



ELECTRICAL INSTALLATION 2

CP8475

Inspiring The Next
Generation Of Engineers

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Contents

Introduction	3
Circuit training	4
Power supplies	5
AC vs DC	7
Measuring AC	9
AC and DC again	10
Conductors and insulators	11
Circuit diagrams	12
Current path	13
Effects of electric currents	15
Motor effect	19
Connect in series	23
Connect in parallel	24
Series / parallel	25
MES bulbs	27
Series / parallel applications	28
Staircase circuit	29
3-way control	33
Measuring voltage	35
Measuring current	39
Kirchhoff's voltage law	43
Kirchhoff's current law	44
Resistance	45
Ohm's law	47
Measuring resistance	49
Resistivity	51
Electrical safety	54
The fuse	55
The circuit breaker	56
The RCD	57
Earthing	58
The energy meter	59
Measuring power	60
Energy and power	61
Electromagnetism	62
Generating electricity	64
Transformers	66
Step-down transformer	68
Step-up transformer	69
Transformer relationships	70
Student Handbook	71

Introduction

The course aims to prepare you for Unit 202 - “Principles of Electrical Science” part of the City and Guilds Level 2 Diploma in Electrical Installations qualification.

As you work through the course, the layouts show you how to build the systems and each task details how to test them.

For your records:

- It is important that you keep accurate records of what you do.
- A Student Handbook will be issued to assist with these records.
- In addition, take whatever notes you feel are necessary to help with this.

Circuit Training

This activity is **optional**.

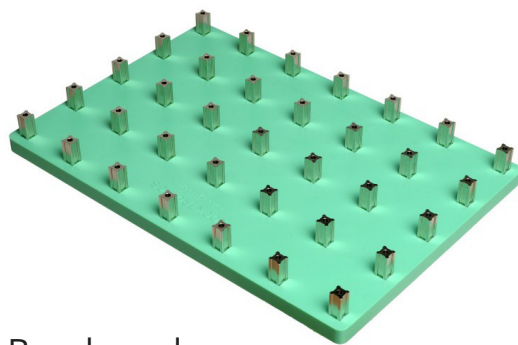
- If you recently followed 'Electrical Installation 1', it is probably unnecessary.
- If you are new to Locktronics, it is a useful way to introduce the kit.

Over to you

Build a circuit that makes a bulb light, using a 12V 0.1A bulb and the 12V AC power supply.



The hardware:



Baseboard



AC power supply carrier



MES lamp holder



Connecting link(s)
(as many as you like!)

Answer the question in the Student Handbook.

Power supply:

- Drives current around the circuit;
- Has two terminals (connection points) one 'positive' the other 'negative';
- Current flows from the positive terminal to the negative terminal.

DC power supply - (DC = direct current):

- One terminal is always positive, the other always negative;
- 'One-way traffic' - current always flows the same way around the circuit.

AC power supply - (AC = alternating current):

- One terminal positive, the other negative and then they swap, repeatedly;
- 'Two-way traffic' - current flows clockwise, then anticlockwise around the circuit.

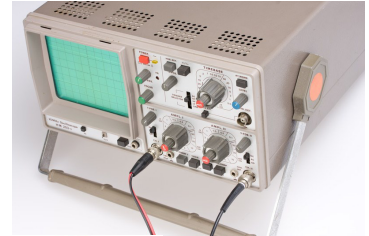
Power Supplies - 1

The difference between DC and AC is best shown by looking how the voltage changes over a period of time, i.e. looking at a voltage / time graph.

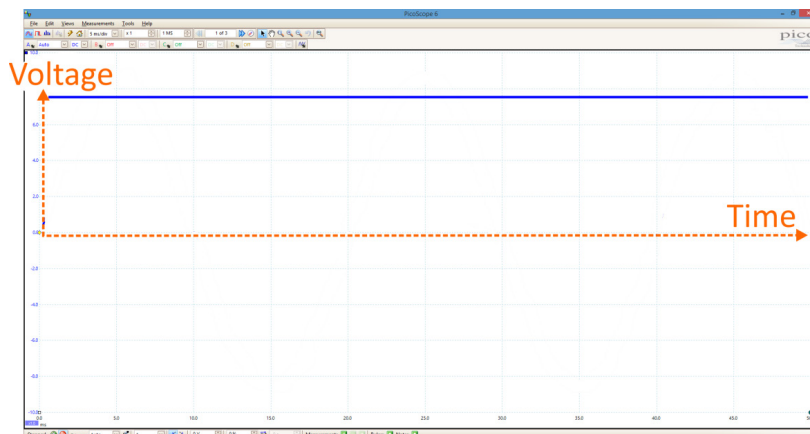
These can be produced using an **oscilloscope**.

Used more in electronics, they display the signal as a graph, with voltage on the vertical axis and time on the horizontal axis.

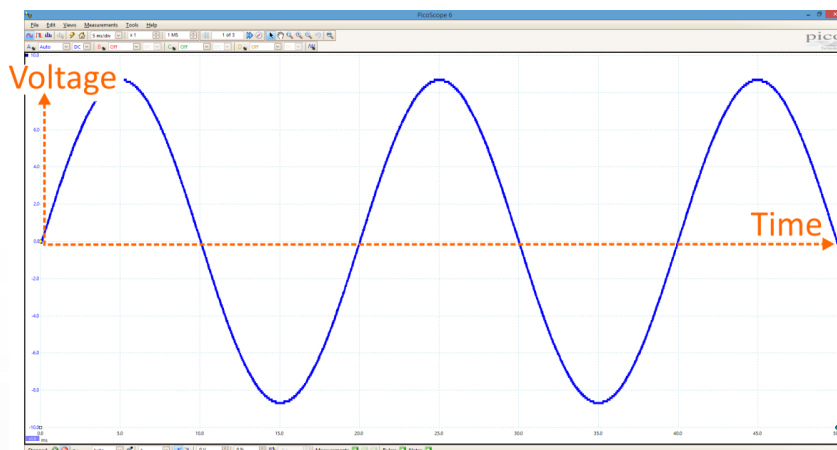
Some digital oscilloscopes, like the 'Picoscope', which produced the signals shown below, generate signals which are processed by a computer connected to it.



DC power - The voltage stays steady over a period of time.



AC power - The voltage changes all the time and even goes negative sometimes.



Power Supplies - 2

AC or DC - which is used?

Each has its uses!

Electricity is usually generated and transmitted as AC because:

- Alternators are generally more efficient than dynamos;
- Transformers can modify voltage and current efficiently.

Electronic devices - mobile phones, computers, televisions etc. usually require DC.

AC power: Can be converted into DC using the processes of rectification and regulation.

DC power: Can be converted into AC using a device called an inverter.

DC power supplies:

- Battery - chemical reactions generate DC voltages, e.g. 'lead-acid' batteries;
- Solar cell - photo-voltaic ('solar') cells convert light energy into DC electricity ;
- Dynamo - a rotating coil of wire near a magnet generates DC using a 'commutator' to connect the coil to the rest of the circuit.



AC power supplies:

- **Alternator** - Another example of a rotating coil of wire near a magnet;
 - A 'slip-ring' connects to the rest of the circuit;
 - The coil can be driven by:
- High-pressure steam, in a power station;
- Wind in a wind-generator;
- Falling water in a hydro-electric power station.



AC Versus DC - 1

The aim of this and the next activity is to compare the performance of an AC and a DC power supply.

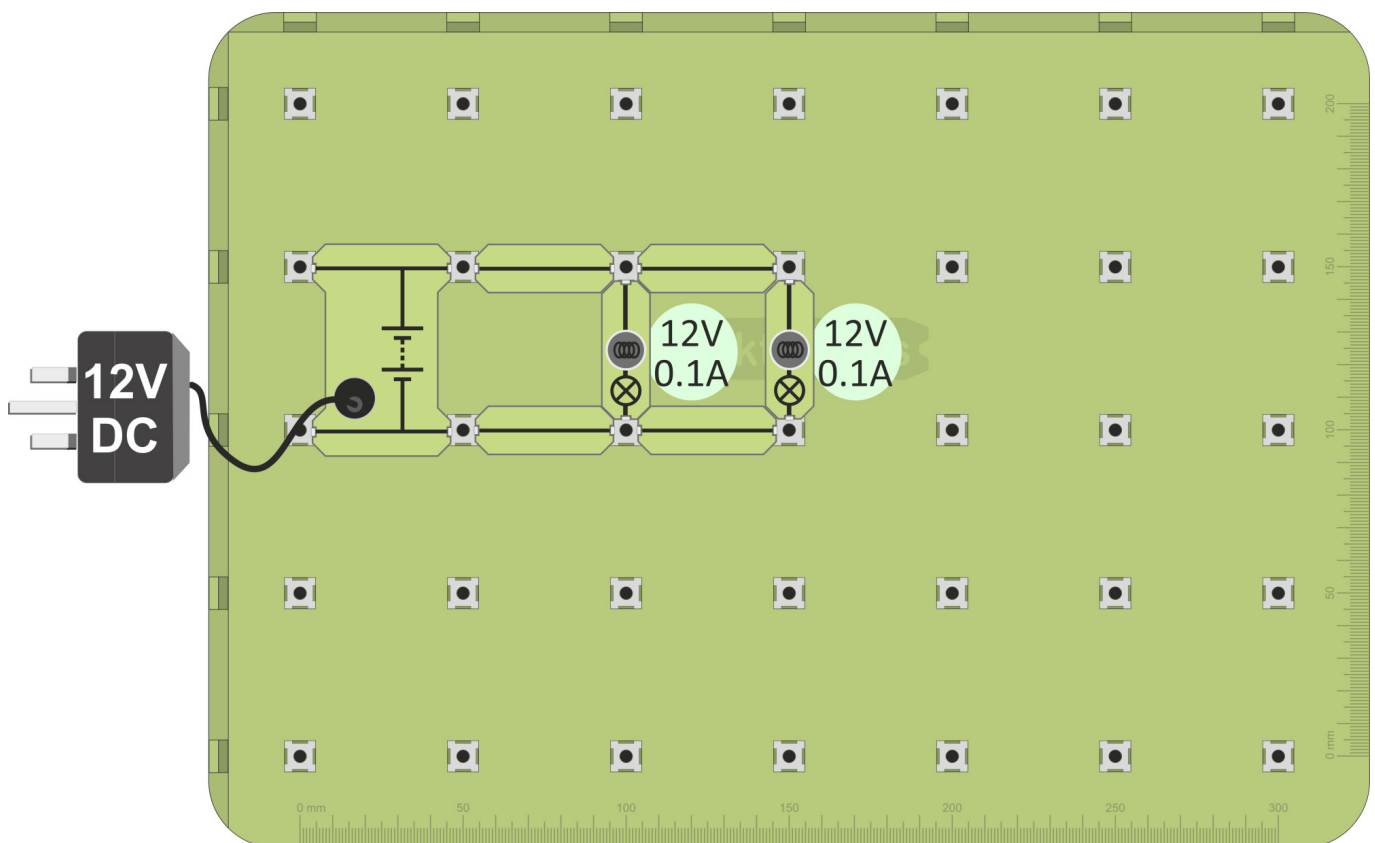
Preliminary experiment - finding two bulbs that have the same brightness.

Over to you

Build the layout shown below.

The lamps are connected in parallel and should be equally bright.

If not, change the bulbs until you find two that are equally bright.



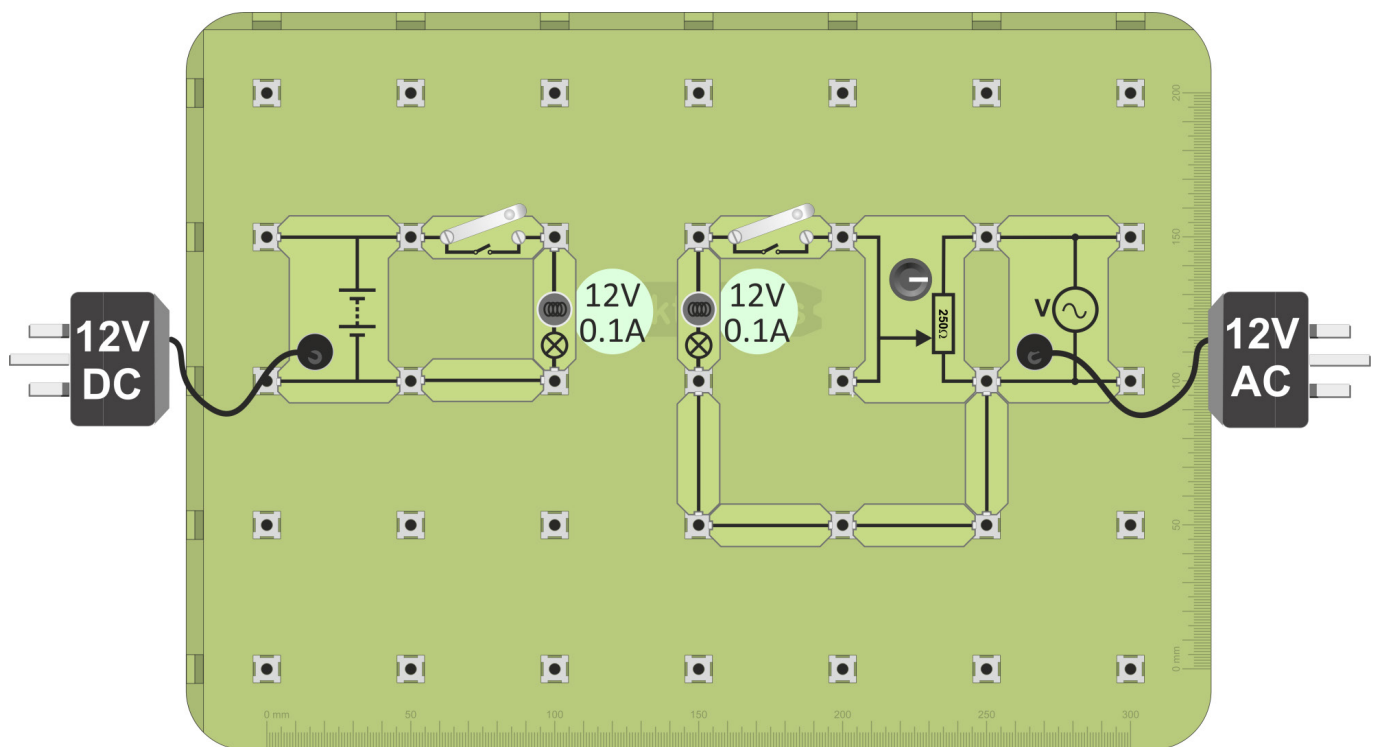
Use these bulbs in the next activity, which has two circuits, one lamp powered by DC, and an identical lamp powered by AC.

AC Versus DC - 2

This activity continues the task of comparing the AC and DC power supply.

Over to you

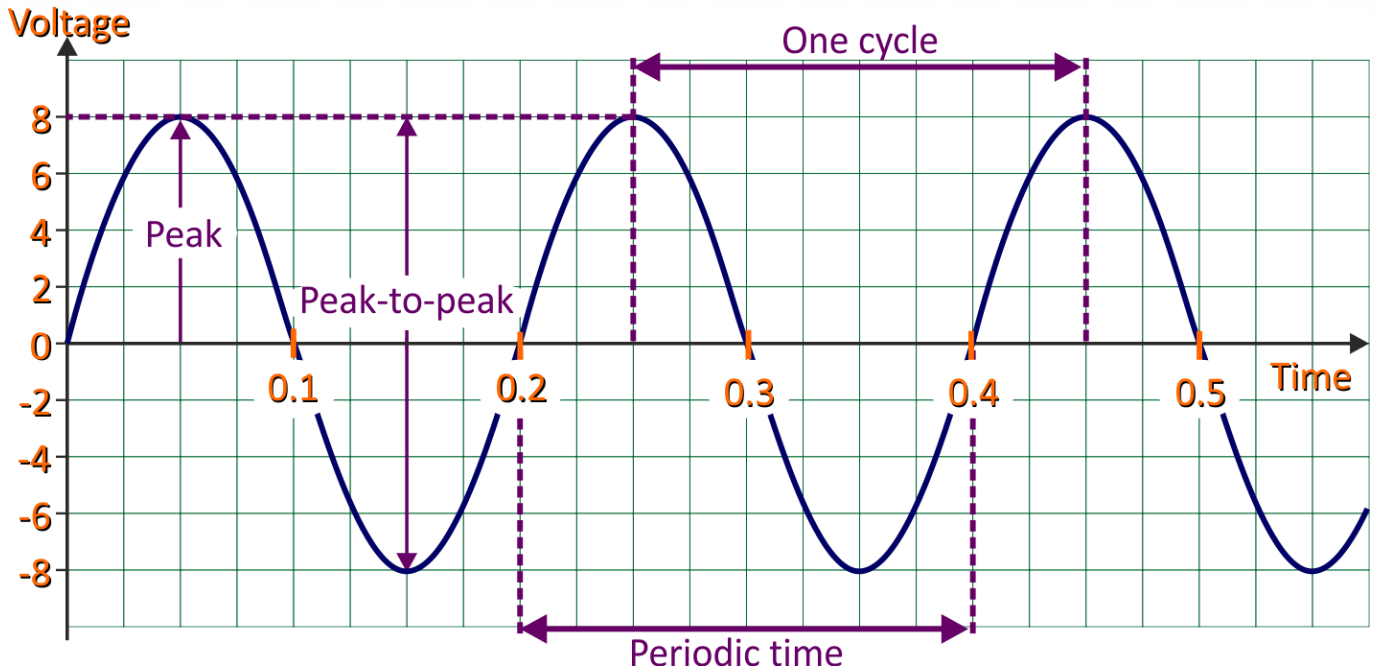
1. Build the layout shown below, using the two bulbs from the previous activity. There are two circuits, one lamp powered by DC, and an identical one powered by AC.
2. Connect the DC power supply, set to 12V, and the AC supply.
3. Switch both on.



4. Adjust the 250Ω 'pot' until the two lamps have the same brightness. Now, the AC voltage has exactly the same effect as the DC supply.
5. Connect a multimeter, set to the 20V DC range, to read the voltage across the DC-powered lamp. This gives the rms value of the AC voltage.
6. Record the reading in the Student Handbook.

Measuring AC

Measuring AC:



The diagram shows the voltage / time graph for an AC signal, labelled with some important quantities:

- **Peak voltage** - Maximum voltage reached by the signal, (8V in this case).
- **Peak-to-peak voltage** - Voltage difference between positive peak and negative peak voltage, equals two x peak voltage, (16V in this case).
- **Periodic time** - Time to get back to its 'starting point';
- Time taken for one complete cycle, (0.2s in this case).

Related to these is the **frequency f** of the signal - the number of cycles completed in one second.

The relationship is logical:

$$f = 1 / T$$

where T is the periodic time.

Frequency is measured in units called hertz (Hz). A frequency of 10 Hz means that ten cycles of the wave are completed each second.

For the AC signal shown above, the frequency is:

$$\begin{aligned} f &= 1 / 0.2 \\ &= 5\text{Hz} \end{aligned}$$

Now answer the questions in the Student Handbook!

AC and DC Again

Issues about AC power:

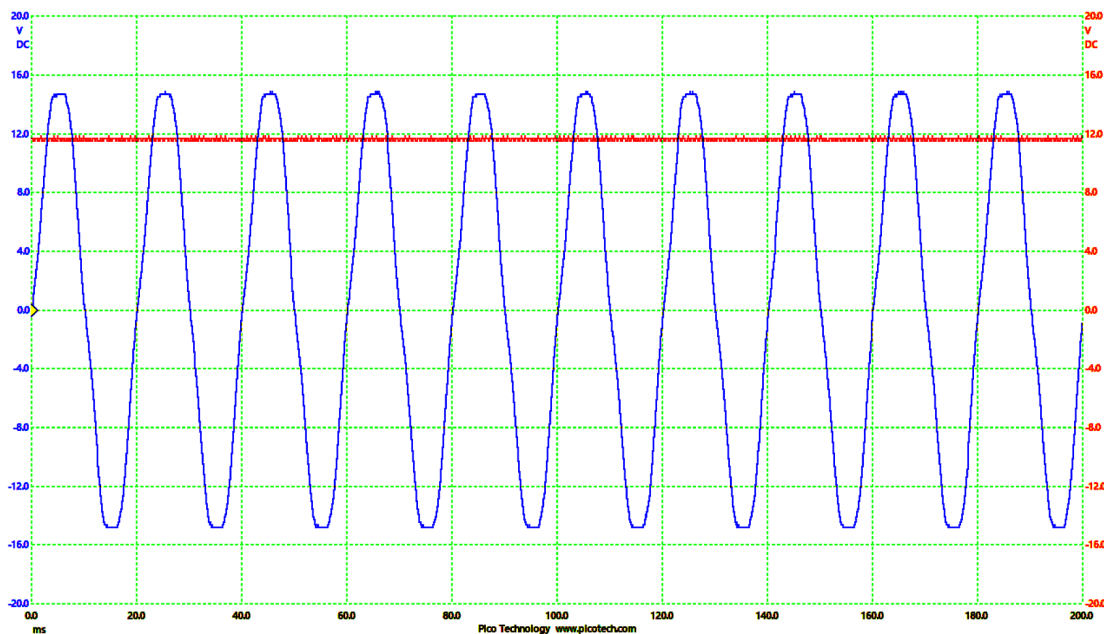
- The average voltage is zero. Looking at the voltage / time graph on the previous page, the voltage is positive for half of the time and negative for half of the time. Over one cycle, these cancel out, leaving an average value of zero.
- The peak voltage may be 8V, but most of the time the voltage is much less.

So what is the “average” effect of an AC supply and how can we compare AC and DC?

The previous activities give the answer - look for the two power supplies having the same effect on a device like a bulb.

The graph shows the AC and DC power supply signals from that activity, where the two bulbs had the same brightness - AC and DC were having the same effect.

Notice that the DC supply voltage sits well below the AC peak value.



It is called the **r.m.s.** value of the AC supply, related to the peak value by the formula:

$$V_{\text{rms}} = 0.7 \times V_{\text{peak}}$$

Or, re-arranging this: $V_{\text{peak}} = V_{\text{rms}} / 0.7$

The AC signal in the graph has a peak value of ~ 15V, giving a r.m.s. voltage of $15 \times 0.7 = \sim 10.5\text{V}$. (The DC voltage shown in the graph is close to this!)

For an AC signal with a r.m.s. value of 35V, the peak voltage would be $35 / 0.7 = 50\text{V}$.
Now answer the questions in the Student Handbook!

Conductors and Insulators

Materials which pass electricity are called **conductors**.

Materials which do not pass electricity are called **insulators**.

