledge

It is recommended that students have followed the LK 4098 “Electrical wiring 1” and LK4063 “Electrical wiring 2”courses, or have equivalent knowledge and experience of building simple circuits, and using multimeters.

Learning Objectives

On successful completion of this course the student will be able to:

- explain the important role of transformers in the electricity distribution network;
- build a circuit using a chain of series resistors to create a range of intermediate output voltages;
- distinguish between the terms ‘magnetic’ and ‘magnetised’;
- explain what is meant by the terms ‘magnetic field’, ‘magnetic pole’ and ‘magnetic flux’;
- perform an experiment to distinguish between a magnetic material and one which is magnetised;
- state that repulsion is the test of whether a material is magnetised;
- state that all magnetic effects result from the behaviour of electrons;
- describe the result of passing a DC current through a coil;
- describe the effect of adding a ferrite core to a coil carrying a current;
- describe the circumstances that lead to the generation of a current in a coil subjected to a magnetic field;
- state the effect of speed of movement of the magnet on the voltage generated in a coil;
- state the effect of the number of turns on the coil on the voltage generated in it;
- distinguish between AC and DC electricity;
- explain the meaning of the terms ‘inductionce’ ‘self induction’ and ‘mutual induction’;
- state that an electromagnet can be provide the magnetic field responsible for voltage generation in a coil;
- describe the effect of adding a ferrite core to the electromagnet and second coil;
- give one use for a step-down transformer;
- state that in a step-down transformer, the secondary voltage is smaller than the primary voltage;
- state that in a step-down transformer, the secondary current is bigger than the primary current;
- give one use for a step-up transformer;
- state that in a step-up transformer, the secondary voltage is bigger than the primary voltage;
- state that in a step-up transformer, the secondary current is smaller than the primary current;
- describe the relationship between the transformer turns ratio and the ratio of primary:secondary voltage for an ideal transformer;
- use data on primary and secondary voltages and currents to calculate the efficiency of a transformer;
- describe why eddy currents form in the core of the transformer;
- explain why these currents are undesirable and describe steps that can be taken to reduce them;
- name three useful applications of eddy currents.

What the student will need:

To complete the combinational logic course, the student will need the following equipment:

- 1 LK8900 Locktronics Baseboard
- 7 LK 5250 connecting link
- 1 HP3728 12V AC power supply
- 1 LK2340 AC voltage source carrier
- 1 HP2666 DC power supply
- 1 LK8275 power supply carrier with battery symbol
- 1 LK4002 100Ω, 3W resistor
- 2 LK4025 10Ω, 3W resistor
- 1 LK5291 MES lampholder
- 1 LK2399 12V MES power LED lamp
- 1 LK2347 6V 40mA MES filament lamp
- 1 LK6209 switch, on/off, carrier
- 1 LK7487 Lenz's law kit
- 1 LK0124 small compass
- 1 LK9998 400 turn coil carrier
- 1 LK3291 ferrite rod
- 1 HP7360 coils and cores activity set
- 1 LK7485 Alnico rod magnet
- 1 LK1110 multimeter, (or equivalent)
- 2 LK 5603 Lead, red 500mm, 4mm to 4mm stackable
- 2 LK5604 Lead, black 500mm, 4mm to 4mm stackable

Using this course:

The experiments in this course should be integrated with teaching to introduce the theory behind it, and reinforced with written examples, assignments and calculations.

The worksheets should be printed / photocopied / laminated, preferably in colour, for the students' use. They should make their own notes to enhance those provided in the Student Handbook. They are unlikely to need their own permanent copy of the worksheets.

This format encourages self-study, with students working at a rate that suits their ability. The instructor should monitor that students' understanding keeps pace with their progress through the worksheets. One way to do so is to 'sign off' each worksheet, as a student completes it, and in doing so have a brief chat with the student to assess grasp of the ideas involved in the exercises it contains.

Time:

It should take students between 3 and 5 hours to complete the worksheets. It is expected that a similar length of time will be needed to support the learning that takes place as a result.

Health and Safety issues:

At the beginning of the course, students are given this warning:

Transformers can be dangerous!

Take care!

Transformers can turn a relatively low voltage into a high voltage.

It is the Instructor's responsibility to enforce sensible precautions when students are using the equipment. The following table gives some information about the dangers of electricity.

It's The Current That Kills

The size of the electric current flowing through someone's body when experiencing an electric shock depends on two factors - the size of the voltage and the resistance of their body. The greater the voltage, the greater the current - the greater the resistance, the smaller the current.

