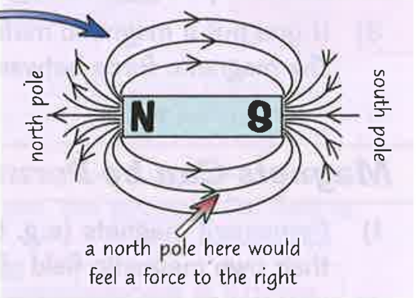
Magnets and Magnetic Fields

I think magnetism is an attractive subject, but don't get repelled by the exam — revise.

Magnets Produce Magnetic Fields

To see the shape of a magnetic field, place a piece of card over a magnet and sprinkle iron filings onto it. The filings line up with the field lines — but they won't show you the direction of the field.

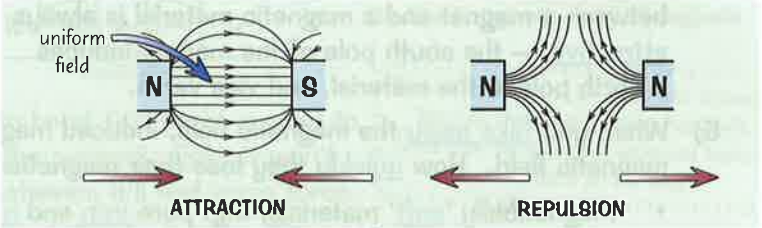
1) All magnets have two poles — north and south.
2) All magnets produce a magnetic field — a region where other magnets or magnetic materials (see next page) experience a force.
3) You can show a magnetic field by drawing magnetic field lines.
4) The lines always go from north to south and they show which way a force would act on a north pole at that point in the field.
5) The closer together the lines are, the stronger the magnetic field.
6) The further away from a magnet you get, the weaker the field is.
7) The magnetic field is strongest at the poles of a magnet. This means that the magnetic forces are also strongest at the poles.



a north pole here would feel a force to the right

Magnetic Fields Cause Forces between Magnets

1) Between two magnets the magnetic force can be attractive or repulsive. Two poles that are the same (these are called like poles) will repel each other. Two unlike poles will attract each other.
2) Placing the north and south poles of two bar magnets near each other creates a uniform field between the two poles. The magnetic field is the same strength everywhere between the poles.
3) If you're asked to draw a uniform magnetic field, you need to draw at least three field lines, parallel to each other and all the same distance apart.

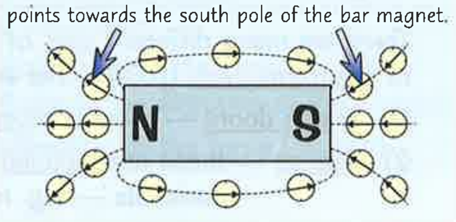


Don't forget the arrows on your field lines.

Plotting Compasses Show the Directions of Magnetic Fields

1) Inside a compass is a tiny bar magnet called a needle. A compass needle always lines up with the magnetic field it's in.
2) You can use a compass to build up a picture of what the field around a magnet looks like:
   - Put the magnet on a piece of paper and draw round it.
   - Place the compass on the paper near the magnet. The needle will point in the direction of the field line at this position.
   - Mark the direction of the compass needle by drawing two dots — one at each end of the needle.
   - Then move the compass so that the tail end of the needle is where the tip of the needle was in the previous position and put a dot by the tip of the needle. Repeat this and then join up the marks you've made — you'll end up with a drawing of one field line around the magnet.
   - Repeat this method at different points around the magnet to get several field lines. Make sure you draw arrows from north to south on your field lines.
3) When they're not near a magnet, compasses always point towards the Earth's North Pole. This is because the Earth generates its own magnetic field (and the North Pole is actually a magnetic south pole). This shows the inside (core) of the Earth must be magnetic.

The compass follows the field lines and points towards the south pole of the bar magnet.



Magnets are like farmers — surrounded by fields...

Magnetism is one of those things that takes a while to make much sense. Learn these basics — you'll need them.