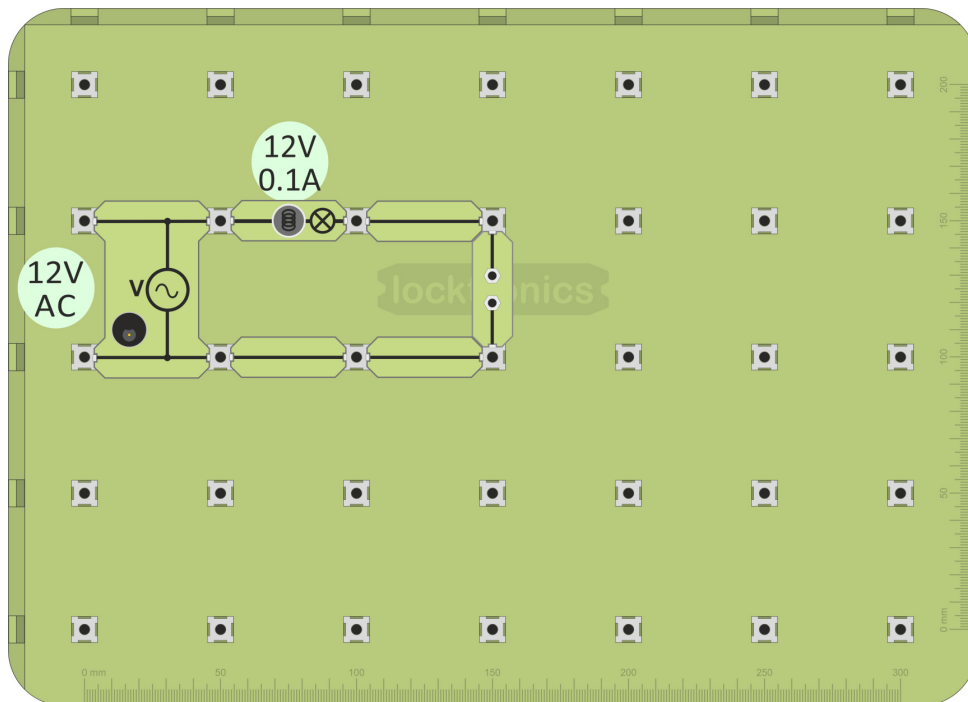
The hardware:



Universal component carrier

Over to you

1. Build the layout shown below.
2. Connect the 12V power supply and switch on.



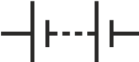
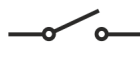
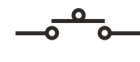
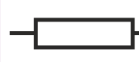
3. Put different materials across the gap in the universal component carrier. See if the bulb lights. (We are using the bulb as a simple continuity tester.) If it does, the material is a conductor; if not, it is an insulator (roughly speaking). Try some of the following: kitchen foil (aluminium), a rubber, paper, polythene, copper, air, lead, pencil lead (graphite), glass, wood, a coin, a piece of cloth, a plastic pen.
4. Fill in the table on the Student Handbook with the findings from your experiment and try to answer the question.

Circuit Diagrams

The aim is to clarify how a circuit is built, using an internationally recognised set of symbols.

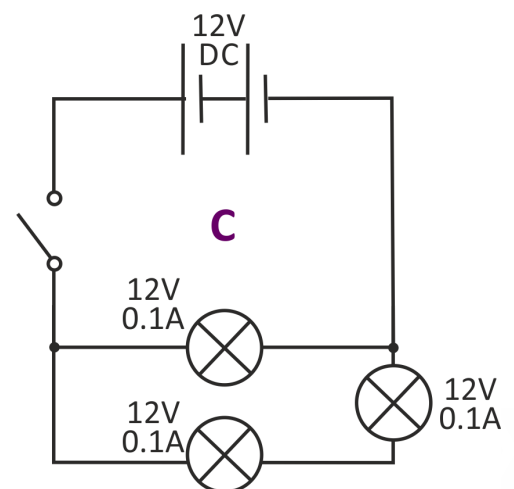
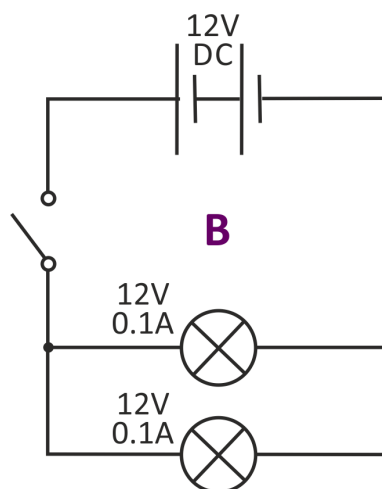
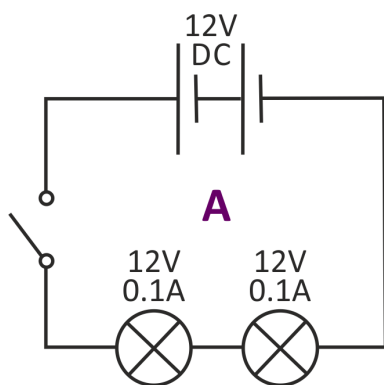
You have already been exposed to some - Locktronics carriers all show the conventional symbols for the components they carry.

Here is a summary of the ones used so far:

					
AC power supply	Battery or DC power supply	Toggle switch	Push switch	Lamp	Resistor

Over to you

1. Build each of the three circuits, shown in circuit diagrams **A**, **B** and **C**, in turn. Each one uses a 12V DC power supply and 12V 0.1A bulbs.
2. Use the brightness of the bulbs to decide which circuit draws the biggest current from the power supply.
3. Record your decision in the Student Handbook.



Current Path - 1

Power supply:

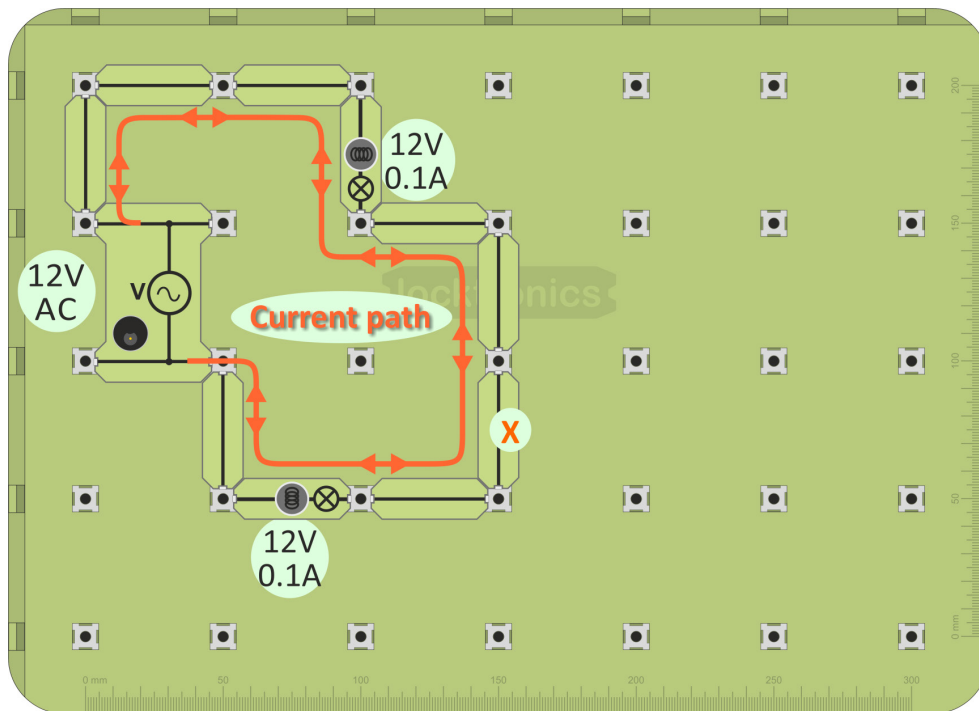
- Drives current around the circuit;
- Has two terminals (connection points) one 'positive' the other 'negative';
- Current flows from positive to negative.

Connecting links: Allow current to flow freely.

Circuit: Continuous length of conductor joining the power supply terminals.

Over to you

1. Build the layout shown below.
2. Connect the 12V power supply and switch on.

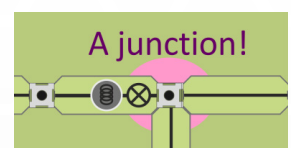


3. What happens if you remove a connecting link (for example 'X' - or any other)?
4. What happens if you unscrew one of the bulbs?

Challenge: Try other circuit shapes.

(Make sure that there are no 'branches' (junctions) in your circuits - these are covered later!)

Does the shape make any difference to the way the circuit works?



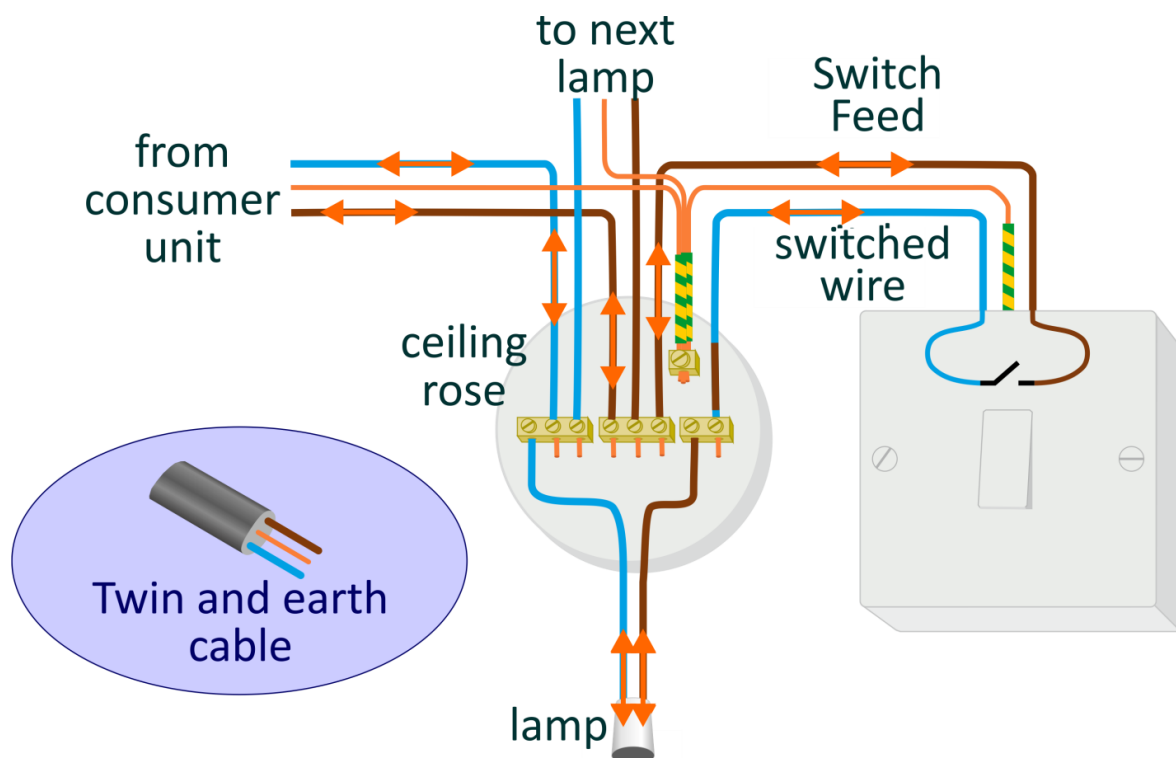
Swap the AC power supply for a 12V DC supply. Does that make any difference?

Answer the questions posed in the Student Handbook!

Current Path - 2

- When a fuse blows, it stops the current flowing to all devices, just like removing a connecting link.
- Turning off a switch has the same effect.

The diagram shows how to wire up a pendant light to a ceiling rose and control it with a switch.



Domestic wiring is slightly different from the circuit you just built. It uses 'twin and earth' cable, containing a 'line', a 'neutral' and an 'earth' cable, bound together in a grey pvc sheath, for protection, rather than using separate single wires.

It is still connected in circuits allowing current to flow from one terminal of the power supply to the other.

Challenge:

The orange arrows show the current path through this circuit.

Trace it yourself to check that you understand it.

Follow it from the consumer unit:

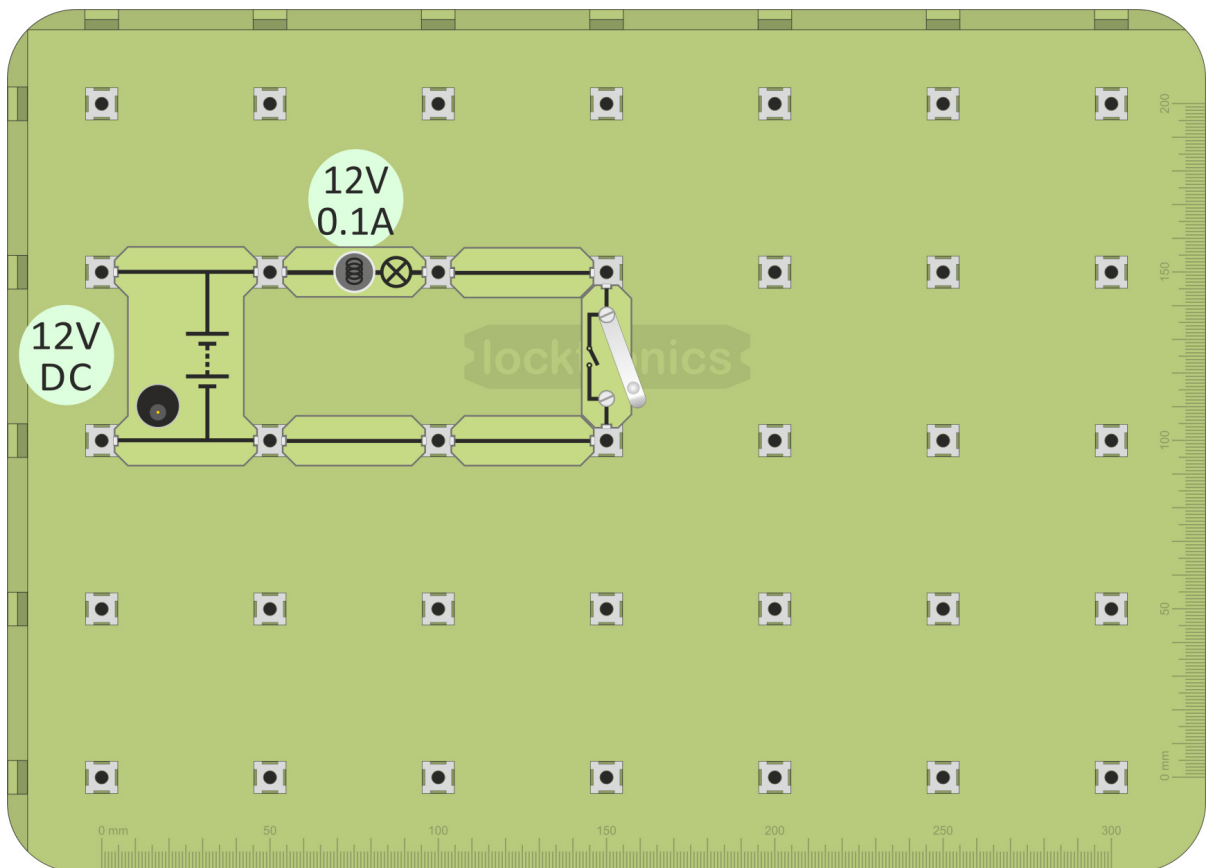
- Through the switch,
- Through the lamp,
- Back to the consumer unit.

Effects of Electric Currents - 1

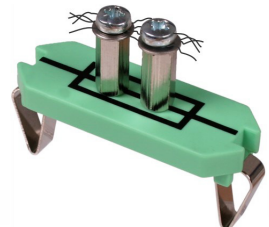
Effect 1 - Heating effect

Over to you

1. Build the layout shown below.
2. Connect the power supply, set to 12V, and switch on.



3. Close the switch. The lamp filament should be glowing yellow-hot.
4. Take hold of the glass envelope of the lamp. Does it feel warm?
5. Switch it off.
6. Clamp a few strands of wire wool between the posts of the universal component carrier, as shown in the diagram.
7. Remove the lamp holder from the circuit and replace it with the universal component carrier.
8. Close the switch and look at the wire wool strands. There should be a noticeable heating effect!



(Take care not to touch the component - it will be extremely hot!)

Heating Effects

When an electric current flows through a material, its energy is converted to heat.

You've seen a common example of the heating effect of a current - the filament lamp.

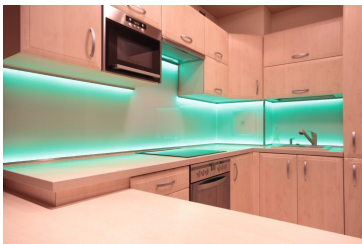
The filament, the coil of wire at the centre of the glass 'bulb', usually made from the metal tungsten, is heated by the current to such a high temperature, over 2000°C , that it glows yellow-hot, giving out light.



Problem - they are very inefficient.

Typically only ~5% of the electrical energy appears as light.

LED (Light-Emitting Diode) lighting, which can be 10 times more efficient.



In the home, electricity supplies a host of other heating appliances, as the picture shows.



The reverse effect is seen in a thermocouple.

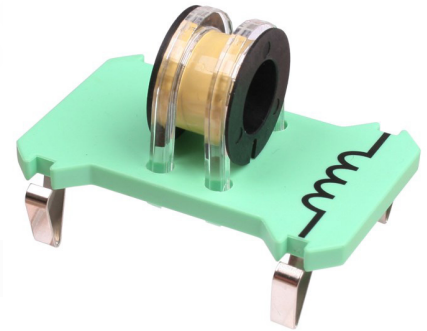
Two legs, made from different metals, are connected together. When this junction is heated, it generates a DC voltage. Thermocouples are used to measure temperature.



Effects of Electric Currents - 2

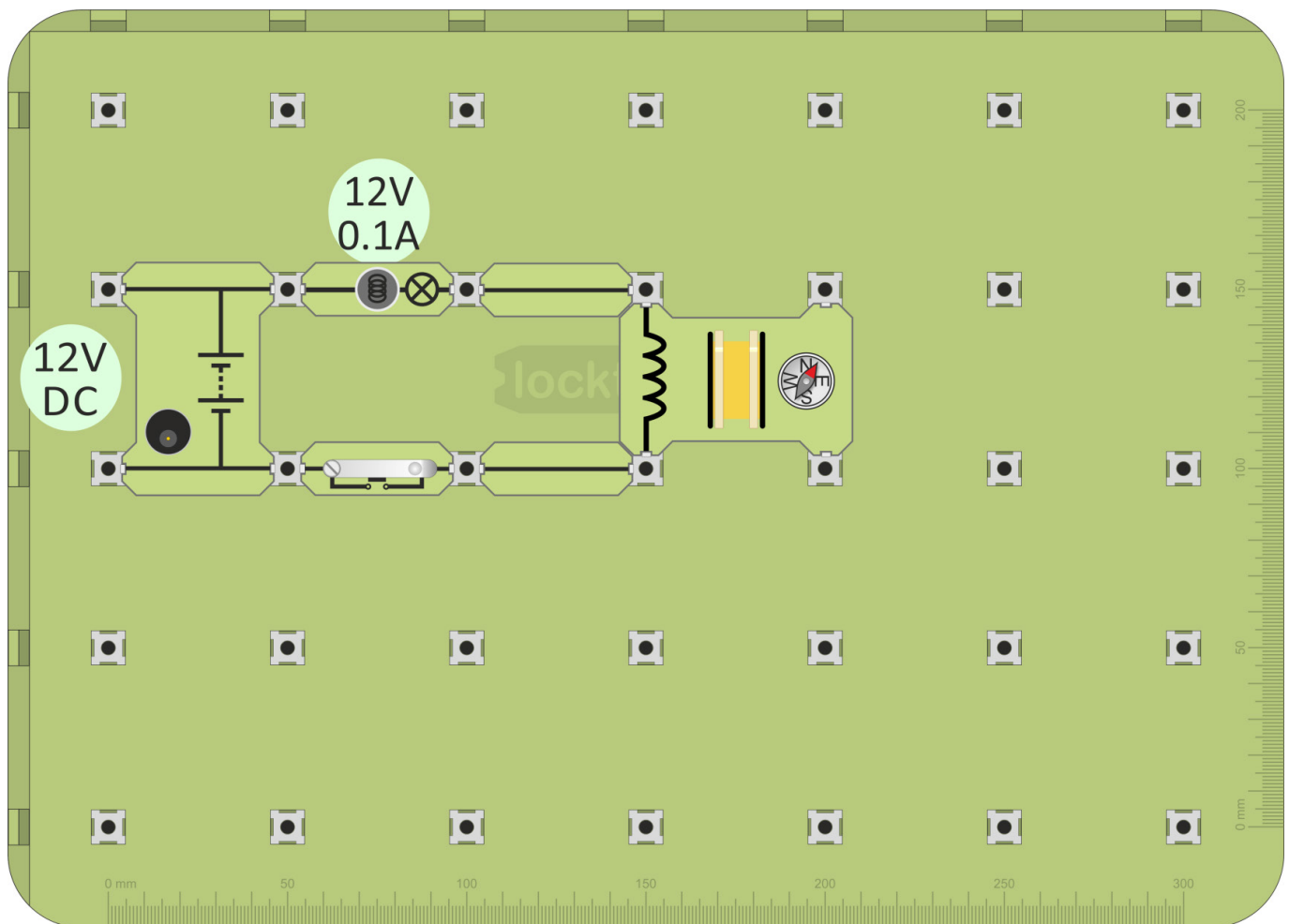
Effect 2 - Magnetic effect

The hardware - a 400 turn coil mounted on a carrier:



Over to you

1. Build the layout shown below.
2. Connect the DC power supply, set to 12V, and switch on.

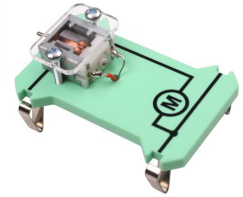


3. Place a magnetic compass next to the coil, as shown.
4. Close the switch and watch the compass needle as you do so.
5. Now switch off and place a steel nail inside the coil.
6. Close the switch again, watching the needle as you do so. Is the effect stronger than before?
7. Wave a magnet near the compass. The effect should be the same. This confirms that the coil was generating magnetism.

Magnetics Effects

An electric current is ALWAYS accompanied by a magnetic field.

The principal application of the magnetic effect of electricity is the electric motor.



There are many examples of its use in the home.

(Some involve heating as well as magnetic effects.)



Other applications of electromagnetism include:

- Transformers - in power supplies, such as mobile phone chargers;
- Generators - used to power tools or as a stand-by in case of power cuts;
- Loudspeakers - in radios, televisions, computers and mobile phones;
- Circuit breakers - another protection against current overload and overheating.



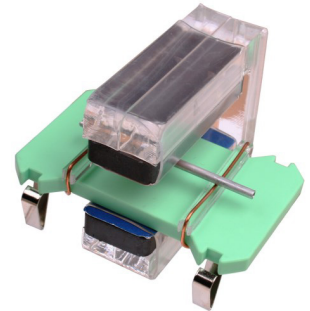
Motor Effect - 1

An electric current produces a magnetic effect.

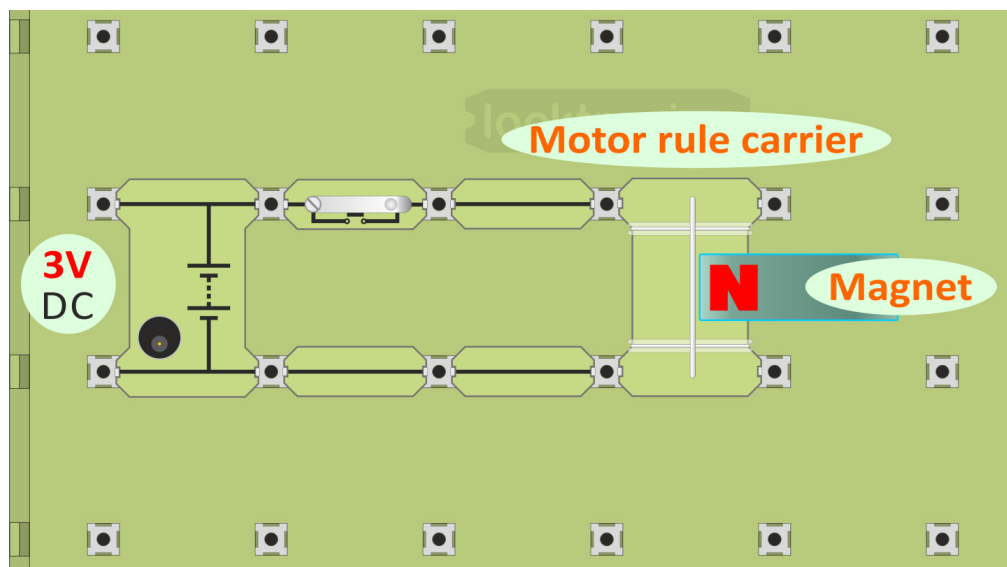
Magnets exert forces on each other.