The body's resistance depends on the path taken by the current and on whether the skin is dry or wet (including sweat). From one ear to the other, the resistance (internal path) can be less than 100Ω. From head to foot, the skin resistance can be 500kΩ when dry but only 1kΩ when wet.

For most, a current of less than 1mA is not detected. Between 1mA and 5mA, the person detects a slight to moderate tingling sensation, not painful but possibly disturbing. A current over 10 mA can cause a painful to severe shock, Currents above 100mA can be fatal.

CLEAPSS (the Consortium of Local Education Authorities for the Provision of Science Services) have adopted the safe limits of 28 V AC / 40 V DC for bench circuit work by students.

For these reasons, the students are told to observe the following precautions:

Precautions:

- **Always used shrouded 4mm plugs and sockets!**
- **Do not touch exposed metal parts!**
- **Do not be tempted to "see what happens if…"!**
  Stick to the instructions given in the investigation.
- **If in doubt, ask the instructor!**

However, the Instructor must supervise all activities involving the Transformer kit very closely!

Scheme of Work

Worksheet	Notes for the Instructor	Time
Preamble	It is assumed that students are able to: • use a multimeter to measure the voltage across a component; • use a multimeter to measure the current through a component; • change the measurement range on the multimeter as appropriate; • understand and be able to manipulate multiples of units, such as milli, micro, kilo etc. The appendices help with the use of multimeters to measure voltage, current and resistance.	
Introduction	The aim of this course is to develop an understanding of transformers. The introduction spells out a major reason why these devices are important and hence establishes a good reason for studying them. The power supply section shows how to use a resistor chain to create different output voltages from the 12V AC power supply. Where students are already familiar with Locktronics, this activity needs little or no intervention from the instructor. Those new to the kit might need help / reassurance in setting up the circuit. Although application of Ohm's law leads to values of 1V, 2V and 12V for the output voltages shown, this approach neglects the effect of the current drawn from the output by the various coils. As a result, these voltages will vary from the ones shown on this page - hence the word '...around...' used to describe the voltages. Even though they are working well within their design power rating, the resistors will get hot, as they are dissipating quite a lot of electrical power. **It is important that students are warned not to touch the resistors.**	**10 - 20 mins**
1	Here, the focus is on distinguishing between the words 'magnetic' and 'magnetised'. The first means only that the material is capable of becoming a magnet. The second means that it has become a magnet. Later, students are told that all magnetic effects stem from electrons. Whenever an electron moves, it creates a magnetic effect. As all materials contain billions of these electrons, it may not be obvious why so few actually exhibit magnetic properties. The answer is that most exhibit these properties but only on a very small scale. On a larger scale, these effects tend to cancel each other out. In a few cases, they can be made to reinforce each other. Then the material appears 'magnetic'. Such materials include iron, nickel and cobalt and their alloys. The core of the Earth has a significant iron content and this gives rise to the Earth's magnetic field, alluded to in the preamble to this worksheet. In the same way that moving electrons give rise to a magnetic field, a magnetic field has an effect on electrons, giving rise, in the case of the Earth's magnetic field, to the 'Northern Lights'. The test for a magnet is that it repels another magnet, here, the compass needle. Attraction is not a sufficient test. The material being tested may be only magnetic and may be attracted by a magnet nearby. Students should make mention of repulsion in their description of the effects of the compass on the two neodymium plugs. The worksheet ends with a short glossary of terms associated with magnetism. In nature, there are a number of weird effects that we struggle to visualise - gravity, for example. We invent the idea of a force 'field' to make it easier for ourselves. A magnetic field is one example. The lines of force can be likened to contour lines on a map. They don't exist either!	**20 - 30 mins**