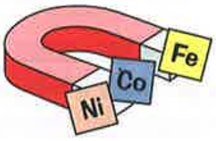
Q1 Draw the magnetic field lines for a bar magnet. Label the areas where the field is strongest. [3 marks]

Q2 Describe how to plot the magnetic field lines of a bar magnet using a compass. [4 marks]

Permanent and Induced Magnets

Magnetic fields don't just affect magnets — they affect a few special magnetic materials too.

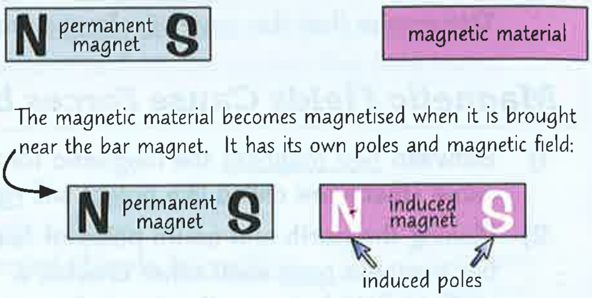
Very Few Materials are Magnetic



1) The main three magnetic elements are iron, nickel and cobalt.
2) Some alloys and compounds of these metals are also magnetic. For example, steel is magnetic because it contains iron.
3) If you put a magnetic material near a magnet, it is attracted to that magnet. The magnetic force between a magnet and a magnetic material is always attractive.

Magnets Can be Permanent or Induced

1) Permanent magnets (e.g. bar magnets) produce their own magnetic field all the time.
2) Induced (or temporary) magnets only produce a magnetic field while they're in another magnetic field.
3) If you put any magnetic material into a magnetic field, it becomes an induced magnet.
4) This magnetic induction explains why the force between a magnet and a magnetic material is always attractive — the south pole of the magnet induces a north pole in the material, and vice versa.



The magnetic material becomes magnetised when it is brought near the bar magnet. It has its own poles and magnetic field:

5) When you take away the magnetic field, induced magnets return to normal and stop producing a magnetic field. How quickly they lose their magnetism depends on the material they're made from.
   - Magnetically 'soft' materials, e.g. pure iron and nickel-iron alloys, lose their magnetism very quickly.
   - Magnetically 'hard' materials, e.g. steel, lose their magnetism more slowly. Permanent magnets are made from magnetically hard materials.

Magnetic Materials have Lots of Uses

There are many different uses of magnetic materials, the number of which has grown since the invention of electromagnets (p.88). For example:

1) Fridge doors — there is a permanent magnetic strip in your fridge door to keep it closed.
2) Cranes — these use induced electromagnets to attract and move magnetic materials — e.g. moving scrap metal in scrap yards.
3) Doorbells — these use electromagnets which turn on and off rapidly, to repeatedly attract and release an arm which strikes the metal bell to produce a ringing noise.
4) Magnetic separators — these are used in recycling plants to sort metal items (like cans).
5) Maglev trains — these use magnetic repulsion to make trains float slightly above the track (to reduce losses from friction) and to propel them along.
6) MRI machines — these use magnetic fields to create images of the inside of your body without having to use ionising radiation (like X-rays, p.47).
7) Speakers and microphones — there's more about these on page 90.

Attractive and with a magnetic personality — I'm a catch...

Remember, induced magnets are also called temporary because they're only magnetic when in a magnetic field.

Q1 State three everyday uses of magnetic materials. [3 marks]

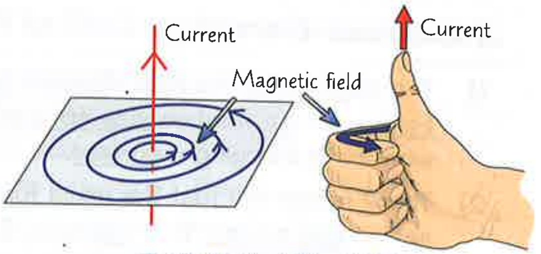
Q2 Give two differences between permanent and induced magnets. [2 marks]

Electromagnetism and the Motor Effect

On this page you'll see that a magnetic field is also found around a wire that has a current passing through it.