It is not surprising, then, that when a magnet is placed near a current-carrying coil, the coil moves - it's an electric motor!

This investigation uses the motor-effect carrier, shown opposite. It has two fixed conductors, with a moveable metal rod sitting across the top, connecting them.



1. Build the system shown in the following picture.



For clarity, the magnet has not been pushed right over the metal rod.

Push it right across, so that the moveable rod sits directly under the magnet.

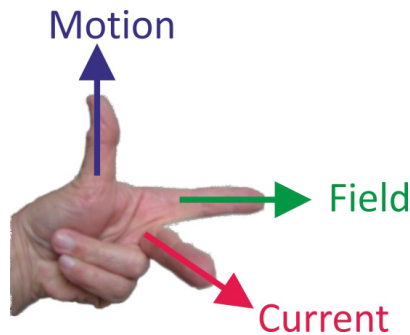
Notice - The power supply is set to 3V initially!

2. Press the push switch, and notice what happens.
3. Next, flip the magnet over so that the South pole is on top.
4. Press the push switch again. What is the difference?
5. Reverse the current direction - turn the power supply carrier so that the negative end (short line on the symbol) is at the top. What happens now when you press the push switch?
6. Increase the power supply voltage to 12V, to increase the current flowing through the rod. Can you see any difference when you close the push switch?

Motor Effect - 2

Fleming's Left-hand Rule:

John Ambrose Fleming devised a way to work out the direction a wire will move in (also known as the motor rule):

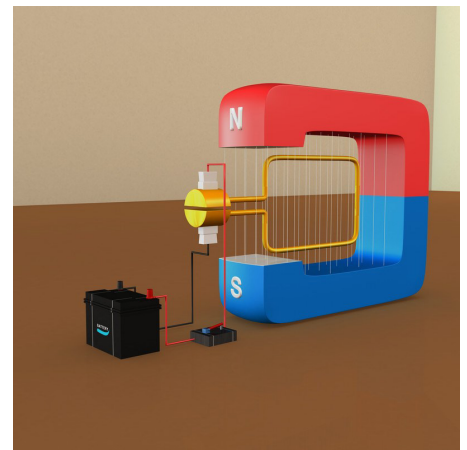


- Clamp your **left**-hand to the corner of an imaginary box, so that thumb, fore-finger and centre-finger are all at right-angles to each other.
- Line up the **Fore**-finger so that it points along the magnetic **Field** (from North pole to South pole,)
- Line up the **Centre**-finger with the direction of the **Current** (from positive battery terminal to negative.)
- The **thuMb** now points in the direction of the resulting **Motion**.

The principle of a single coil DC motor is shown opposite.

Challenge: Use Fleming's Left-hand Motor rule to obtain the direction of rotation of the coil. (You should find that it rotates anti-clockwise, viewed from the battery.)

Practical DC motors use multiple coils, to smooth out the torque. They may also use an electromagnet instead of a permanent magnet.

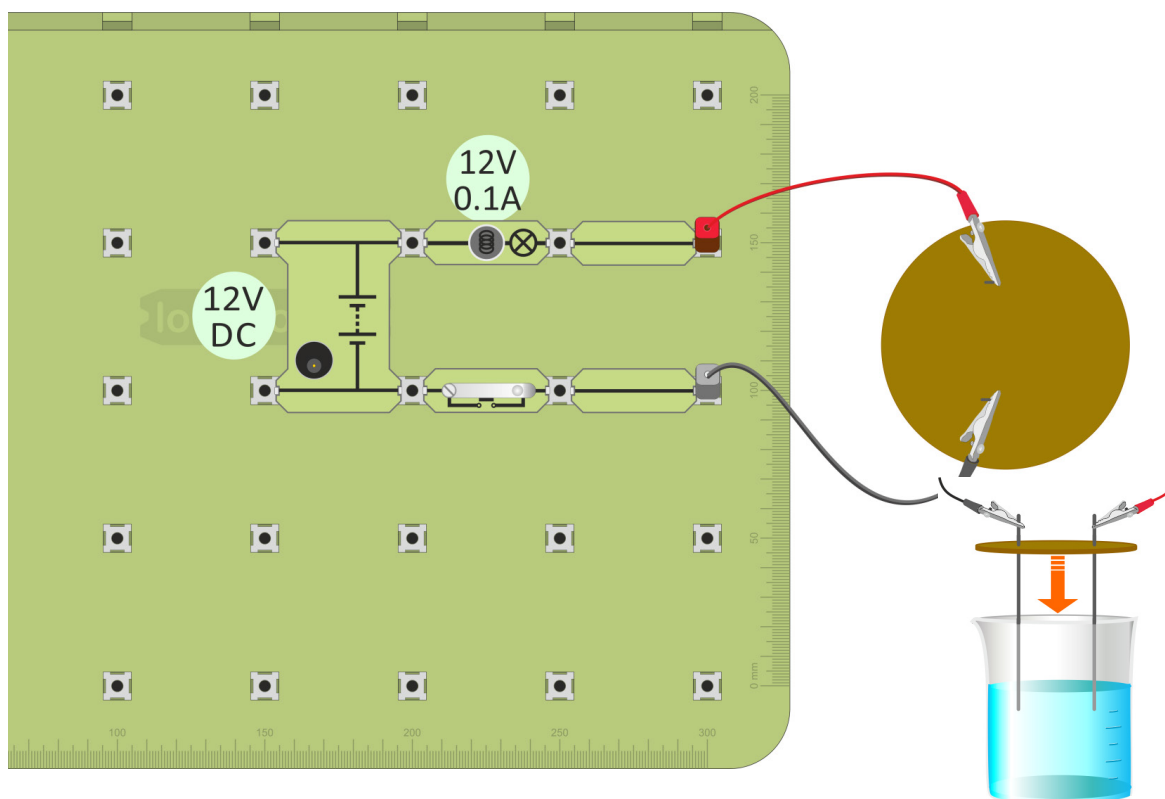


Effects of Electric Currents - 3

Effect 3 - Chemical effect (Optional Experiment)

Over to you

1. Build the layout shown below. The lamp is included so that you can see when an electric current is flowing.
2. Connect the 12V DC supply and switch on.



3. Carefully push the two graphite rods through the hardboard disc. Take care not to snap them! **Now put on goggles to protect your eyes.**
4. Pour about 200ml of the copper sulphate solution into a 250ml beaker. This concentration of copper sulphate is not hazardous, but make sure that you wash your hands at the end of the investigation.
5. Lower the rods into the beaker, so that the disc sits on top of the beaker.
6. Connect the rods to the rest of the circuit using crocodile clips.
7. Close the switch and watch carefully to see what is happening in the beaker. A chemical reaction is taking place, driven by the electric current.

Warning about copper sulphate solution:

Harmful if swallowed. Irritating to eyes and skin. Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

See CLEAPSS Hazcard 27C for further details.

Chemical Effects

An electric current can create/be created by a chemical reaction.

An electric current is a flow of electrons, (which are tiny particles found in all atoms.)

A chemical reaction involves electrons transferring between atoms. No wonder electric currents and chemical changes are related!

The most obvious example of this link is the battery.

In 'dry' batteries, a chemical reaction generates a voltage which can drive an electric current.

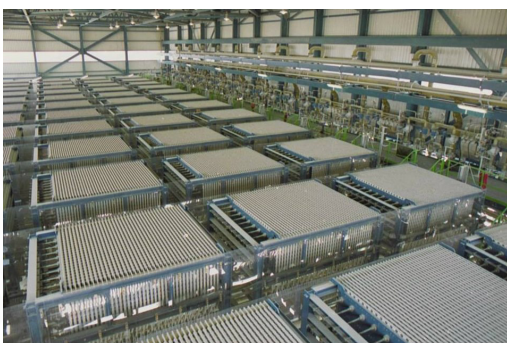
In rechargeable batteries, this process can be reversed - a current flowing the 'wrong' way can reverse the chemical reaction, storing up energy for later use.



Another example is the technique known as electroplating. In this, an electric current flowing through a chemical solution deposits a metal on one of the electrodes.

This may be done:

- For protection - objects made from iron can be protected from corrosion by plating them with zinc (galvanising);
- For decoration - objects made from a cheaper metal can be plated with a more expensive one such as gold or silver.



Electrolysis is a related technique.

Here, the electric current is used to extract or purify chemicals such as chlorine and copper.

Connect in Series

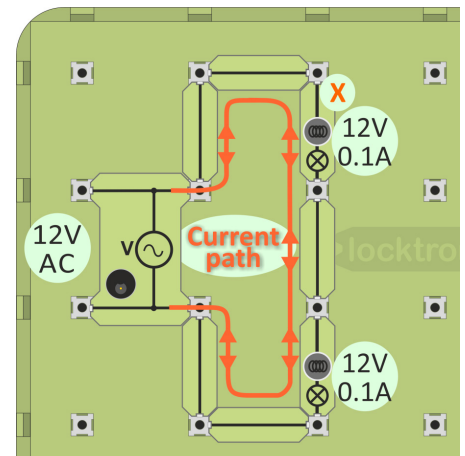
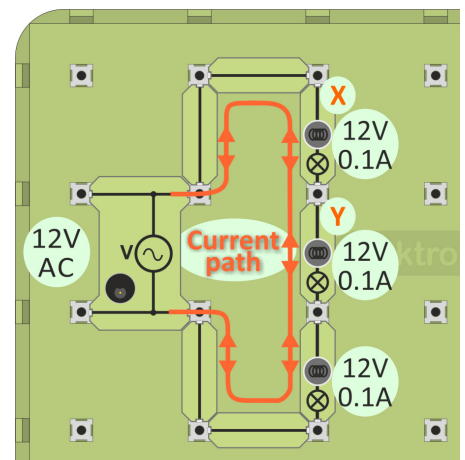
Series:

- Devices connected one after the other in a line;
- No alternative routes, no branching;
- Only one path for the current through the connection.

Remember! - the brighter the bulb, the bigger the current!

Over to you

1. Build the layout shown opposite. This is a series circuit - the lamps are connected in a line with no junctions.
2. Connect the 12V power supply.
3. Switch on. What do you notice about the brightness of the three lamps?
4. What happens if you unscrew one of the bulbs (bulb 'X' for example)?
5. Now replace bulb 'Y' with a connecting link, as shown opposite.
6. Switch on the power supply.
7. What about the brightness of the two lamps? How does it compare with brightness of the lamps in first circuit?
8. What does this show about the current flowing in the circuit?
9. Unscrew one of the bulbs. Is the effect the same as before?
10. Write all your findings in the Student Handbook.



**If the lamps are of different brightness, look at
MES bulbs
and then come back to the next worksheet!**

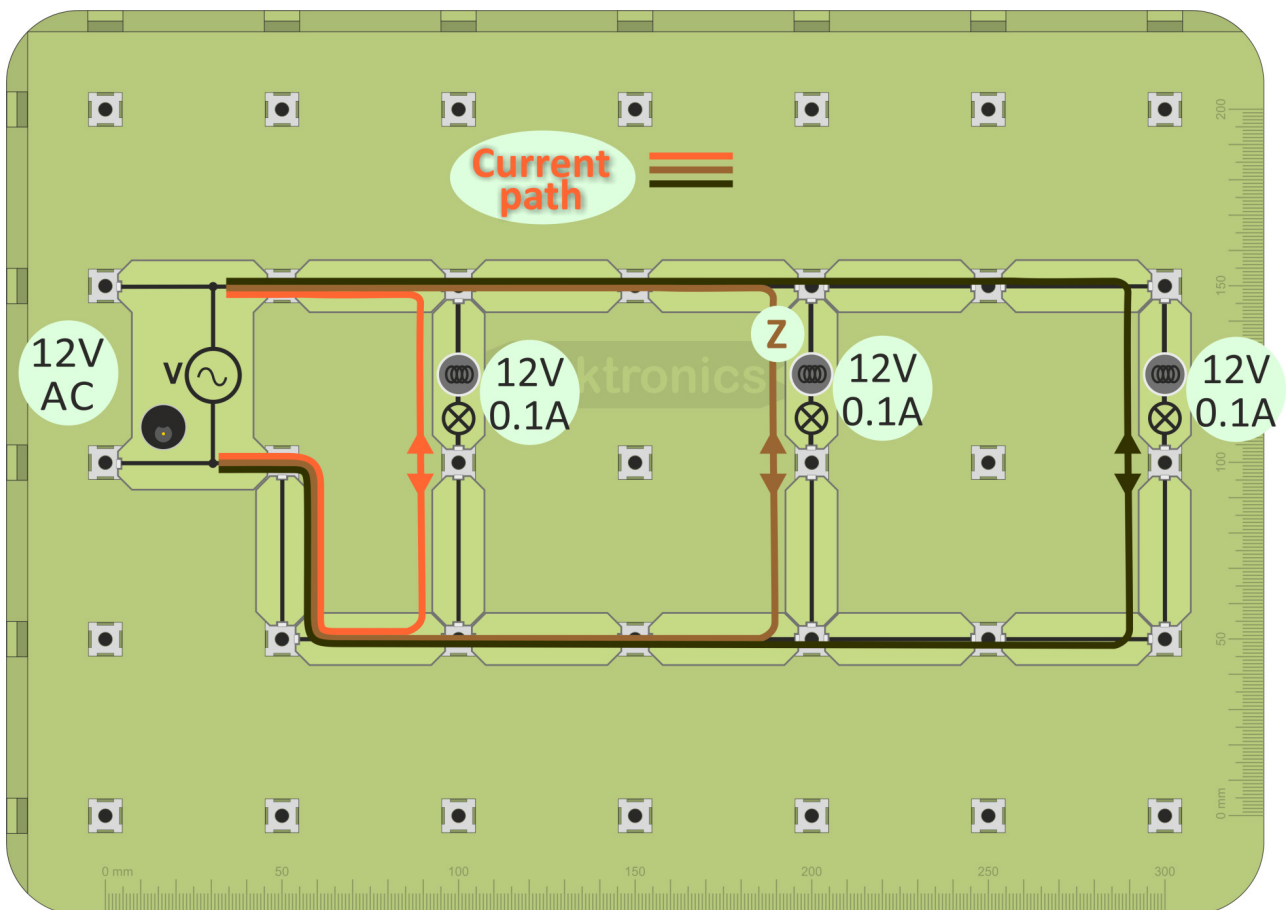
Connect in Parallel

Parallel:

- Devices have their own separate 'branch-line';
- Ends of a device connect to corresponding ends of all other devices;
- Each device has its own path for the current through the connection.

Over to you

1. Build the layout shown below. This is a parallel circuit - each lamp is connected in its own 'branch-line'.
2. Connect the 12V power supply and switch on.



3. What do you notice about the brightness of the three lamps?
4. What happens if you unscrew one of the bulbs (bulb 'Z' for example)?
5. Notice how the current path differs from that for the series circuit!
6. Answer the questions in the Student Handout.

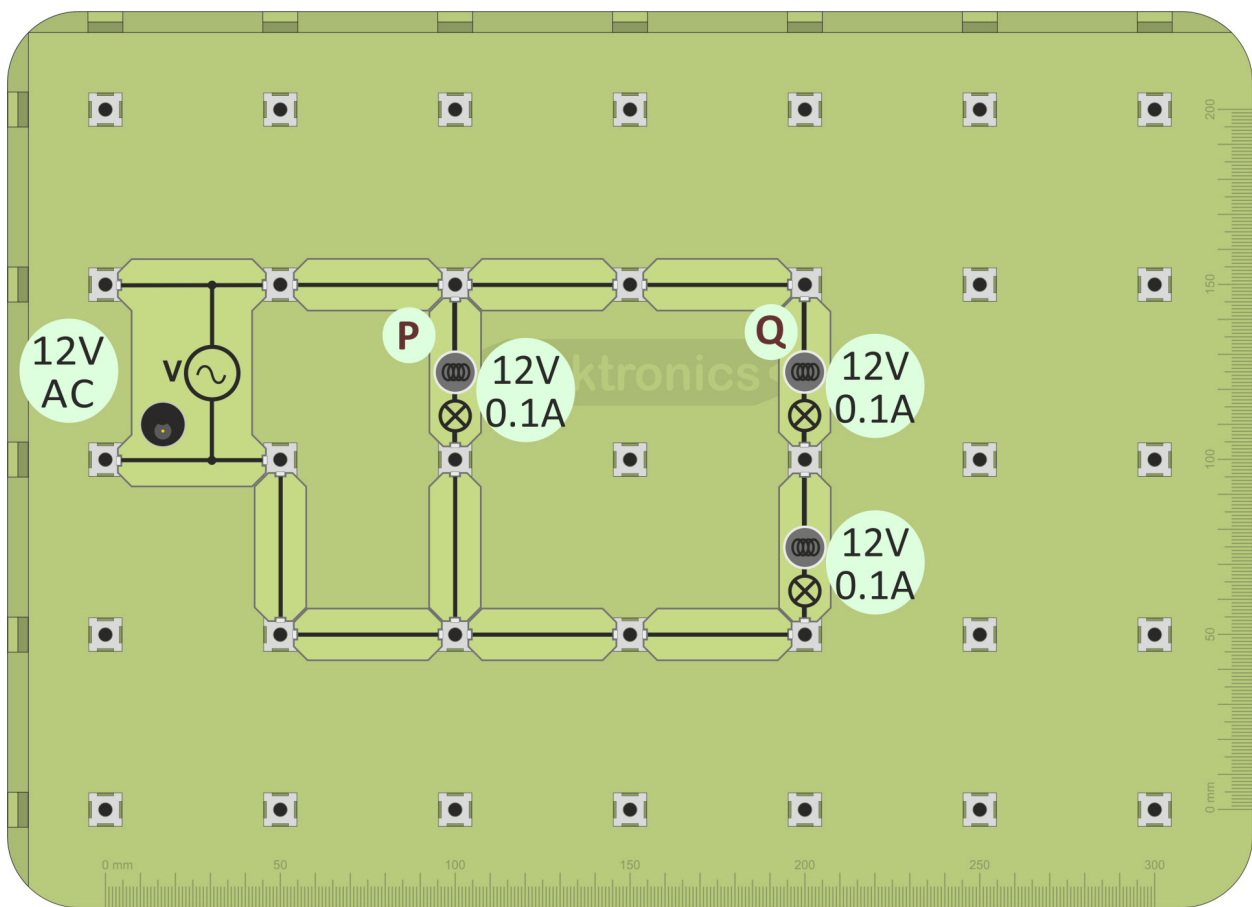
If the lamps are of different brightness, look at
MES bulbs
and then come back to the next worksheet!

Series/Parallel - 1

Often, some parts of a circuit are connected in series while other parts are in parallel. The rules you have observed in the previous circuits still apply.

Over to you

1. Build the layout shown below. Which bulbs are in series and which in parallel? (Try to picture the current paths through the bulbs!)
2. Connect the 12V power supply and switch on.



3. What do you notice about the brightness of the three lamps now?
4. What happens if you unscrew:
 - Bulb 'P'?
 - Bulb 'Q'?
5. Can you explain these differences?
6. Answer the questions in the Student Handout.

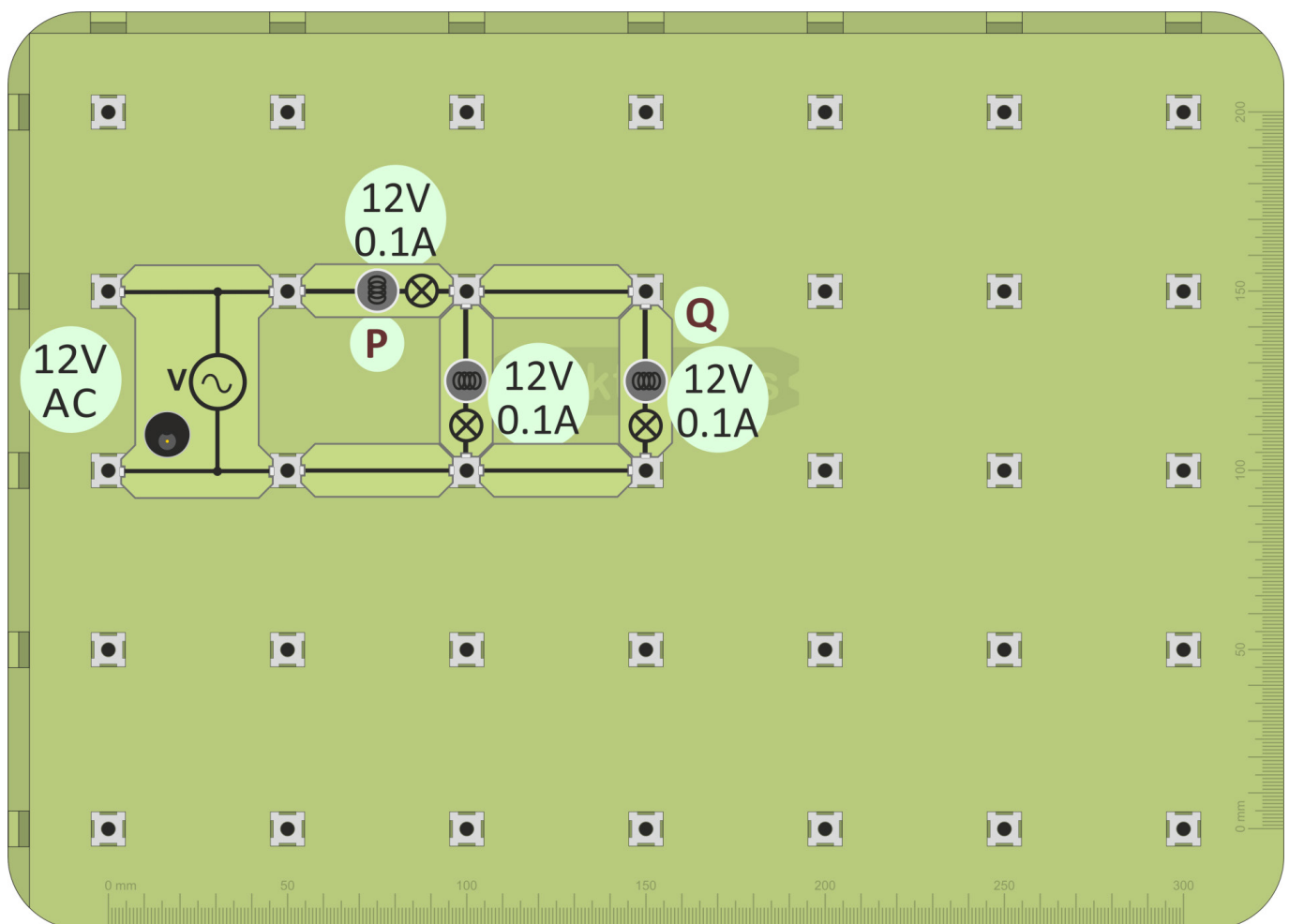
Series/Parallel - 2

Here is another circuit with a mixture of series and parallel connections.

- Decide where the series and parallel connections are. (Once again, picture the current paths!)
- Predict which bulb will be the brightest and then check to see if you were right!

Over to you

1. Build the layout shown below.
2. Connect the 12V power supply and switch on.



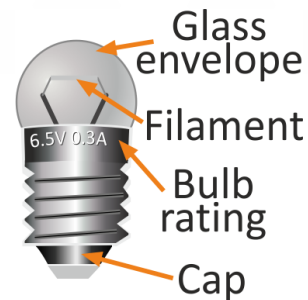
3. Compare the brightness of the three lamps? Were you right?
4. What happens if you unscrew:
 - Bulb 'P';
 - Bulb 'Q'?
5. Can you explain these differences?
6. Answer the questions in the Student Handout.