Worksheet	Notes for the Instructor	Time
2	Once again, students with no previous experience of using Locktronics may need some supervision in setting up the circuit. The instructor should check that the DC power supply is set to 6V and that they have inverted the power supply carrier correctly in the 'Challenge' section. The purpose of the 6V lamp is to indicate the presence of a current and also to limit the current to the coil which otherwise may overheat. The results may be clearer if the board is rotated so that the Earth's magnetic field does not mask the effect.	**20 - 30 mins**
3	The students should be aware that the multimeter samples the input signal periodically. It may be that when they plunge the magnet into the coil, the effect occurs between samples and so is missed by the multimeter. Repeating the action several times gets over this problem. A more rapidly moving magnetic field should induce a greater voltage but, again, this could be masked by the input sampling. Once again, the answer is to repeat the action, paying careful attention to keeping consistent speed. The students are more likely to notice the effect of speed if they compare a slow speed of insertion with a really fast one. Working in pairs here is a real benefit as one can carry out the action while the other watches the effect. Sensible choice of meter range helps too. The greater the number of turns, the greater the induced voltage. The students should aim for a valid scientific approach, varying only one factor at a time. In other words, they should aim to keep the speed the same for all coils.	**25 - 35 mins**
4	The procedure for this investigation is relatively straightforward. The instructor should check that students have correctly selected 3V on their DC power supply. When the power supply is off, obviously, there is no magnetic field present. When it is switched on, the magnetic field builds up, quickly. When switched off again, the magnetic field collapses. Effectively, this amounts to a moving magnetic field, in one direction and then the other. As usual, the students should repeat the actions several times to overcome the multimeter's input sampling. When a section of the transformer core is inserted, the magnetic field of the powered coil magnetises it. The resulting field is much stronger and so induces a bigger voltage in the second coil. Increasing the number of turns in the powered coil intensifies the magnetic field and so should induce a greater voltage in the other coil. Similarly, increasing the number of turns in the second coil should also increase the induced voltage. Students should be encouraged to adjust the multimeter to find the best range for seeing the effects.	**20 - 30 mins**
5	Now the science gets a bit more mysterious. So far, we have emphasised the need for movement. The magnet or the conductor should move. The previous investigation, where the power supply was switched on and off gives the clue. Now, instead of DC, suddenly turned on and then off, the AC current changes slowly, rising, falling and reversing. The magnetic field matches it. In doing so, it builds up and dies away, effectively moving across the turns of the lower coil. **The instructor should emphasis the warning about not touching the resistors. They are designed to 'run hot', and will do so!** Some students may need help in setting up and connecting the power supply circuit. An advantage of this arrangement is that it limits the current available to the coils.	**20 - 30 mins**

Worksheet	Notes for the Instructor	Time
6	Having looked at the ingredients that go to make a transformer, this investigation looks at the step-down version, where the number of turns on the primary coil exceeds that on the secondary. The instructor could preface this session by exploring students' ideas as to why this configuration leads to stepping down the voltage. The investigation does not require the resistor chain. The output of the AC supply could be applied directly to the primary coil. The instructor should decide whether to preserve continuity and use the baseboard layout. If so, then it essential to stress the importance of not touching the hot resistors. Some students may require a prompt as to how to measure the primary and secondary current. Appendix 2 shows them how to do this, though the instructor may wish to expand on this, particularly if using a different multimeter. The first challenge could start with a group making a presentation to the rest of the class. Although the choice of coils may be straightforward, the test results are unlikely to support this choice exactly. The instructor may have to be prepared with an explanation, in terms of imperfections in this simple design. At this point, details of practical transformers could be discussed. The investigation ends with the student taking measurements to determine the efficiency of this transformer in this particular configuration. This again may need the instructor's explanation about imperfect design.	**25 - 35 mins**
7	In many ways the mirror-image of the previous device, the step-up transformer is the subject of this investigation. The introduction points out an important reason for their existence - for use in high voltage power transmission, but for obvious reasons, the voltages involved here must be much smaller. The choice of coils for the investigation is aimed at limiting the voltages the students experience. For similar reasons, the resistor-chain power supply limits the current delivered to the transformer. The instructor should again emphasise the need for care when touching the hot resistor carriers. Some of the issues mentioned above, current measurement, design imperfections etc, apply to this investigation too. So too does the opportunity for brain-storming and class presentations. One significant factor is the way that the lamp 'loads' the transformer output. When it is unscrewed, the output voltage changes drastically. The cause lies in the current-limiting function of the resistor chain.	**25 - 35 mins**
8	Hidden in the detail of transformer design is the need for a laminated core - thin sheets (laminae) of iron, glued together. This worksheet investigates the background. The activity takes only seconds to complete but students should be allowed time to explore. The two neodymium plugs look identical, but one is magnetised, and the other is not. The unmagnetised one falls 'normally' under gravity. The magnet, however, induces currents in the copper tube - a moving magnetic field encountering a conductor. In turn, these currents generate magnetic fields that oppose the effect producing them - the falling magnet. As a result, the magnet falls only slowly.	**10 - 15 mins**