A Moving Charge Creates a Magnetic Field

1) When a current flows through a long, straight conductor (e.g. a wire) a magnetic field is created around it.
2) The field is made up of concentric circles perpendicular to the wire, with the wire in the centre.
3) Changing the direction of the current changes the direction of the magnetic field — use the right-hand thumb rule to work out which way it goes. (In experiments, you can use a plotting compass to find its direction, p.85.)
4) The larger the current through the wire, or the closer to the wire you are, the stronger the field is.



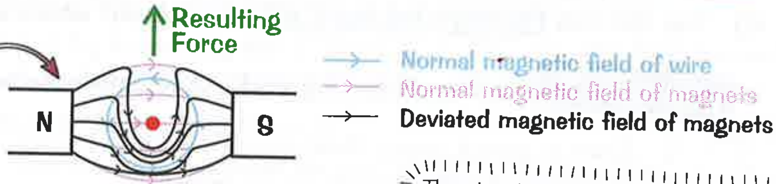
The Right-Hand Thumb Rule

Using your right hand, point your thumb in the direction of current and curl your fingers. The direction of your fingers is the direction of the field.

The Motor Effect — A Current in a Magnetic Field Experiences a Force

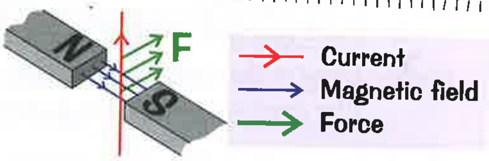
When a current-carrying conductor (e.g. a wire) is put between magnetic poles, the two magnetic fields interact. The result is a force on the wire.

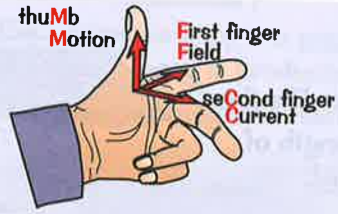
This is an aerial view. The red dot represents a wire carrying current "out of the page" (towards you). (If it was a cross ('×') then that would mean the current was going into the page.)



1) To experience the full force, the wire has to be at 90° (right angles) to the magnetic field. If the wire runs along the magnetic field, it won't experience any force at all. At angles in between, it'll feel some force.
2) The force always acts in the same direction relative to the magnetic field and the direction of the current in the wire. So changing the direction of either the magnetic field or the current will change the direction of the force.

The wire also exerts an equal and opposite force on the magnet (from Newton's Third Law, see p.19) but we're just looking at the force on the wire.





1) Fleming's left-hand rule is used to find the direction of the force on a current-carrying conductor.
2) Using your left hand, point your First finger in the direction of the magnetic Field and your seCond finger in the direction of the Current.
3) Your thuMb will then point in the direction of the force (Motion).

You Can Find the Size of the Force Using F = BIl

The force acting on a conductor in a magnetic field depends on three things:

1) The magnetic flux density — how many field (flux) lines there are in a region. This shows the strength of the magnetic field (p.85).
2) The size of the current through the conductor.
3) The length of the conductor that's in the magnetic field.

When the current is at 90° to the magnetic field it is in, the force acting on it can be found using the equation on the right.

$$F = B \times I \times l$$

Force (N)

Current (A)

Magnetic flux density (T, tesla or N/Am)

Length (m)

Left-hand rule for the motor effect — drive on the left...

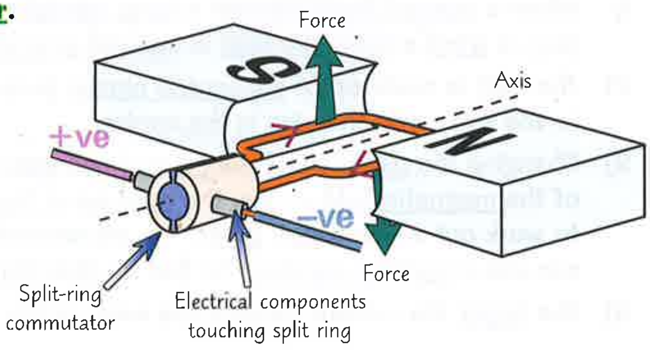
Learn the left-hand rule and use it — don't be scared of looking like a muppet in the exam.