MES Bulbs

- MES bulbs are mass-produced to reduce cost.
- As a result, they are not quite identical:

They may have:

- Different filament lengths;
- Different filament diameters;
- Different heat losses.



Given identical conditions, they will not give the same brightness.

You've been directed to this worksheet because the lamps in your circuit are not the same brightness.

There are two possible reasons for this:

- The bulbs are not quite identical;
- Different currents flow through them.

Challenge: Try the following test:

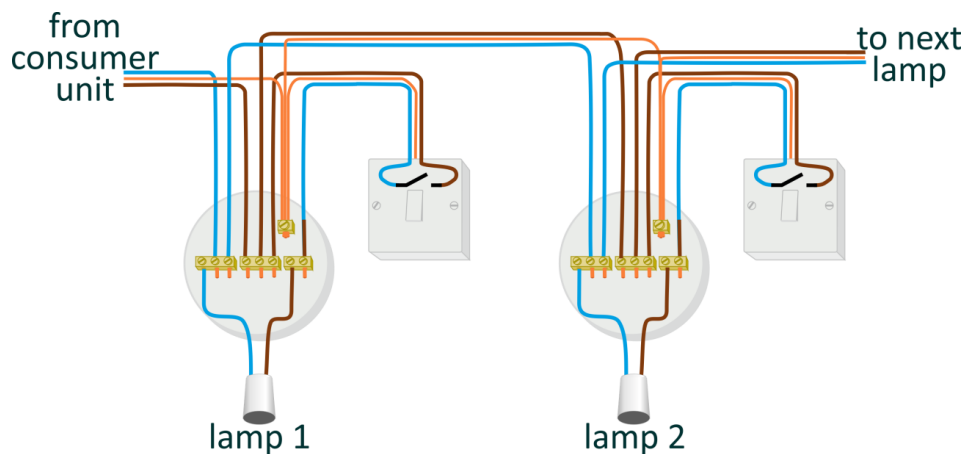
- Swap the lamps round.
- If the pattern of brightness is the same as before, then the currents are different.
- If the brightest bulb is still the brightest, then the bulbs are different.

What does your test show?

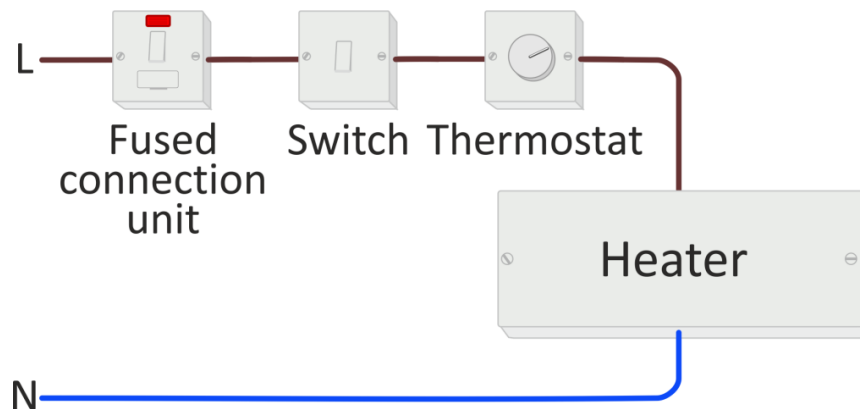
Series/Parallel Applications

In domestic lighting, it is important that lamps operate independently especially when one bulb 'blows'.

Hence they are connected in parallel, as the diagram shows.



Controls, like fuses, switches and thermostats, must be able to 'break' the circuit and stop current flow to the load device, such as a heater. As a result, they are connected in series with the load.



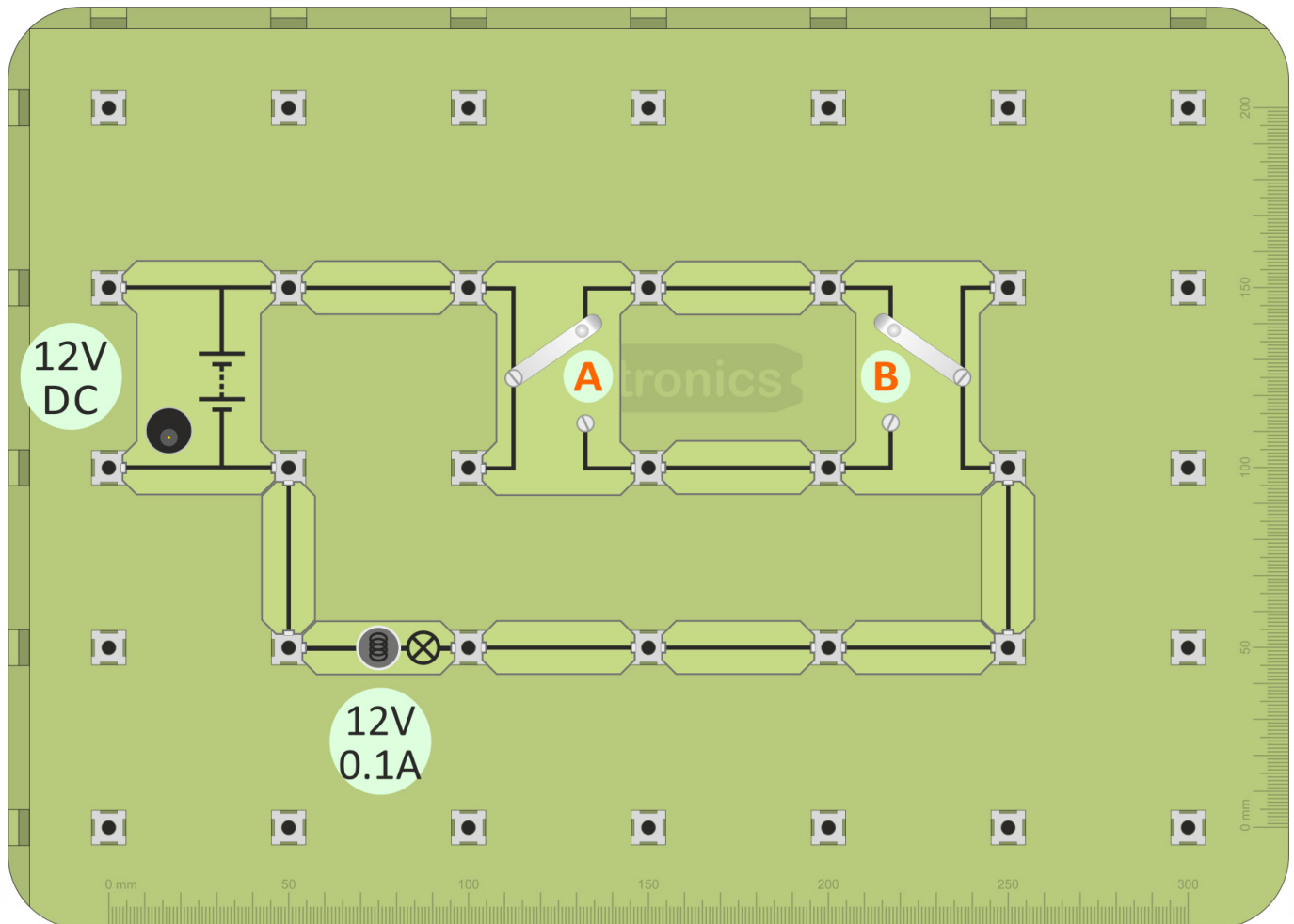
Staircase Circuit - 1

Here is another common circuit - a two-way switching circuit used to operate a light using either switch **A** or switch **B**. The light may be at the top of a staircase, with one switch at the bottom of the stairs and the other at the top.

It uses two changeover switches for **A** and **B**. These are sometimes called 'single-pole-double throw' or SPDT switches and are connected by two wires, - this method is sometimes called '2-wire control'.

Over to you

1. Build the layout shown below, using two 'changeover' switches, 'A' and 'B'.
2. Connect the 12V power supply and switch on.

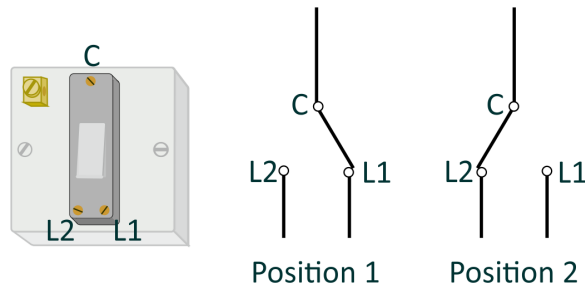


3. Move switch **A** into the other position. What happens?
4. Now move switch **B** into the other position. What happens?
5. For both of these, trace out the current paths.
6. Complete the diagram in the Student Handout by adding the current path for the arrangement shown there.

Staircase Circuit - 2

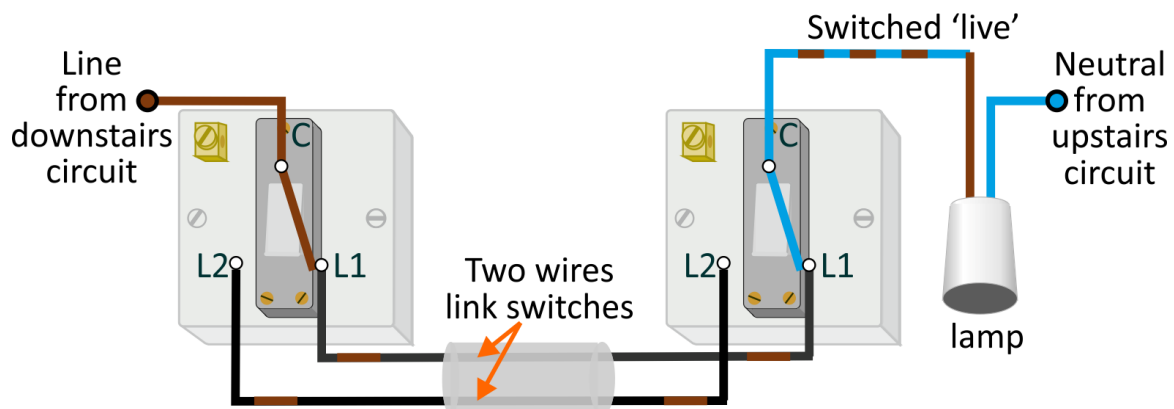
The circuit uses two changeover switches like the one shown.

Each has three terminals, **C** (for Common), **L1** and **L2**.



Operating the switch connects **C** to either **L1** or **L2**.

The '2-wire control' system is shown in the next diagram.



It works **but** there may be safety issues!

- The circuit may take its line connection from one circuit (e.g. downstairs) and its neutral from another (e.g. upstairs.) An electrician working on it might switch off the upstairs lighting circuit and think that the system is safe to work on. However, parts may still be 'live' because the downstairs circuit is still switched on.
- An RCD monitoring the downstairs circuit may trip unnecessarily because line and neutral currents downstairs may be different. Similarly, an RCD looking after the upstairs circuit may be unreliable. (RCDs are investigated in a few pages time.)

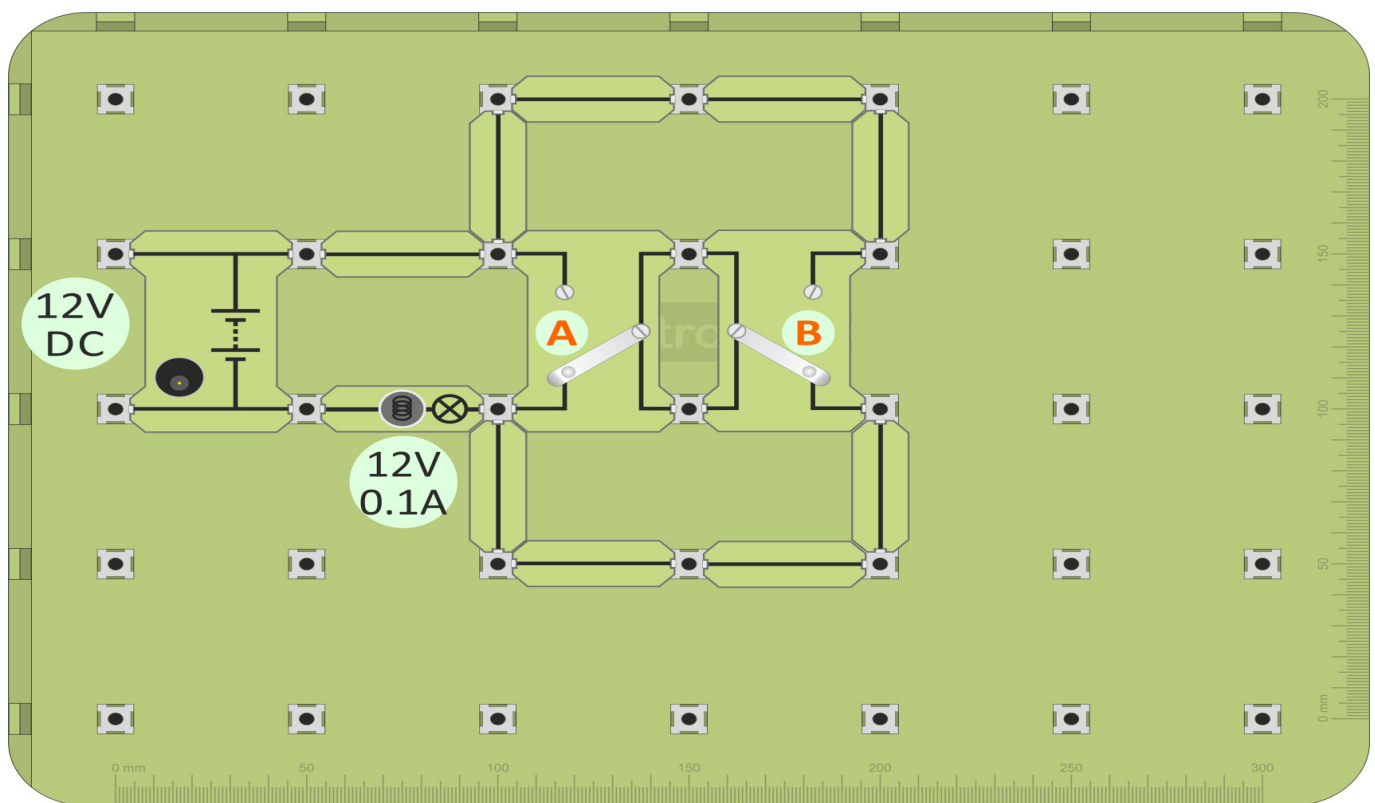
Staircase Circuit - 3

Over to you

The next layout demonstrates the safer '3-wire control' system. This time, both line and neutral connections can be taken from the same circuit, either downstairs or upstairs.

The potential problems created by the '2-wire control' system are avoided.

1. Build the layout shown below, again using two 'changeover' switches.
2. Connect the 12V power supply and switch on.



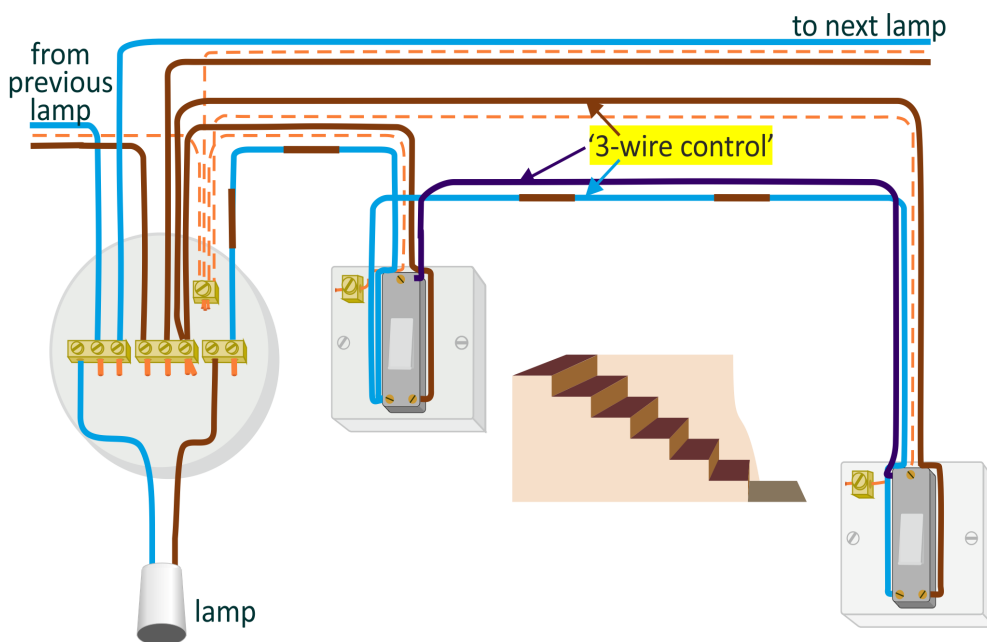
3. As before, you should be able to switch the lamp on an off using either switch.
4. Complete the diagrams in the Student Handbook.

Staircase Circuit - 4

The next diagram shows a practical form of the '3-wire control' system, so-called because three wires link the two switches together.

For clarity:

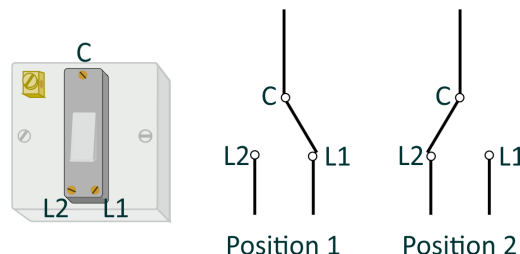
- The earth connections are shown as dotted lines;
- The wire connecting the two common connections is shown in purple.



Points to note:

- L1 terminals are connected together and to the incoming 'line' connection;
- L2 terminals connected to each other and to the 'switched wire';
- C terminals are connected together.

Challenge: Starting with the 'live' connection, (brown) from the previous lamp, trace out the circuit.



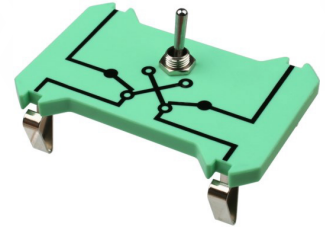
Notice that:

- With the left-hand switch is in position 1, L1 is connected to C, making it 'live';
- The C terminal in the other switch is connected to it, and so is also 'live';
- With the right-hand switch is in position 2, L2 is connected to C and so is 'live';
- This makes the brown wire to the lamp 'live' and so the lamp lights.

Then, in the same way, trace out the circuit with the switches in other positions.

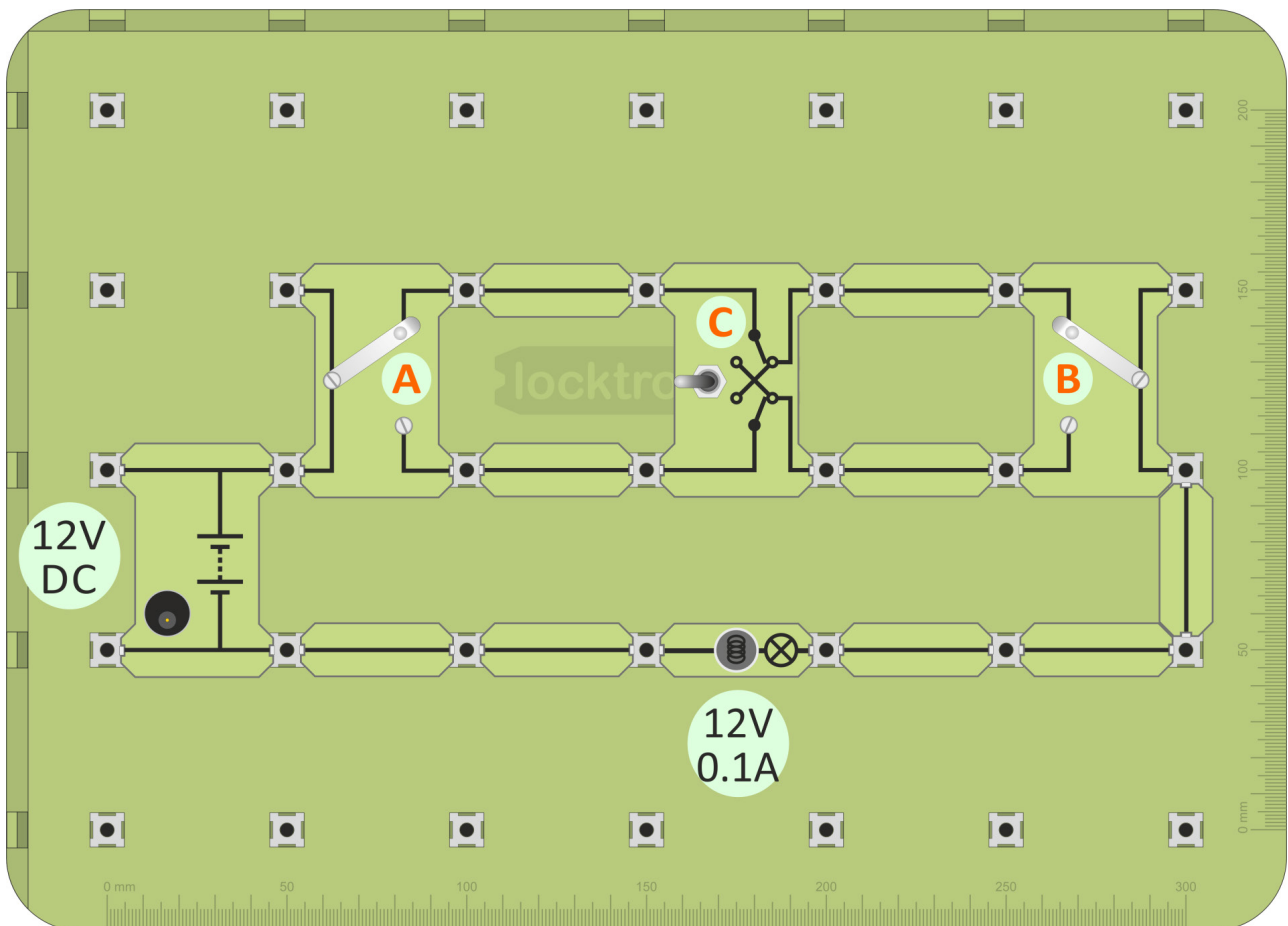
3-Way Control - 1

This is a modification of the previous circuit. By adding a third switch - an intermediate switch, (also called a reversing or a double-pole-double-throw (DPDT) switch,) the lamp can be controlled by three switches, **A** or **B** or **C**.



Over to you

1. Build the layout shown below, using two 'changeover' switches, '**A**' and '**B**' and an intermediate switch '**C**' (or modify the previous circuit by adding '**C**' .)
2. Connect the 12V power supply and switch on. (The layout shows the AC supply, reflecting the domestic electricity supply.)

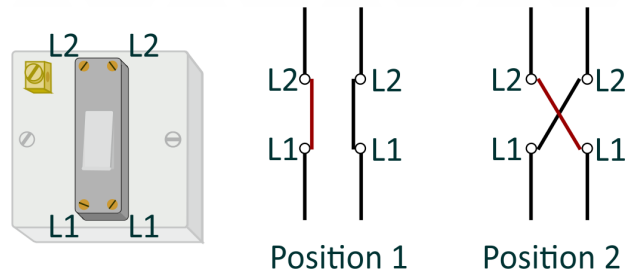


3. Check that the lamp can be controlled by all the switches.
4. For all eight combinations of switch positions, trace out the current paths.
5. Complete the diagram in the Student Handout by adding the current path for the arrangement shown there.

This is another '2-wire control system' and suffers from the same potential problems as the 2-way (staircase) system.

3-Way Control - 2

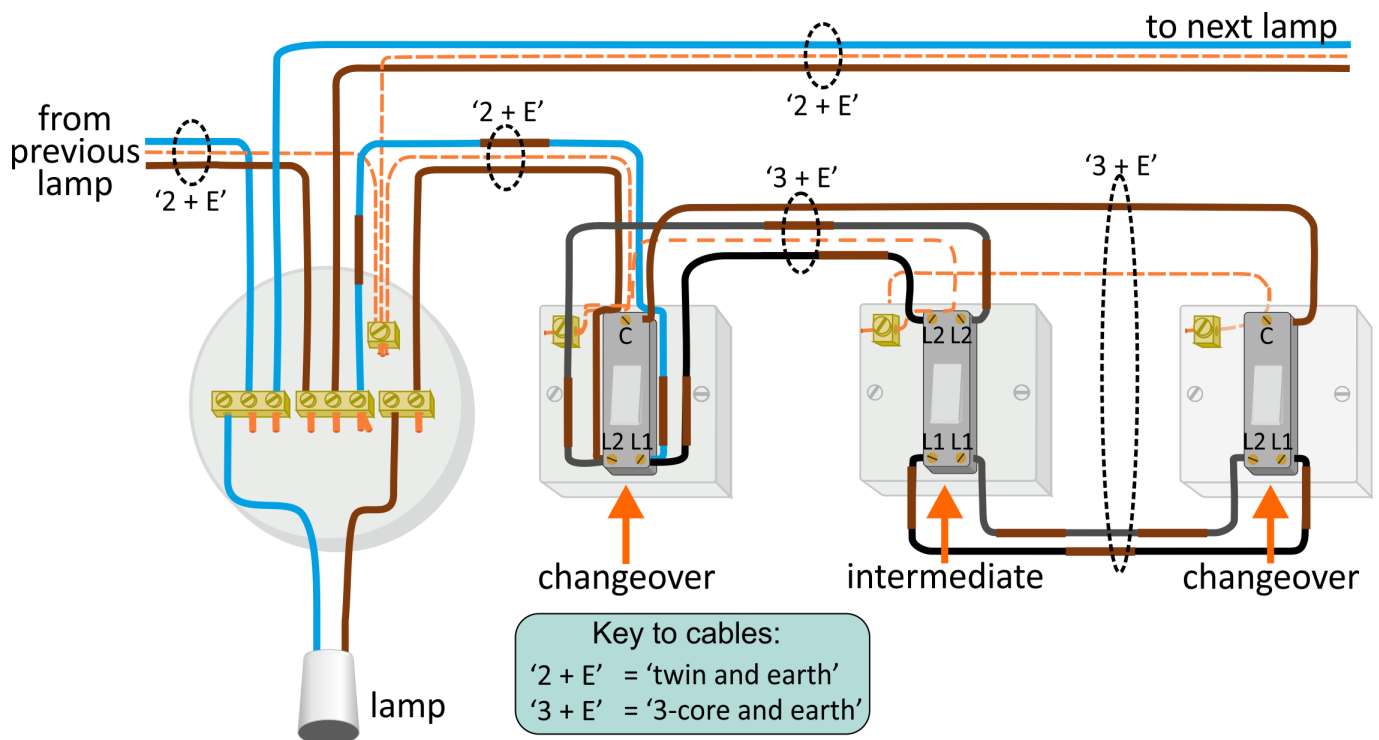
The third switch is known (in the UK) as an intermediate switch.



It has four terminals, two labelled L1 and two labelled L2.

Operating it makes the connections shown above.

The '3-wire control' version of the three-way switching circuit is shown below.



Challenge:

Compare this circuit with the one you just built using 'Locktronics'.

Measuring Voltage - 1



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

When using a multimeter, before you switch it on:

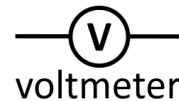
- Take care to plug the probes into the correct sockets;
- Select the correct range.

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

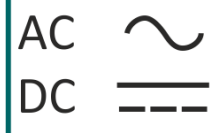
Voltage:

- 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:

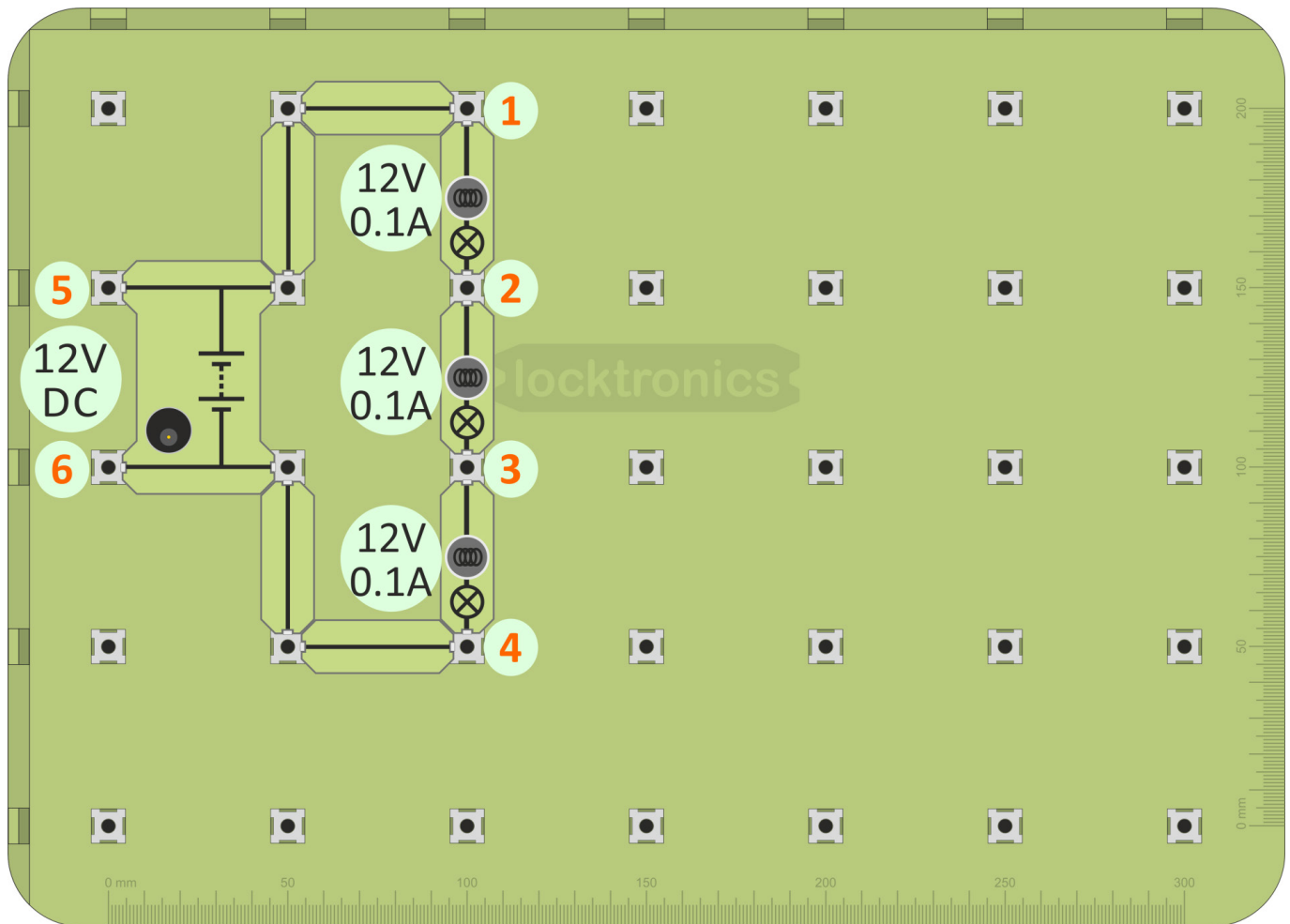
- Plug one wire into the black ‘COM’ socket.
- Plug another into the red ‘V’ socket.
- Select the 20V DC range by turning the dial to the ‘20’ mark next to the ‘V’ symbol. (It is good practice to set the meter on a range that is much higher than the reading you are expecting. Then refine it by choosing 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!



Measuring Voltage - 2

Over to you

1. Build the layout shown below - a series circuit with only one route around it.
2. Connect the power supply, set to 12V, and switch on.

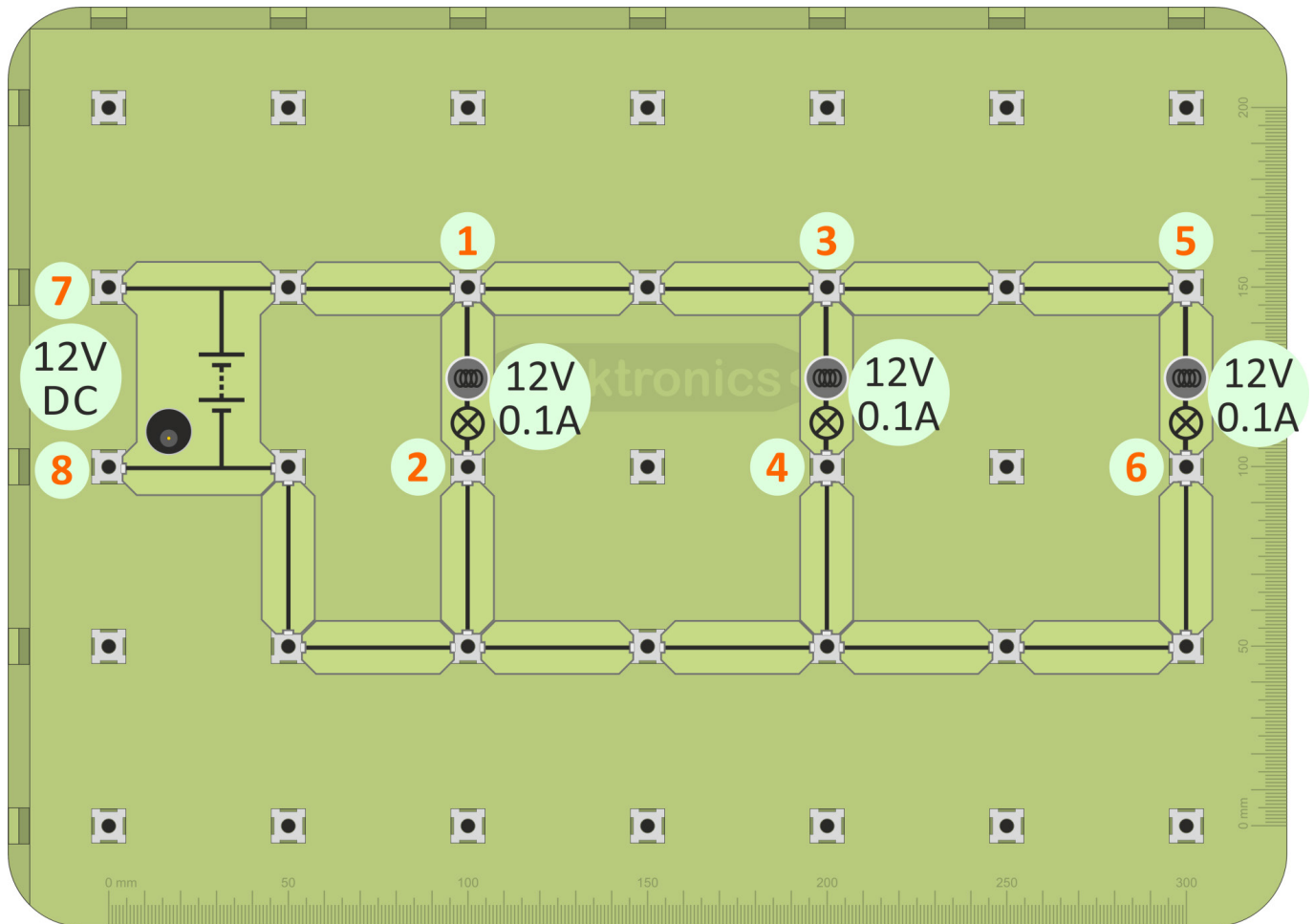


3. Set up the multimeter to read voltages up to 20V DC - see the previous page.
4. Measure the voltage across the top bulb, by plugging the multimeter leads into posts '1' and '2'.
5. Next, measure the voltage across the middle bulb, using posts '2' and '3'.
6. Then measure the voltage across the third bulb, using posts '3' and '4'.
7. Finally, measure the supply voltage, using posts '5' and '6'.
8. Add together the voltages across the three bulbs and compare it with the supply voltage. What do you notice?
9. Enter all your results into the table in the Student Handout and answer the question.

Measuring Voltage - 3

Over to you

1. Build the layout shown below - this time a parallel circuit.
2. Connect the power supply, set to 12V, and switch on.



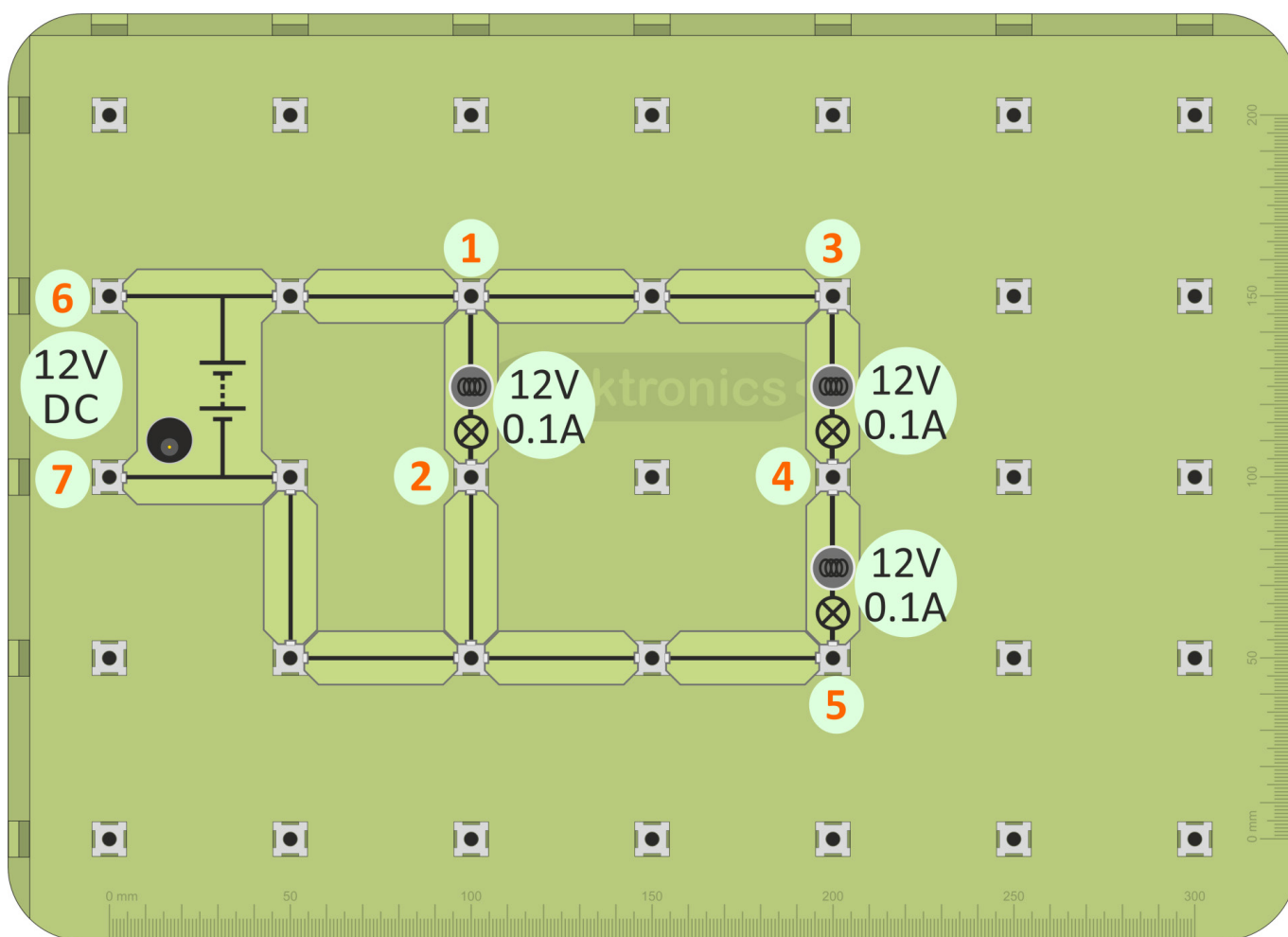
3. Set up the multimeter to read voltages up to 20V DC.
4. Measure the voltage across the first bulb, by plugging the multimeter leads into posts '1' and '2'.
5. Next, measure the voltage across the middle bulb, using posts '3' and '4'.
6. Then measure the voltage across the third bulb, using posts '5' and '6'.
7. Finally, measure the supply voltage, using posts '7' and '8'.
8. Look at the voltages across the three bulbs and across the supply voltage. What do you notice?
9. Enter all your results into the table in the Student Handout and answer the question.

Measuring Voltage - 4

Now we return to one of the circuits that have both series and parallel connections to see why the bulbs have the brightness we observed earlier.

Over to you

1. Build the layout shown below and switch on the power supply.



2. Measure the voltage across the first bulb, using posts '1' and '2'.
3. Next, measure the voltages across the other two bulbs, using posts '3' and '4' and then '4' and '5'.
4. Finally, measure the supply voltage, using posts '6' and '7'.
5. Look at the voltages across the bulbs. Does this explain the different brightness?
6. What do you notice about the supply voltage and the voltages across the bulbs?
7. Enter all your results into the table in the Student Handout and answer the question.

Challenge: Investigate the other mixed circuit which you built earlier.

Measuring Current - 1



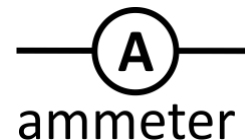
When using a multimeter to measure current, plug the probes into the 'A' and 'COM' sockets, or equivalents.

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.



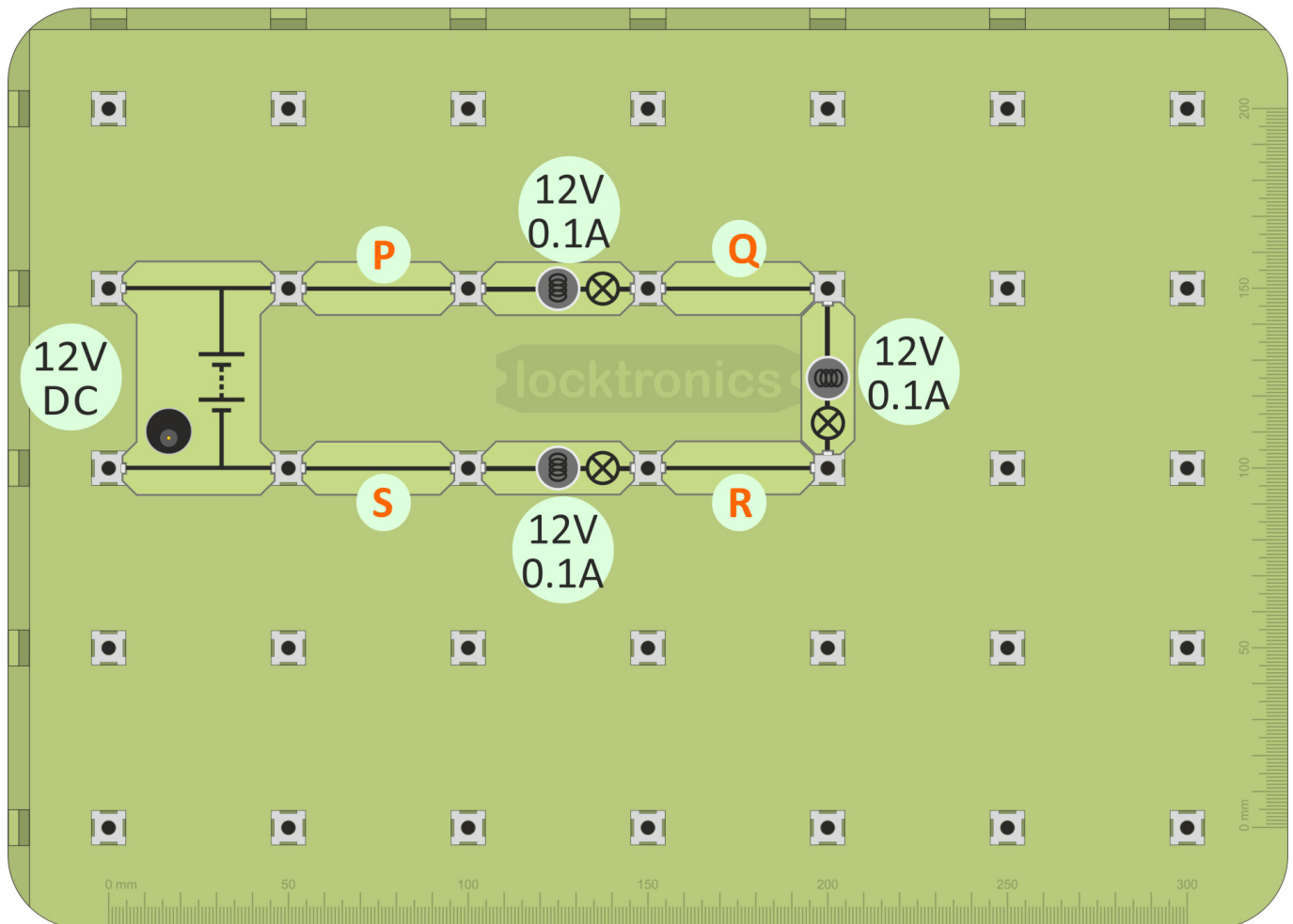
Using a multimeter to measure current:

- 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 wires 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.

Measuring Current - 2

Over to you

1. Build the layout shown below - a series circuit of three lamps but this time spread out to allow easy insertion of the ammeter when needed.
2. Connect the DC power supply, set to 12V, and switch on.