Q1 A 35 cm long piece of wire is at 90° to an external magnetic field. The wire experiences a force of 0.98 N when a current of 5.0 A is flowing through it. Calculate the magnetic flux density of the field. [2 marks]

Motors and Solenoids

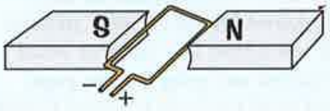
Electric motors might look a bit tricky, but it's really just applying the stuff you learnt on the previous page.

A Current-Carrying Coil of Wire Rotates in a Magnetic Field

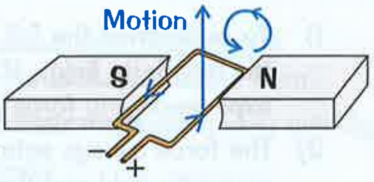


1) The diagram on the right shows a basic d.c. motor. Forces act on the two side arms of a coil of wire that's carrying a current.
2) These forces are just the usual forces which act on any current in a magnetic field (p.87).
3) These forces act in opposite directions on each side, so the coil rotates.
4) The split-ring commutator is a clever way of swapping the contacts every half turn to keep the motor rotating in the same direction.
5) The direction of the motor can be reversed either by swapping the polarity of the d.c. supply (reversing the current) or swapping the magnetic poles over (reversing the field).
6) You can use Fleming's left-hand rule to work out which way the coil will turn.

EXAMPLE: Is the coil turning clockwise or anticlockwise?

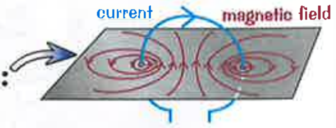


1) Draw in current arrows (from positive to negative, p.71).
2) Use Fleming's left-hand rule on one branch (here, I've picked the right-hand branch).
3) Point your first finger in the direction of the magnetic field (remember, this is north to south).
4) Point your second finger in the direction of the current.
5) Draw in the direction of motion (the direction your thumb is pointing in).

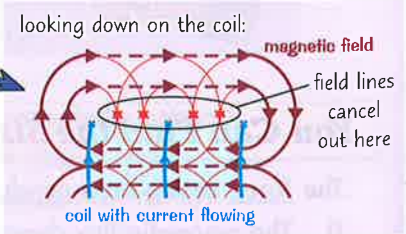


The coil is turning anticlockwise.

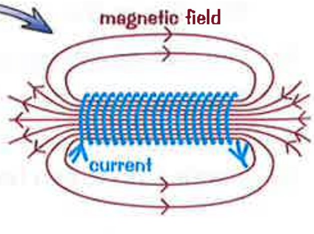
A Solenoid is a Long Coil of Wire



1) Around a single loop of current-carrying wire, the magnetic field looks like this:
2) You can increase the strength of the magnetic field produced by a length of wire by wrapping it into a long coil with lots of loops, called a solenoid.
3) The field lines around each separate loop of wire line up.
   - Inside the solenoid, you get lots of field lines pointing in the same direction. The magnetic field is strong and almost uniform.
   - Outside the coil, the overlapping field lines cancel each other out — so the field is weak apart from at the ends of the solenoid.



4) You end up with a field that looks like the one around a bar magnet. The direction of the field depends on the direction of the current (p.87).
5) A solenoid is an example of an ELECTROMAGNET — a magnet with a magnetic field that can be turned on and off using an electric current.
6) You can increase the field strength of the solenoid even more by putting a block of iron in the centre of the coil. This iron core becomes an induced magnet (see p.86) whenever current is flowing.



Give me one good raisin why I should make the currant joke...

Motors and solenoids are used in loads of everyday things from speakers to alarm clocks.