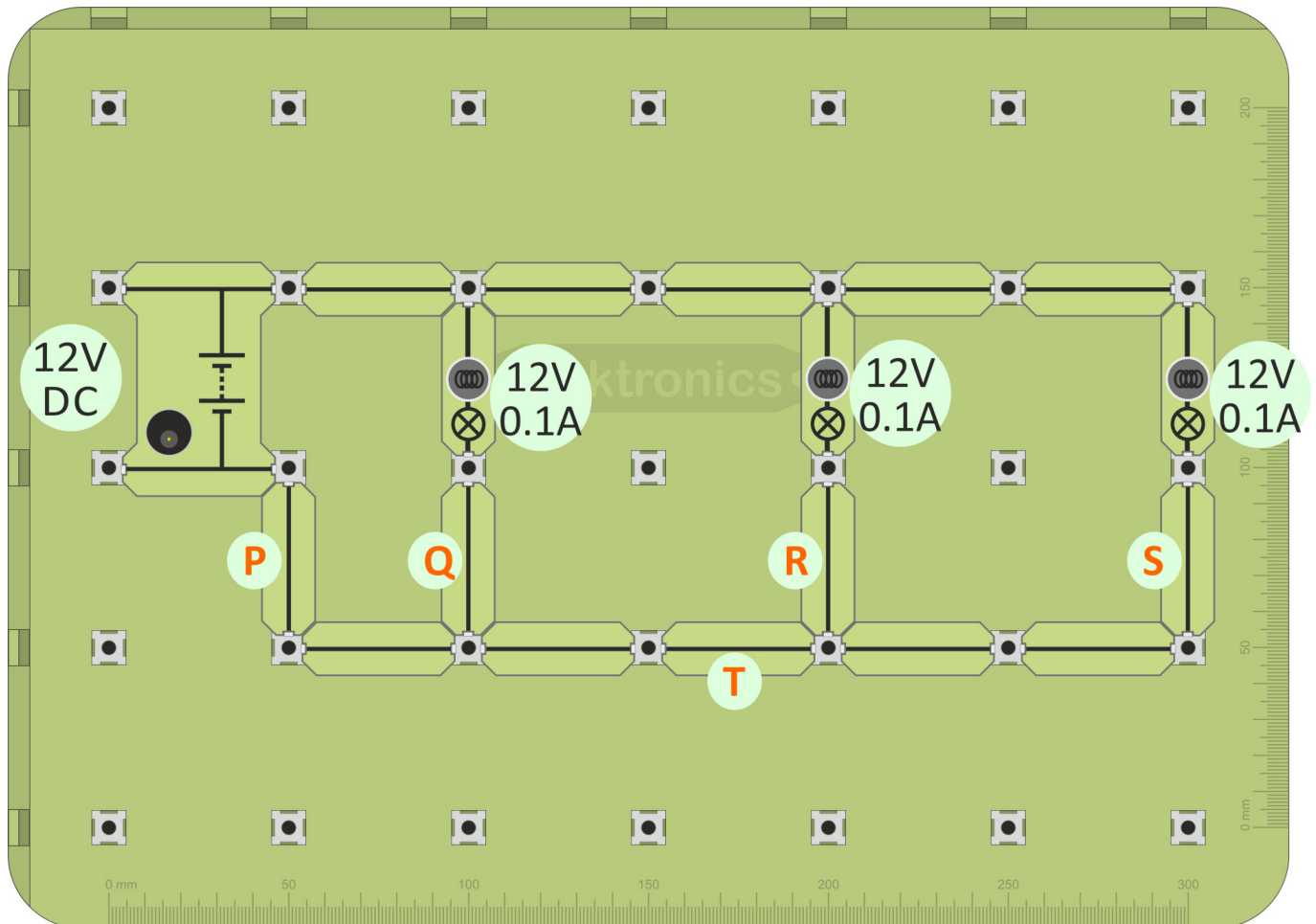


3. Set up the multimeter to read currents up to 200mA DC - see the previous page.
4. Measure the current at point 'P', by removing the connecting link and plugging the multimeter leads into the posts at either end of it.
5. In the same way, measure the current at points 'Q', 'R' and 'S'. You could say that the current at 'P' is the current delivered by the power supply, or the current flowing into the first bulb. Equally, the current at 'Q' is that leaving the first bulb, or entering the second one - and so on.
6. What do you notice about all the current readings?
7. Enter all your results into the table in the Student Handout and answer the question.

Measuring Current - 3

Over to you

1. Build the layout shown below - a parallel circuit of three lamps, again spread out to allow easy insertion of the ammeter when needed.
2. Connect the DC power supply, set to 12V, and switch on.



3. Set up the multimeter to read currents up to 200mA DC as before.
4. Measure the current at points 'P', 'Q', 'R' and 'S', by removing appropriate connecting links.
5. Enter your results into the table in the Student Handout and answer the question.

Challenge:

6. Use your results to estimate the current flowing at point 'T'.
7. Now measure it. Were you correct?

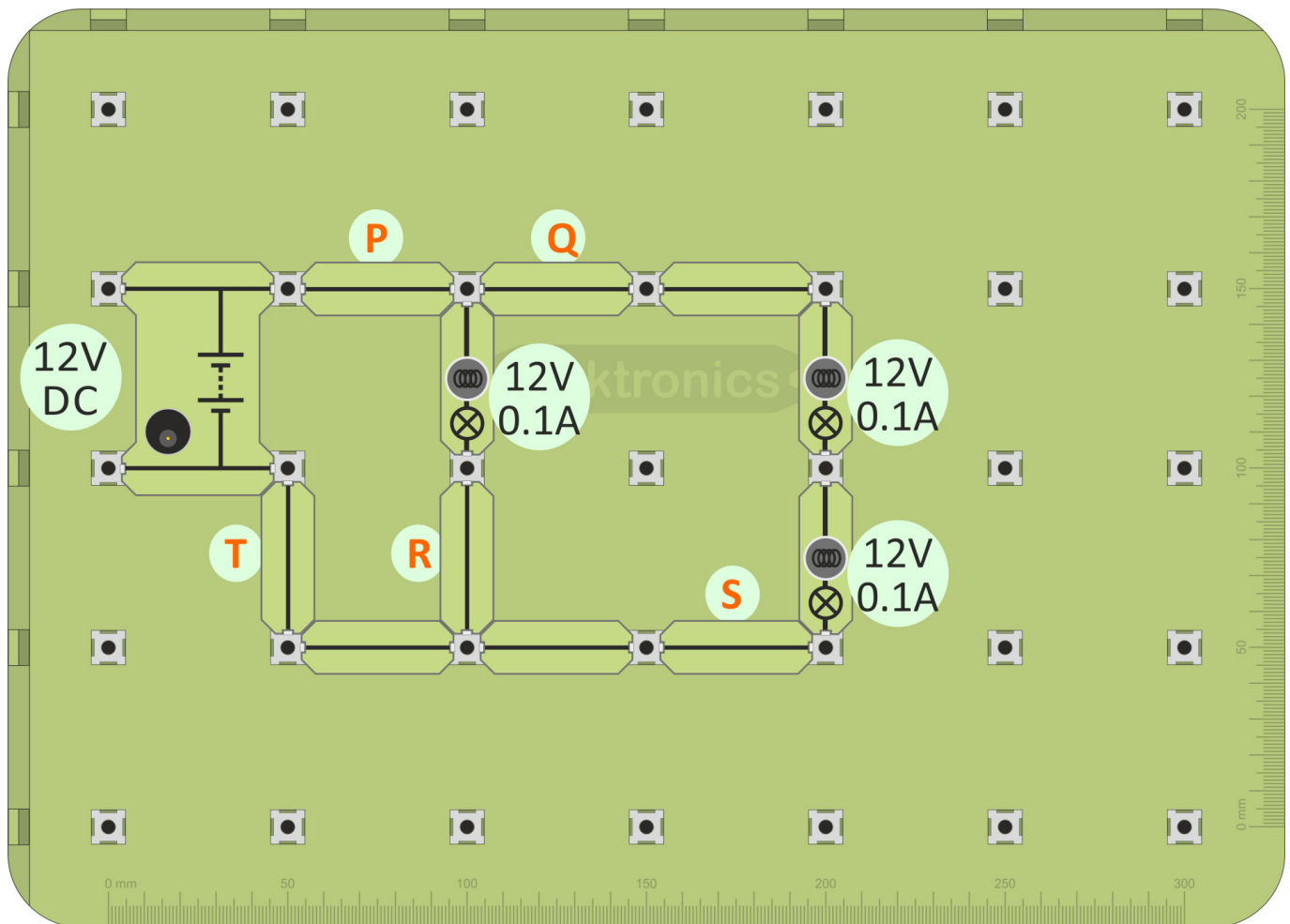
Write its value in the Student Handout.

Measuring Current - 4

Now we look at the currents flowing in one of the circuits that have both series and parallel connections.

Over to you

1. Build the layout shown below.
2. Connect the DC power supply, set to 12V, and switch on.



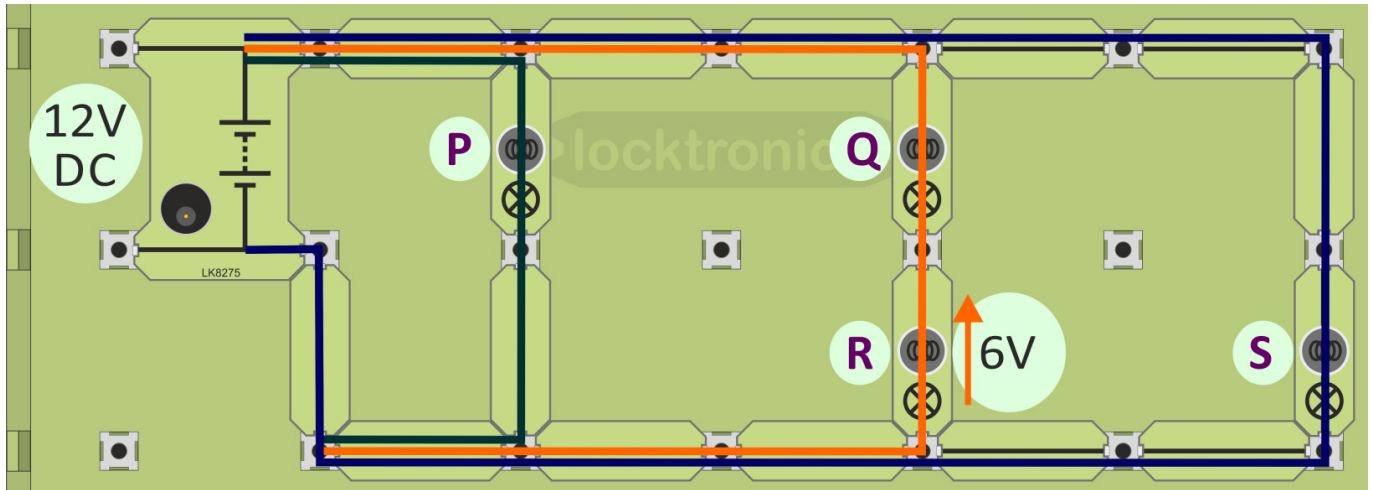
3. Measure the current at points 'P', 'Q', 'R', 'S' and 'T'.
4. Enter all your results into the Student Handout.
5. Explain why the current readings at points 'P' and 'T' are equal.
6. Explain why the current readings at points 'Q' and 'S' are equal. What does this imply for the brightness of the two bulbs between these points?
7. Compare these readings with the current at point 'R'. What does this mean for the brightness of the nearby bulbs?

Challenge: Carry out a similar investigation on the other mixed circuit, built earlier.

Kirchoff's Voltage Law

The voltage law - the sum of voltages around any loop in the circuit equals the power supply voltage in that loop.

The implications - In the circuit that follows there are a number of 'loops'.



In the **green** loop:

- Total power supply voltage in the loop = 12V;
- Only one bulb in the loop, so voltage across bulb **P** = 12V.

In the **blue** loop:

- Total power supply voltage in the loop = 12V;
- Only one bulb in the loop, so voltage across bulb **S** = 12V.

In the **orange** loop:

- Total power supply voltage in the loop = 12V;
- Two bulbs in the loop, so voltages across them must add up to 12V;
- Voltage across bulb **R** = 6V, (we are told);
- So voltage across **Q** must be $12 - 6 = 6V$.

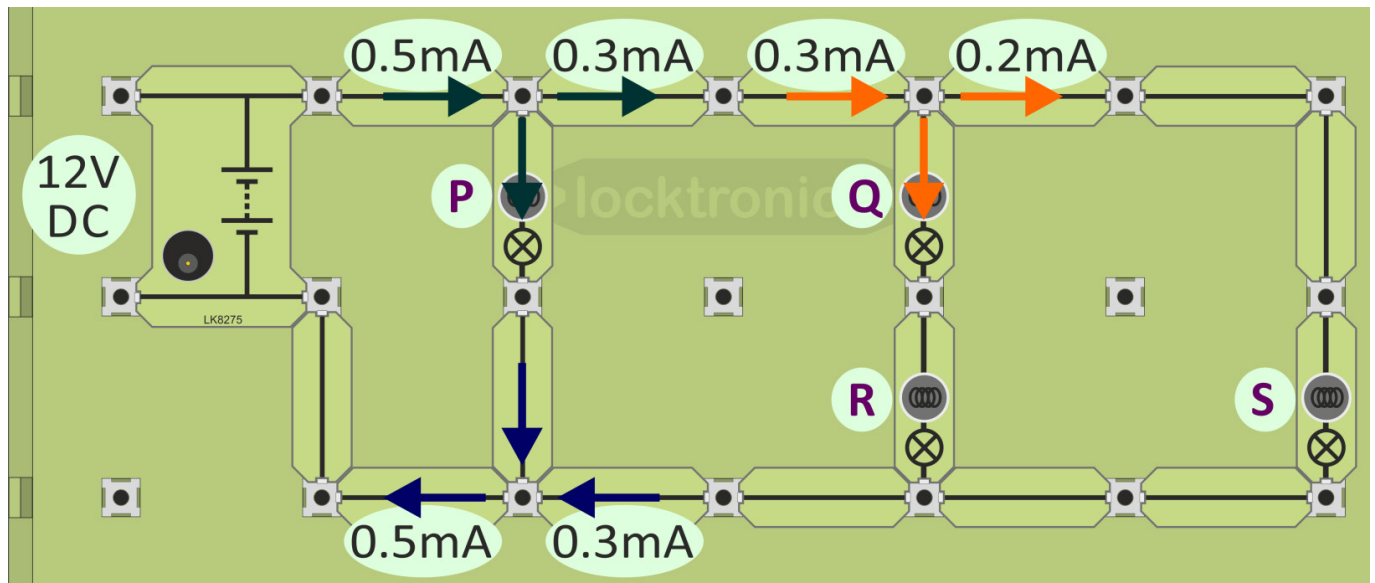
Challenge: If you are unsure about these results, build the circuit and check them!

Answer the questions in the Student Handbook.

Kirchoff's Current Law

The current law - the total current flowing into any junction in the circuit is equal to the total current flowing out of that junction.

The implications - In the circuit that follows there are a number of 'junctions'.



At the **green arrow** junction:

- Total current flowing into junction = 0.5mA;
- Total current flowing out of junction = 0.3mA + current through lamp P;
- So current through bulb P = 0.2mA.

At the **orange arrow** junction:

- Total current flowing into junction = 0.3mA;
- Total current flowing out of junction = 0.2mA + current through lamp Q;
- So current through lamp Q = 0.1mA.

At the **blue arrow** junction:

- Total current flowing into junction = 0.3mA + current through lamp P = 0.5mA;
- So current flowing out of junction = 0.5mA.

Lamps Q and R are in series, so the same current flows through them. Hence, current through R = 0.1mA

Challenge: If you are unsure about these results, build the circuit and check them!

Answer the questions in the Student Handbook.

Resistance - 1

So far it has been on/off control of electric currents, using conductors or insulators. Now we want a more subtle control.

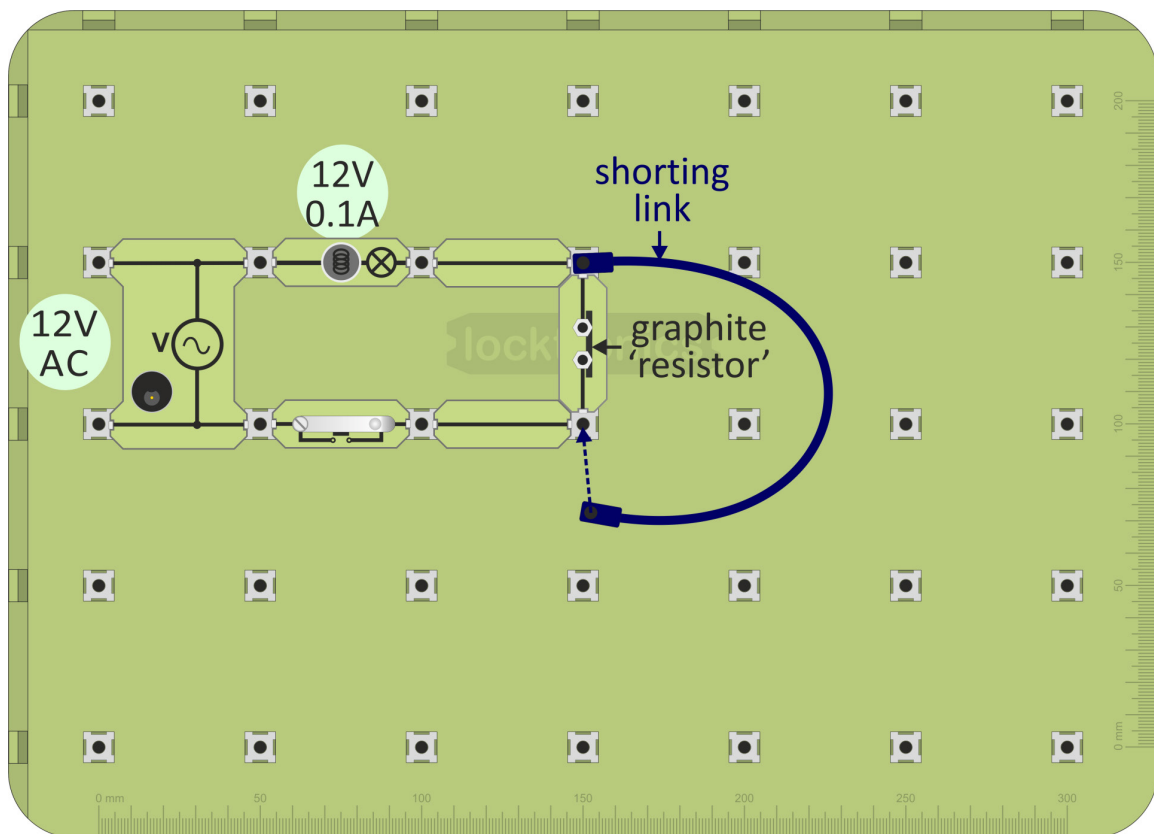
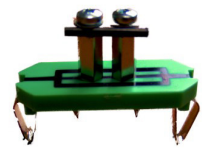
Using a tap, we can change the flow of water.



With electricity, we change the flow using a **resistor**.

Over to you

1. Create your resistor, using a short length of graphite (pencil lead) in the universal component carrier.
2. Build the layout shown below.
3. Connect the 12V power supply and switch on.



4. Close the switch and notice how bright the bulb looks. Remember – the brighter the bulb, the greater the current flowing.
5. Next, 'short-circuit' the resistor by joining both ends with a wire, as shown. What do you notice about the bulb? What does this tell you about the electric current when you add the resistor?

Now answer the questions in the Student Handbook!

Resistance - 2

For electrons, adding resistance is like asking you to run in mud.

It takes more energy!

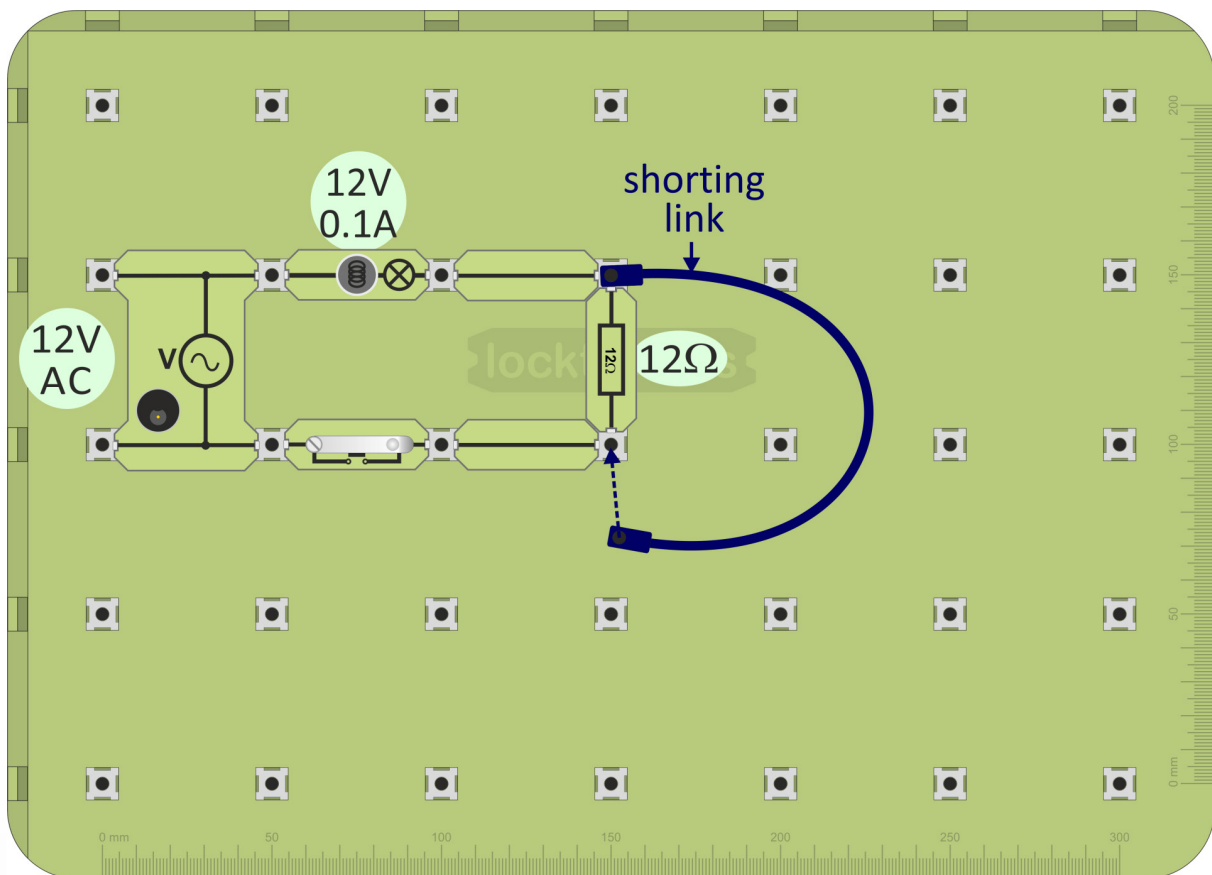


Commercially-made resistors often look like the one opposite.

The colour of the stripes is significant, but that is for later!



1. Build the layout shown below.
2. Connect the 12V power supply and switch on.



3. Close the switch and notice how bright the bulb looks.
4. Next, 'short-circuit' the resistor with the wire. What happens to the bulb? What does that tell you about the current?

Ohm's Law - 1

Ohm's Law:

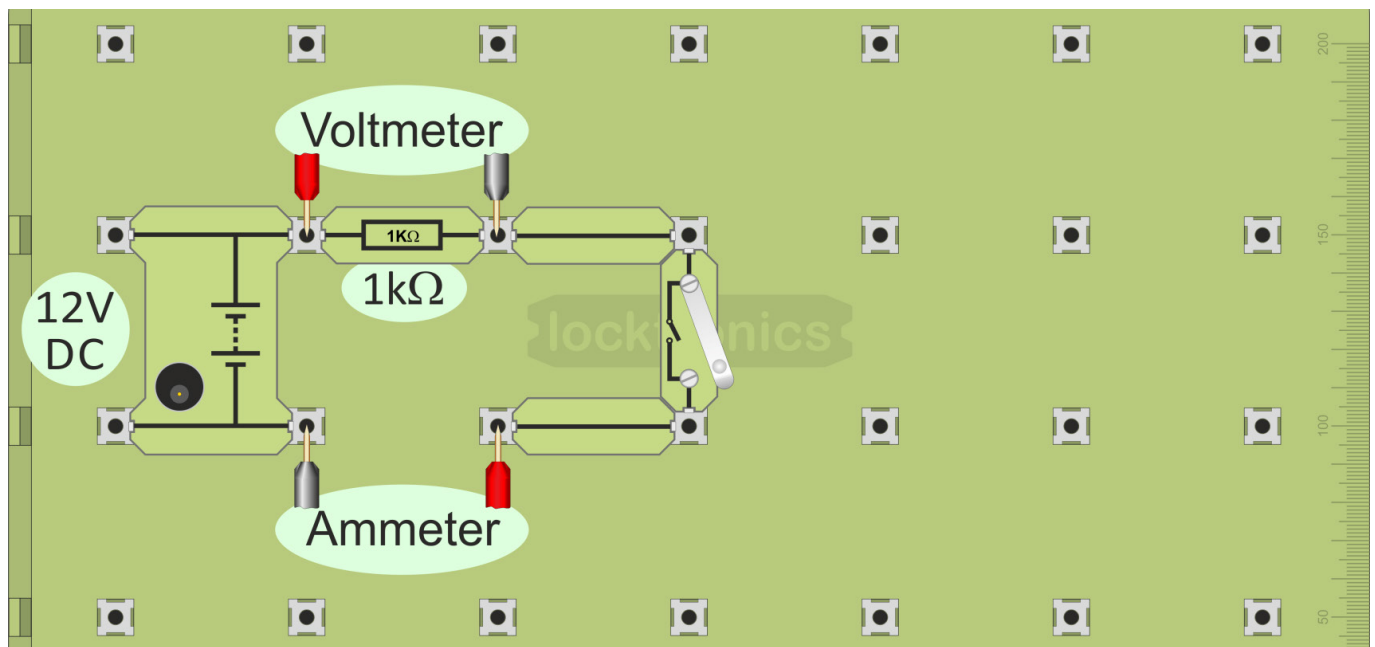
- Relates the current, I , through a resistor, R , to the voltage, V , across it;
- Results in the formula: $V = I \times R$ (or $I = V / R$, or $R = V / I$), using either volts / amps / ohms or volts / milliamps / kilohms;
- Applies only when the temperature of the conductor stays steady.

When devising a new test procedure, it's reassuring to start with a situation where you know the answer!

In this case, we are going to work out the resistance of a $1\text{k}\Omega$ resistor!

Over to you

1. Build the following layout, using multimeters for the voltmeter and ammeter.
Settings:
voltmeter - greater than 12V, **ammeter** - around 20mA.
2. Set the power supply to 12V, connect it to the circuit and switch on.



3. Close the switch.
4. Measure the voltage across the resistor and the current flowing through it.
5. Record the results in the Student Handbook and calculate the resistance of the resistor.
6. Repeat the process with the power supply voltage to 6V.
7. Replace the $1\text{k}\Omega$ resistor with a 12V 0.1A lamp. In the same way, work out its resistance at 12V and at 6V. Record your findings in the Student Handbook.

Ohm's Law - 2

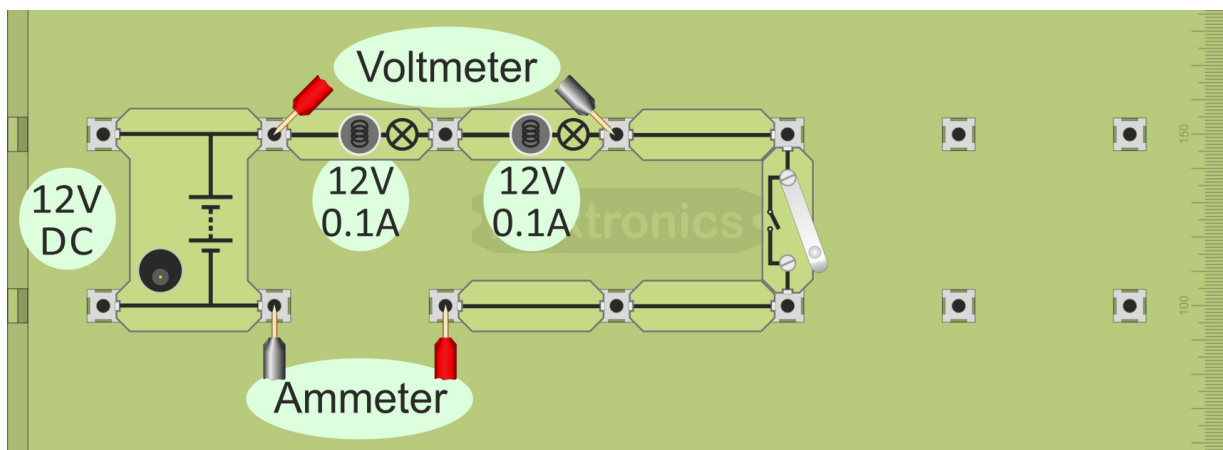
Now, take a look at what happens when we combine resistors together.

In the last activity, you worked out the resistance of a 12V 0.1A bulb, at 6V and 12V.

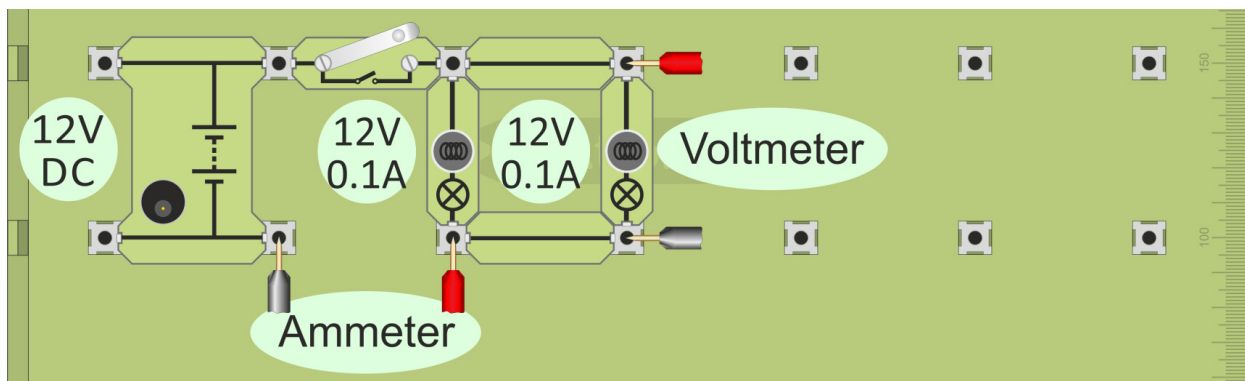
This activity uses two of these, first in series and then in parallel.

Over to you

1. Build the layout shown below. The two lamps are in series.
2. Connect the 12V power supply and switch on.



3. Close the switch.
4. Measure the voltage across the lamp combination and the current through it.
5. Record your readings in the Student Handbook and work out the resistance of the two lamps in series.
6. Answer the questions about your results.



7. Modify the circuit, as shown, so that the lamps are connected in parallel.
8. Measure the voltage across the combination and the current through it.
9. Once again, record your readings in the Student Handbook and work out the resistance of the lamps in parallel. Answer the questions about your results.

Measuring Resistance - 1



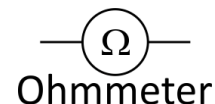
When using a multimeter to measure resistance, the component must be removed from the circuit first!

As before, 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), by an ohmmeter. (1 kilohm = 1 000 ohms.)



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. (As before, 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.

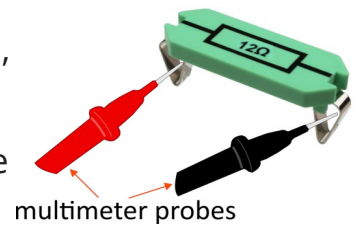
Measuring Resistance - 2

Over to you

The first task is to measure the resistance of the 12Ω carrier.

Although we know what answer to expect, the value displayed is unlikely to be exactly 12Ω and it will show that the multimeter is working!

1. Set the multimeter on the 200Ω range.
2. Make sure that the probes are plugged into the ' Ω ' and 'COM' sockets.
3. Press the tips of the probes against the metal clips on the universal component carrier, as shown in the diagram.
4. Read the value of resistance shown on the multimeter.
5. Record this value in the Student Handbook.



(The measurement is unlikely to be exactly 12Ω !)

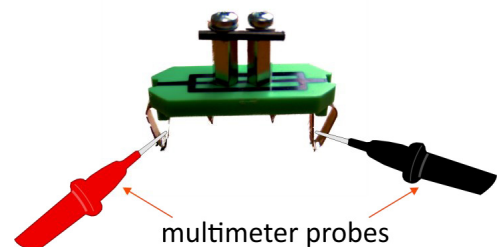
The quandary - is there some inaccuracy in the resistor, or is the multimeter not totally accurate?

(The answer is probably a little bit of both!)

Next, do the same for the home made resistor.

We expect this to have quite a low resistance, judging by its effect on the bulb earlier.

Nevertheless, keep the meter on the 200Ω range, at least to begin with.



Record its value in the Student Handbook as well.

Finally, use the same procedure to measure the resistance of the 12V 0.1A bulb. Again, record its value in the Student Handbook.

Obviously, this measurement is done with the filament at room temperature.

In the 'Ohm's law - 1' activity, you measured its resistance when glowing dimly (6V) and brightly (12V). The difference between the resistance measurements is caused by temperature.

Answer the question in the Student Handbook.

Resistivity - 1

The resistance of a wire depends on three factors - its length, cross-sectional area and the resistivity of the material it is made from.

It is measured in units called Ω m (ohm metres).

"Which is heavier, a ton of lead or a ton of feathers?"

Silly question - both weigh the same!



The next question is just as bad -

"Which has a bigger resistance, a copper 1k Ω resistor or a nichrome 1k Ω resistor?"
(Nichrome - nickel-chromium alloy designed for use in resistors.)

Both are the same - 1k Ω , but the copper one would be enormous by comparison. Why?

The answer - **Resistivity**

(how strongly a material opposes the flow of electric current through it)!

Nichrome's resistivity is 60 times that of copper!

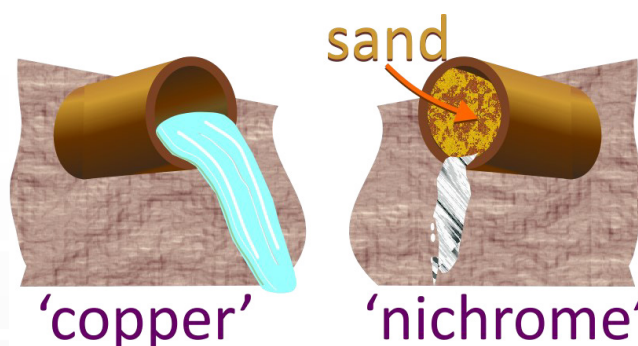
All other things being equal, the copper resistor would have to be 60 times larger!

Picture it:

Flow of electricity is often likened to flow of water - the wider the pipe, the greater the flow of water, the fatter the wire, the greater the current etc.

To picture resistivity, think of water flowing down an empty pipe and compare it with water flowing down the same sized pipe full of sand.

The first = copper; the second = nichrome.



Resistivity - 2

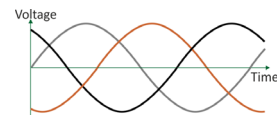
The four Locktronics resistivity carriers are described in the table below:

Sample	Material	Length L in m	Cross-section a in mm ²
A	Nichrome	0.5	0.075
B	Nichrome	0.25	0.075
C	Nichrome	0.5	0.21
D	Constantan	0.5	0.075

(Constantan - a copper-nickel alloy designed for use in resistors.)

Over to you

1. Use a multimeter to measure the resistance of each of the samples.
2. Record your results in the Student Handbook.
3. Answer the questions raised in the Student Handbook.



Comparing the results, following the approach below, shows the effect of the factors that affect resistance.

The logic behind this approach:

A and B :

- The same material;
- The same cross-sectional area;
- **Different length.**

Comparing them shows the effect of **length** on resistance.

A and C :

- Same material;
- Same length;
- **Different cross-sectional area .**

Comparing them shows the effect of **cross-section** on resistance.

A and D :

- Same length;
- Same cross-sectional area;
- **Different materials.**

Comparing them shows the effect of **resistivity** on resistance.

Resistivity - 3

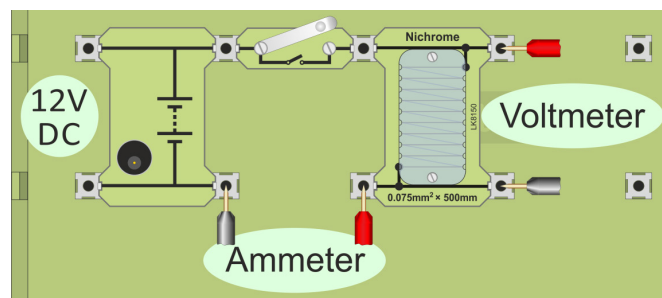
Over to you

Measure the resistivities of nichrome and constantan!

1. Build the layout shown below, using the nichrome carrier.
2. Make sure that the DC power supply is set to 6V!

Ammeter - set up a multimeter to read currents up to 200mA DC.

Voltmeter - set up a multimeter to read currents up to 6V DC.



3. Connect the power supply and switch it on.
4. Close the switch.
5. Measure the voltage V across the nichrome and the current I flowing through it.
6. Calculate the resistance R of the nichrome using the formula:

$$R = \frac{V}{I}$$

7. Record your results in the table given in the Student Handbook.

Resistivity of nichrome:

The results also allow us to calculate the resistivity of nichrome, using the formula:

Resistivity $\rho = \frac{R \times A}{L}$ where R is the resistance of the sample

For example:

A sample of copper of length $L = 1.5\text{m}$, cross-section $A = 0.01 \text{ mm}^2 (= 0.01 \times 10^{-6} \text{ m}^2)$ has a resistance $R = 2.5\Omega$

Using these values, copper has a resistivity of: $\rho = \frac{2.5 \times 0.01 \times 10^{-6}}{1.5} = 1.7 \times 10^{-8} \Omega\text{m}$

Following the same steps, use your results for the resistance of the nichrome sample to calculate the resistivity of nichrome. Write your result in the Student Handbook.

Now repeat the process, replacing the nichrome carrier with the constantan carrier. Once again, record your results in the Student Handbook.

Electrical Safety



Electricity is **dangerous!**

Our bodies can sense electric currents as small as 1mA.

A current of 10 mA DC can cause muscle contractions which mean that the victim cannot release the electrified object.

The voltage required to deliver these currents depends on a number of factors including the electrical resistance of the human body.

This, in turn, depends on factors like:

- The presence of sweat on the skin;
- The hydration level of the body - 45 to 70% of the weight of the body is water;
- The body fat content;
- Where on the body the electrical contact occurs;
- Skin has a high resistance unless it has cuts or blisters;
- Current flowing from hand to foot experiences more resistance than current flowing from one finger to the next.

The resistance of the human body is typically between 1k Ω and 100k Ω .

Safety devices explored in the next sections:



Fuses and circuit breakers (MCBs) protect the appliance and the wiring connecting it, but **NOT** the user!

A fuse may happily pass a 10A current without 'blowing'.

A human body would not be happy with a current of 10A!



The **RCD** (residual current device) compares the current it supplies to the appliance with the current, which flows back **from** the appliance. An imbalance might indicate a fault, such as an electric current flowing to earth through the user. The RCD 'trips', shutting off the electricity supply to the appliance and the user.

The Fuse



Electricity is **dangerous!**

'Short-circuits' are a potentially harmful effect of electrical heating. Worn or damaged insulation lets wires touch, allowing very large currents to flow.

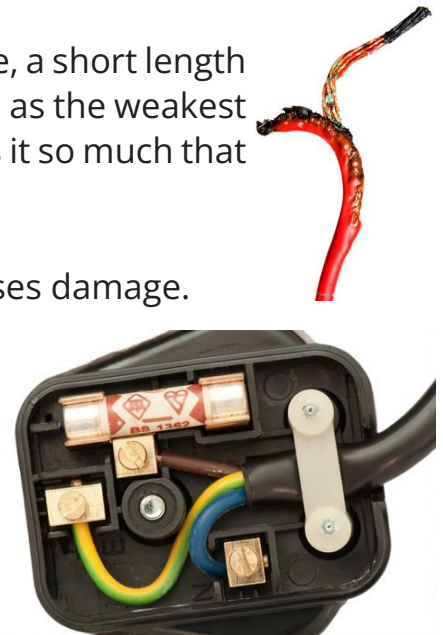
These can generate a lot of heat, causing fires.

One solution is an application of electrical heating, the fuse, a short length of wire made from a metal with a low melting point. It acts as the weakest point in the circuit. A large current flowing through it heats it so much that it melts.

This breaks the circuit, stopping the current before it causes damage.

The image shows the connections in a UK 13A plug.

The 'cartridge fuse' protects the wiring installation and appliance. It is important that the correct fuse rating is used for the appliance. These cartridge fuses typically come in values of 3A, 5A and 13A.



Calculating fuse values:

We need:

- The power rating, **P**, of the appliance;
- The voltage, **V**, it is designed to work on.

From these, we first use the formula **$P = I \times V$ (or $I = P / V$)** to work out the normal current, **I**, flowing through the appliance. This current is fine - no overheating will occur.

Then we choose a fuse value just greater than this so that the fuse will 'blow' cutting off all current when a problem occurs.

For example:

A modern TV - power rating (P) 200W on a 240V power supply (V).

Normal current (I) = $200 / 240 = 0.8A$.

The best cartridge fuse rating for this is 3A.

Challenge:

Calculate the normal current and best cartridge fuse value for the appliances listed in the Student Handbook.

The Circuit Breaker

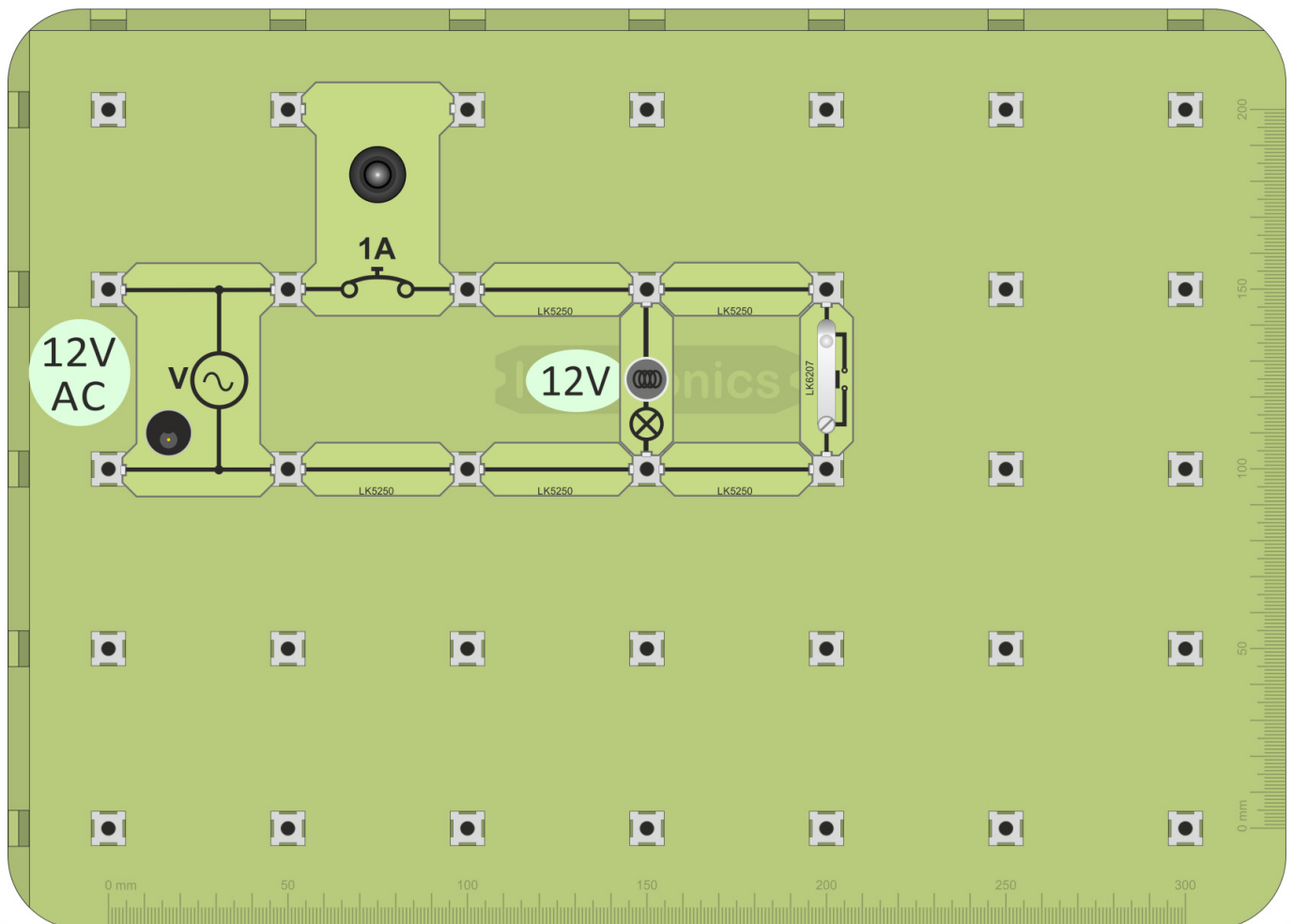
The modern consumer unit contains both MCBs (miniature circuit breakers) and RCDs.

However, these have different functions.



The circuit breaker switches off the current when it senses a fault. Like the fuse, it protects the appliance and the wiring connected to it. However, a fuse must be re-wired or replaced before normal operation can resume, whereas the mcb can be reset, by pressing a reset button or operating a switch.

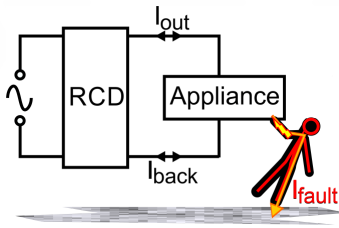
1. Build the layout shown below.



2. Connect the AC 12V power supply and switch on.
3. Press the circuit breaker 'Reset' button if necessary. The lamp should turn on.
4. Press the switch. The circuit breaker should trip as its rated current is exceeded.
5. Restore the supply by pressing the 'Reset' button again.

Challenge: Add an ammeter to measure the current that causes the circuit breaker to 'trip'. Record your results in the Student Handbook.

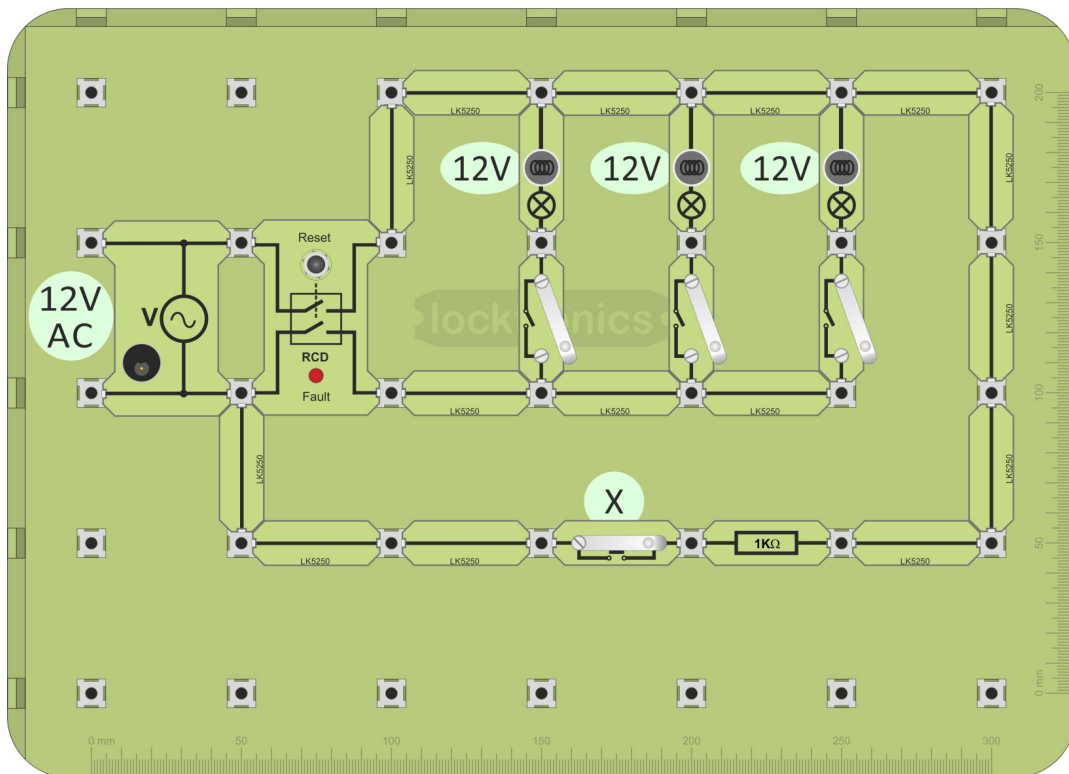
The RCD



A faulty electrical appliance might give the user an electric shock, with a current, I_{fault} , flowing to earth through the user. The **RCD** compares the current (I_{out}) flowing to with that (I_{back}) returning from an appliance. If the difference ($I_{\text{out}} - I_{\text{back}}$) reaches a set value (typically 30mA), the RCD 'trips', shutting off the electricity supply.