Q1 Sketch the magnetic field in and around a solenoid. [3 marks]

Electromagnetic Induction in Transformers

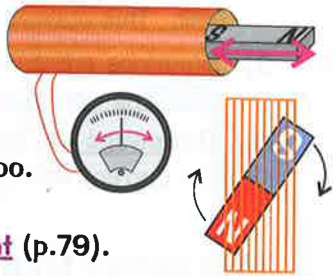
Transformers use electromagnetic induction — don't panic, it's not as bad as it sounds.

A Changing Magnetic Field Induces a Potential Difference in a Conductor

Electromagnetic Induction: The induction of a potential difference (and current if there's a complete circuit) in a wire which is experiencing a change in magnetic field.

Induces is a fancy word for creates.

1) There are two different situations where you get electromagnetic induction. The first is if an electrical conductor (e.g. a coil of wire) and a magnetic field move relative to each other.
   - You can do this by moving/rotating either a magnet in a coil of wire OR a conductor (wire) in a magnetic field ("cutting" magnetic field lines).
   - If you move or rotate the magnet (or conductor) in the opposite direction, then the p.d./current will be reversed. Likewise if the polarity of the magnet is reversed, then the potential difference/current will be reversed too.
   - If you keep the magnet (or the coil) moving backwards and forwards, or keep it rotating in the same direction, you produce an alternating current (p.79).

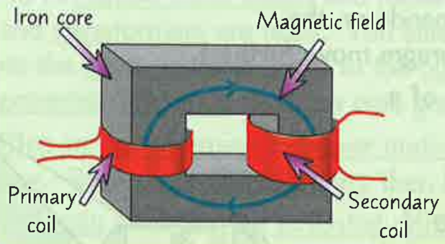


2) You also get an induced p.d. when the magnetic field through an electrical conductor changes (gets bigger or smaller or reverses). This is what happens in a transformer (below).
3) You can increase the size of the induced p.d. by increasing the STRENGTH of the magnetic field, increasing the SPEED of movement/change of field or having MORE TURNS PER UNIT LENGTH on the coil of wire.
4) The induced p.d./current always opposes the change that made it:
   - When a current is induced in a wire, that current produces its own magnetic field (p.87).
   - The magnetic field created by an induced current always acts against the change that made it. Basically, it's trying to return things to the way they were.

Transformers Change the p.d. — but Only for Alternating Current

1) Transformers use induction to change the size of the potential difference of an alternating current.
2) They all have two coils of wire, the primary and the secondary coils, joined with an iron core.
3) When an alternating p.d. is applied across the primary coil, it produces an alternating magnetic field.
4) The iron in the core is a magnetic material (see p.86) that is easily magnetised and demagnetised. Because the coil is producing an alternating magnetic field, the magnetisation in the core also alternates.
5) This changing magnetic field induces a p.d. in the secondary coil.

There's more about transformers on p.91.



STEP-UP TRANSFORMERS step the potential difference up (i.e. increase it). They have more turns on the secondary coil than the primary coil.

STEP-DOWN TRANSFORMERS step the potential difference down (i.e. decrease it). They have more turns on the primary coil than the secondary.

6) Transformers are almost 100% efficient. So you can assume that the input power is equal to the output power. Using $P = I \times V$ (page 78), you can write this as:

$$V_p \times I_p = V_s \times I_s$$

p.d. across primary coil (V)

Current through primary coil (A)

Current through secondary coil (A)

p.d. across secondary coil (V)

$V_p \times I_p$ is the power input at the primary coil. $V_s \times I_s$ is the power output at the secondary coil.

Transformers — NOT robots in disguise...

Make sure you know how transformers work, and then take a stab at using that equation with this question.

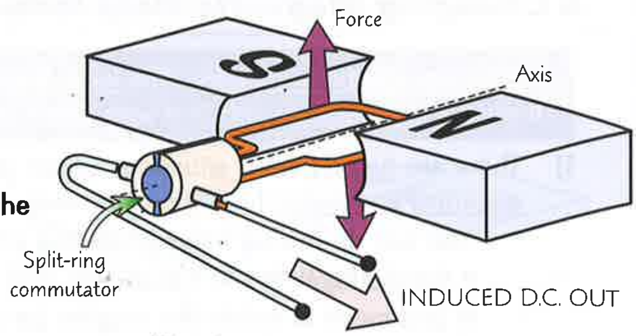
Q1 A transformer has an input potential difference of 1.6 V. The output power is 320 W. Calculate the input current. [2 marks]

Generators, Microphones and Loudspeakers

Generators make use of electromagnetic induction from the previous page to induce a current. Whether this current is alternating or direct depends on exactly how the generator's put together.

Dynamos Generate *Direct* Current

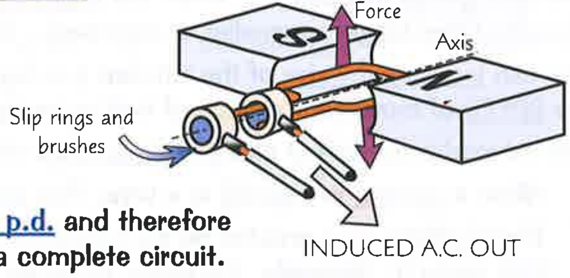
1) Generators apply a force to rotate a coil in a magnetic field (or a magnet in a coil) — their construction is a lot like a motor.
2) As the coil (or magnet) spins, a current is induced in the coil. This current changes direction every half turn.
3) Dynamos are d.c. generators. They have a split-ring commutator (like a d.c. motor, p.88).
4) This swaps the connection every half turn to keep the current flowing in the same direction.



The current induced in an alternator or dynamo will be greater if there are more turns of wire in the coil, the magnetic flux density is increased or if the speed of rotation is increased.

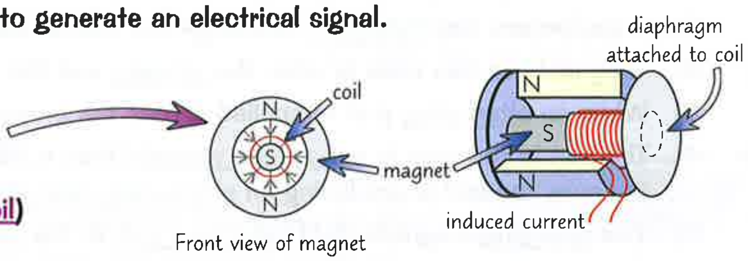
Alternators Generate *Alternating* Current

1) Alternators work in the same way as dynamos, apart from one important difference.
2) Instead of a split-ring commutator, a.c. generators have slip rings and brushes so the contacts don't swap every half turn.
3) This means an alternator produces an alternating p.d. and therefore an alternating current (a.c.) if the coil is part of a complete circuit.



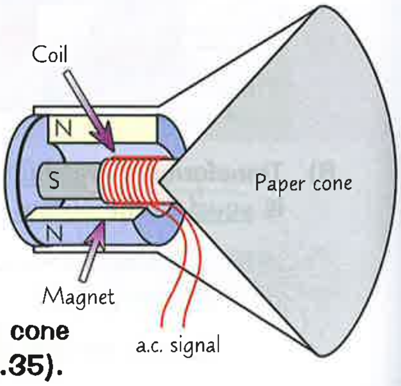
Microphones Generate Current From *Sound Waves*

1) Microphones use electromagnetic induction to generate an electrical signal.
2) Sound waves hit a flexible diaphragm that is attached to a coil of wire. The coil of wire surrounds one pole of a permanent magnet and is surrounded by the other pole.
3) This means as the diaphragm (and so the coil) moves, a current is generated in the coil.
4) The movement of the coil (and so the generated current) depends on the properties of the sound wave (louder sounds make the diaphragm move further).
5) This is how microphones can convert the pressure variations of a sound wave into variations in current in an electric circuit.



Loudspeakers are like Microphones in *Reverse*

1) In a loudspeaker, the diaphragm is replaced with a paper cone.
2) The coil is wrapped around one pole of a permanent magnet, so the a.c. signal causes a force on the coil (which moves the cone).
3) When the current is reversed, the force acts in the opposite direction.
4) These movements make the cone vibrate, which makes the air around the cone vibrate and creates the variations in pressure that cause a sound wave (p.35).



If a loudspeaker falls in the forest does it still make a sound...

Generators, microphones and loudspeakers all use electromagnetism — make sure you know how for the exam.

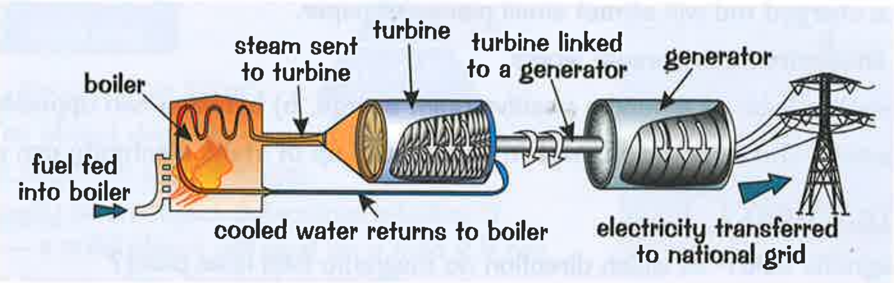
Q1 Explain how a loudspeaker converts electrical signals into sound waves. [4 marks]

Generating and Distributing Electricity

Now it's time for the big leagues — how electricity is generated and distributed on a national scale.

A Power Station uses a Turbine to Turn a Huge Alternator

1) Most of the electricity we use is generated from burning fuels (coal, oil, gas or biomass) in the boilers of big power stations.
2) The burning fuel is used to heat water and convert it to steam, which turns a turbine.



3) The turbine is connected to a powerful magnet (usually an electromagnet, see p.88) inside a generator — a huge cylinder wound with coils of copper wire.
4) As the turbine spins, the magnet spins with it, inducing a large p.d. and alternating current in the coils.
5) The coils are joined together in parallel (see p.75) to produce a single output from the generator.
6) A similar set-up is used for most other types of electricity generation as well. In hydroelectric, tidal and wind power (see p.29) the turbine is turned directly, without needing to turn water into steam first.
7) The only type of power generation that doesn't use a turbine and generator system is solar (p.29).

Transformers in the National Grid Produce a High p.d. and a Low Current

1) Once the electricity has been generated, it goes into the national grid — a network of wires and transformers that connects UK power stations to consumers (anyone who uses electricity).
2) The national grid has to transfer loads of energy each second, which means it transmits electricity at a high power (as power = energy transferred ÷ time taken, $P = E \div t$, p.78).
3) Electrical power = current × potential difference ($P = IV$, p.78), so to transmit the huge amounts of power needed, you either need a high potential difference or a high current.
4) But a high current makes wires heat up, so loads of energy is wasted to thermal stores. The power lost due to resistive heating is found using electrical power = current² × resistance ($P = I^2R$, p.78).
5) So to reduce these losses and make the national grid more efficient, high-voltage, low-resistance cables, and transformers are used. You saw on page 89 that transformers are (almost) 100% efficient, so the input power is equal to the output power. For a given power, as you increase the potential difference across a coil, you decrease the current through it ($V_p \times I_p = V_s \times I_s$).
6) Step-up transformers at power stations boost the p.d. up really high (400 000 V) and keep the current low. Step-down transformers then bring it back down to safe, usable levels at the consumers' end.
7) The ratio between the potential differences in the primary and secondary coils of a transformer is the same as the ratio between the number of turns on the coils.
8) So as long as you know the input p.d. and the number of turns on each coil, you can calculate the output p.d. from a transformer using the transformer equation:

Input p.d. (V)
Output p.d. (V)

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

Number of turns on primary coil
Number of turns on secondary coil

9) It works either way up, so $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ works just as well.

I once had a dream about transforming into a hamster...

Make sure you can remember the stuff about transformers from page 89 too, then have a go at this question:

Q1 A transformer has 16 turns on its primary coil, 4 turns on its secondary coil and an output potential difference of 20 V. Calculate the potential difference across the primary coil. [2 marks]