Over to you

1. Build the layout shown below.
2. Connect the AC 12V power supply and switch on.



3. Press the 'Reset' button on the RCD if necessary. The three lamps can now be controlled separately by the on/off switches.
4. Simulate a fault by pressing switch 'X'. This diverts some current around the RCD, producing an imbalance in the currents leaving and returning to it.
5. The RCD 'trips', switching off the supply and lighting the 'Fault' LED on the RCD.
6. Restore the supply by pressing the 'Reset' button again.

Challenge: Replace the 1kΩ resistor with a 250Ω variable resistor. Measure the fault current which causes the RCD to trip. Record your result in the Student handbook.

Earthing

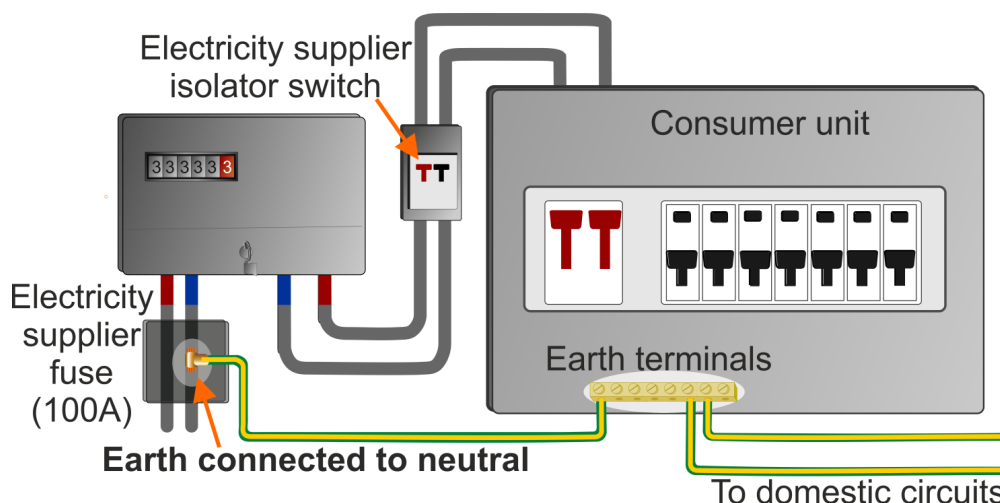


Electricity is **dangerous!**

Sometimes, part of an electrical appliance, such as the outer metal casing, can become 'live' (wrongly connected to the mains electricity line cable.) Anyone touching this receives an electric shock which can cause serious injury or death.

'Earthing' is the procedure used to ensure that when part of an appliance becomes 'live', a large current flows causing a fuse to blow, or circuit-breaker or RCD to trip. In this way, the user is protected from electric shock. A cable, the 'earth' lead, connects vulnerable parts of the appliance to the earth, or ground.

The following diagram shows a common way to do this, using the TN-C-S system.

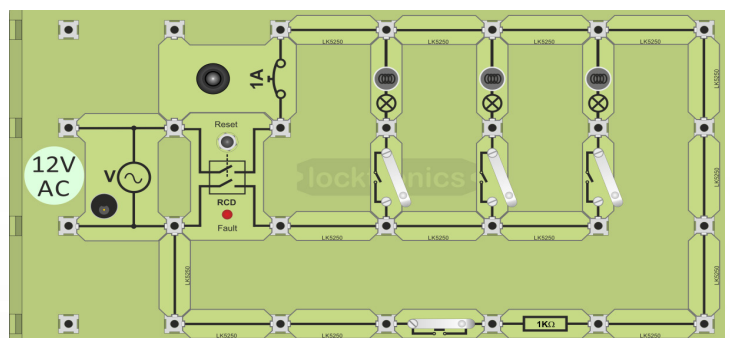


All earth leads are connected to the incoming neutral lead, usually inside the electricity supplier's fuse, where the electricity supply cables enter the building.

Challenge: The next layout combines the benefits of a circuit breaker and a RCD.

Investigate it by:

- Short circuiting a bulb;
- Unbalance the currents in the 'line' and 'neutral' wires.



Make sure that you are clear about the different roles of the circuit breaker and RCD.

The Energy Meter

Energy:

- Many forms - heat, light, sound, electricity etc.;
- Measured in joules (J) or kilowatt-hours (kW-h);
- What we pay for, at filling stations, in electricity and gas bills etc.

Power:

- Energy used (or converted) per second;
- Measured in watts (W), or kilowatts (kW). (1 kilowatt = 1 000 watts.)

The energymeter: (Optional Experiment)



- Measures voltage, current, power and energy consumption;
- Measurement chosen by pressing function button;
- 'Start / Pause' and 'Reset' buttons offer measurement of energy consumption over a period of time;
- Display adjusts to show appropriate units.

Using the energymeter to measure energy consumption:

1. Connect the energy source (battery, power supply, DC generator etc.) to the 'Source' terminals.
2. Connect the load (bulb, resistor, motor etc.) to the 'Load' terminals.
3. Plug in the energymeter power supply, and switch on. The display shows the word 'Initialising...' for a few seconds and then looks like the picture below.

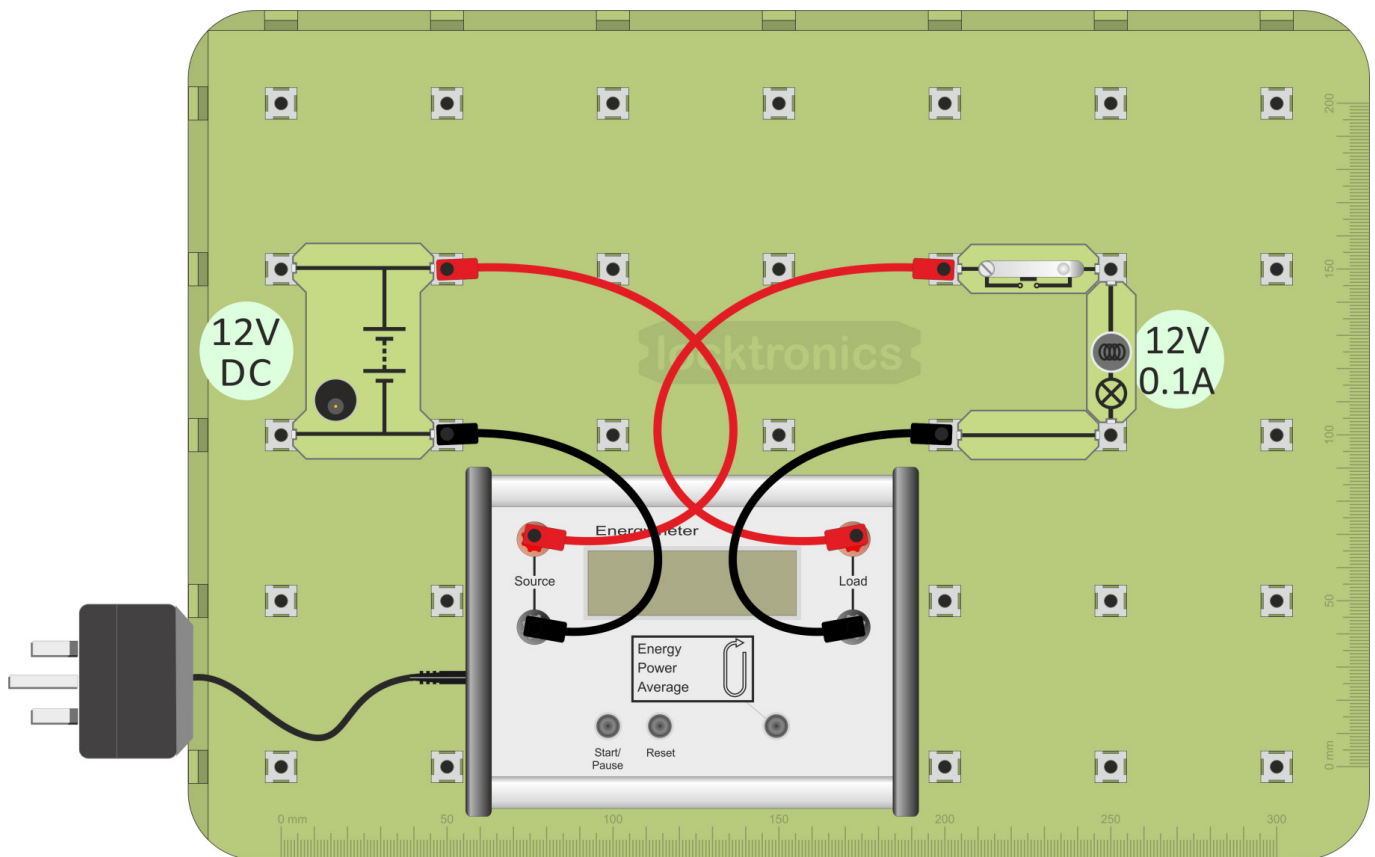
4. Press the 'Start / Pause' button. The energymeter starts to record the energy transferred from the source to the load. The arrow '➡' at the lower right-hand corner of the display, shows that the meter is continuing to measure.
5. Press the 'Start / Pause' button again. The display freezes and the arrow turns to a 'P' to show that the meter has paused.
6. To clear the readings, press the 'Reset' button.

Measuring Power

Over to you

(Optional Experiment)

1. Build the layout shown below.
2. Connect the 12V power supply and switch on. Plug in the energymeter power supply, and switch on.



3. Press the 'Function' button until the display shows
4. Press down the push switch to make the bulb light.
5. The display now shows the power consumed by the bulb.
6. Record the reading in the Student Handbook.

Challenge: Modify the circuit to measure the combined power consumption of **two** bulbs, connected:

- In parallel;
- In series.

In each case record your results in the Student Handbook.

Comment on your results.

Energy and Power

Energy:

- Comes from sources such as fossil fuels, the Sun, nuclear fission;
- Appears in many forms, heat, light, sound, electricity etc.;
- Is measured in units called joules (J) or kilowatt-hours (kW-h).

Power:

- Measures how much energy we use (or convert) each second;
- Is measured in watts (W), or kilowatts (kW). (1 kilowatt = 1 000 watts.)

For example:

- A 100W lamp is much brighter than a 40W lamp - it converts more electrical energy into light each second;
- A 3kW heater generates three times as much heat as a 1kW heater.

Calculating electrical power:

Use the formula:

$$P = I \times V$$

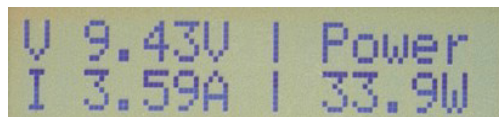
meaning :

power = current x voltage.

Example 1: What is the power rating of a bulb that takes a current of 0.25A from the mains 240V supply?

Power = current x voltage = $0.25 \times 240 = 60W$.

Example 2: The energy meter displayed the readings shown in the picture.



The power measurement = current x voltage = $3.59 \times 9.43 = 33.9W$

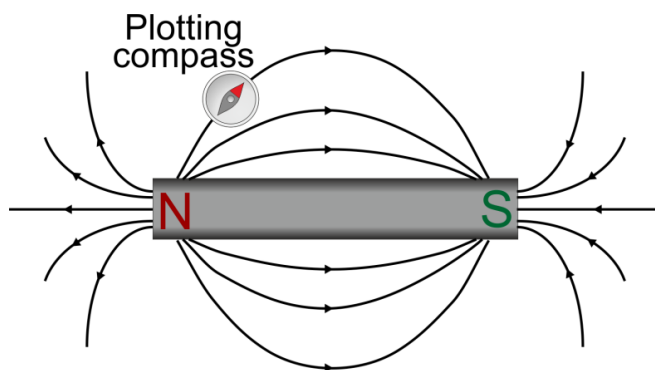
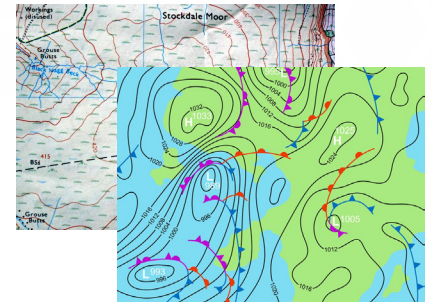
In the UK, consumers are encouraged to use 'smart' meters, offering a range of functions including displaying the power dissipated in individual appliances or in the whole domestic installation.



Electromagnetism - 1

'Ordnance Survey' maps use 'contour lines' to show the steepness of slopes.

On weather maps 'isobars' show weather patterns. Winds are strongest where the isobars are closest together.



In the same way, we map magnetic fields using 'lines of force' or 'flux lines'.

The magnetic force is strongest where they are packed most tightly.

A line of force is the path that a free north pole (which doesn't exist either!) would follow.

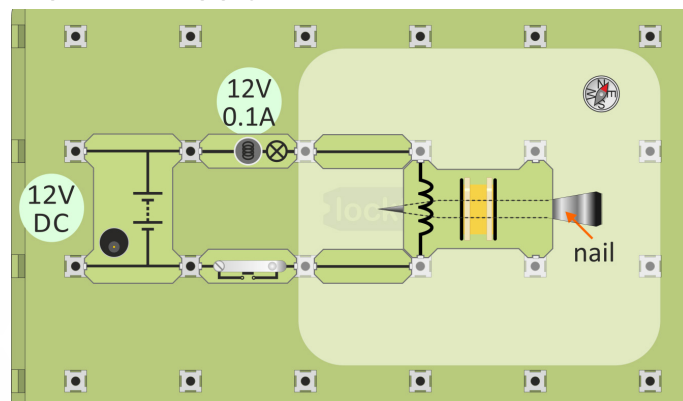
A free south pole, if it existed, would go in the other direction.

In practice, the needle of a plotting compass indicates a line of force, as shown.

You don't trip over contour lines when walking up a hill! 'Contour lines', 'isobars' and 'lines of force' don't exist! They are just tools used to create different kinds of map.

Over to you

1. Build the layout shown. It is similar to that used in the activity on page 18.
2. Connect the 12V DC power supply and switch on.

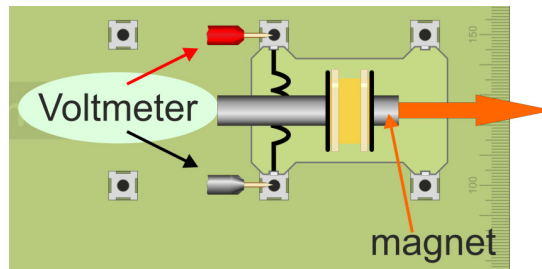


3. Move the plotting compass around the area shown in the lighter shade. As you do so, visualise the 'lines of force' around the electromagnet.
4. Sketch a magnetic field pattern for the electromagnet on the template given in the Student Handbook.

Electromagnetism - 2

Over to you

1. Build the layout shown.
2. To begin with, the cylindrical magnet sits inside the coil, as shown.
3. Now, withdraw the magnet from the coil as quickly as possible, watching the voltmeter as you do so.
4. The effect you are looking for is very short-lived. A digital voltmeter samples its input at intervals and so may have missed it - the reading stayed at zero. In that case, repeat the steps several times until you catch the resulting effect on the meter.



5. Next, turn the magnet the other way round and repeat the process.
6. Investigate the effect of speed of movement on the size of the voltage produced.

It can be shown that the voltage generated has :

- A **size** that depends on the speed of movement and the number of turns of wire in the coil;
- A **direction** that depends on the direction of motion.

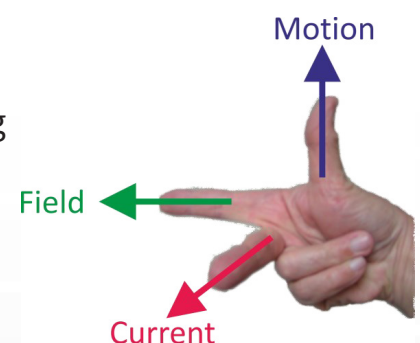
Fleming's Right-hand Rule (also known as the dynamo rule):

Fleming devised a second, equally painful gesture , in order to predict the direction of the generated current, this time using the **right-hand**.

Set the **F**ore finger in the direction of the magnetic **F**ield (from North pole to South pole,) and the **th**uMb in the direction of the **M**otion.

The **C**entre finger now points in the direction of the resulting **C**urrent.

This is illustrated in the diagram.

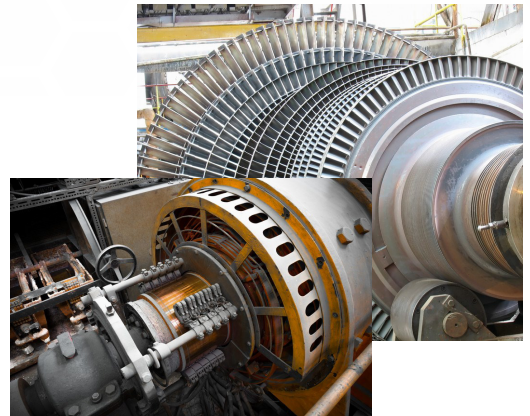


Generating Electricity - 1

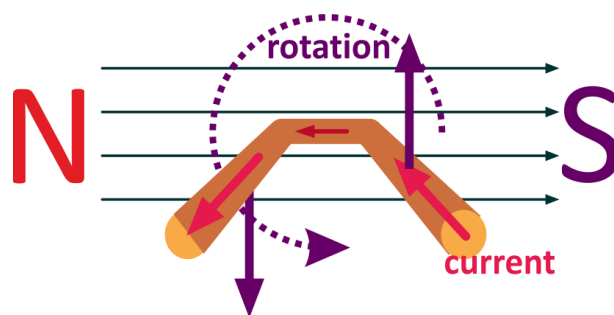
The requirements for generating electricity using electromagnetism are:

- A magnetic field;
- A conductor;
- Relative motion between them.

Most generators rotate, often driven by turbines like the one shown, operated by high-pressure steam from coal-fired, gas-fired or nuclear power stations.



The principle is illustrated by looking at a single coil of wire rotating in a magnetic field. The diagram shows this coil, cutaway and disappearing into the sheet of paper. There is a magnetic field from left to right.



The coil is driven by a turbine or similar device. As one side of the coil moves up, the other side moves down, both in the same magnetic field. The currents induced in the two sides flow in opposite directions, one into the paper, the other out of it. In other words, the induced current flows around the coil.

Challenge: Apply Fleming's Right-hand rule to check the direction of current flow in the two arms of the coil.

Reverse the direction of rotation and you reverse the direction of the current flow.

Electrical connection to the rotating coil can be made in two ways using:

- A commutator - produces a DC output;
- Slip-rings - gives an AC output.

Challenge: Find out the difference between commutators and slip-rings.

Write an explanation in the Student Handbook.

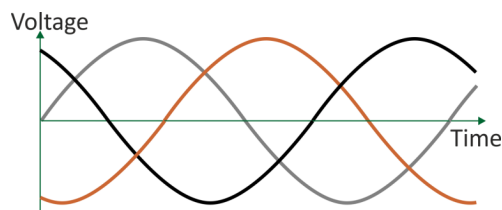
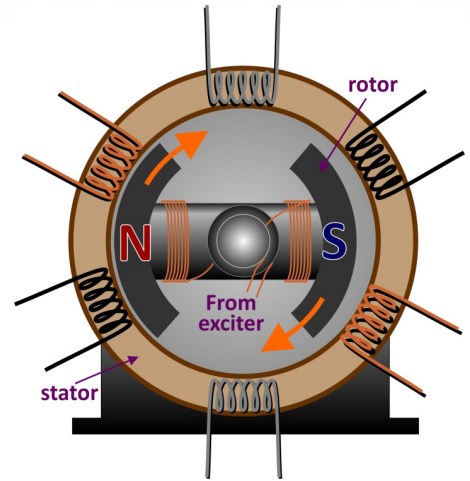
Generating Electricity - 2

Most electricity is generated by a rotating magnetic field inside a stator containing coils of wire.

The magnetic field could be produced by rotating a magnet. However, more often it is produced by a rotating electromagnet, using a small DC current from an 'exciter'.

In modern systems, this current is drawn from the main generator output, rectified to DC and fed to the electromagnet via 'slip rings'.

The diagram shows the basics of a three-phase alternator, which generates three AC outputs, out of step with each other. The graph shows this output.



Over to you

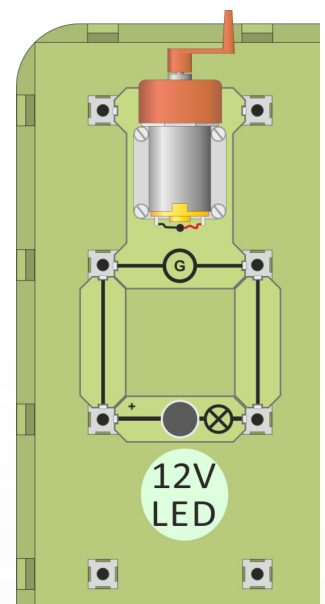
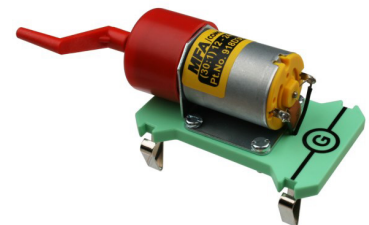
Time to generate some electricity!

The hardware - a hand-cranked generator:

1. Build the layout shown opposite. Make sure that you use a 12V LED bulb carrier! (Look for the '+' sign at one end!)
2. **GENTLY**, turn the handle on the generator. The LED bulb should light. If it does not, turn it in the opposite direction. (The generator outputs DC. Some LED bulbs are polarised—they need connecting the right way round..)
3. Replace the LED carrier with a MES lamp holder containing a 12V 0.1A filament lamp. Turn the handle again.

Which is easier to turn?

(This relates to the efficiency of the filament lamp and LED, discussed earlier.)



Transformers - 1

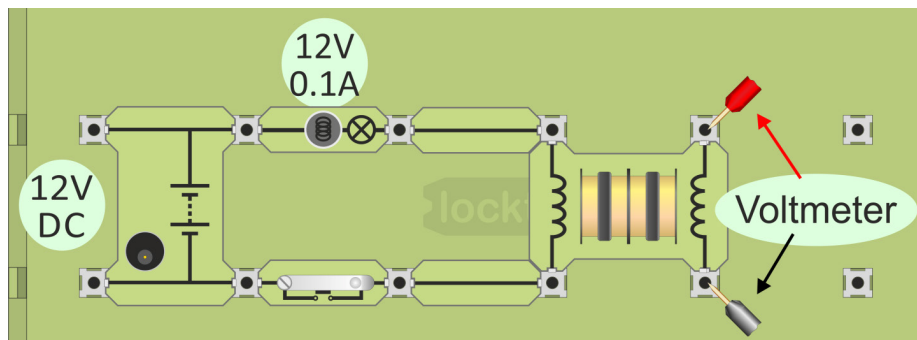
Generating electricity as AC allows us to use of transformers to change the 'format' of the electricity supply. They can change from high to low voltage, or the reverse, without losing much energy as heat in the process.

Moving a magnet into a coil of wire generates electricity. This activity starts by replacing the magnet with an electromagnet, using a transformer carrier. This holds two separate coils of wire, with no electrical connection between them. A rod made from ferrite a magnetic material can be slid into the coils.



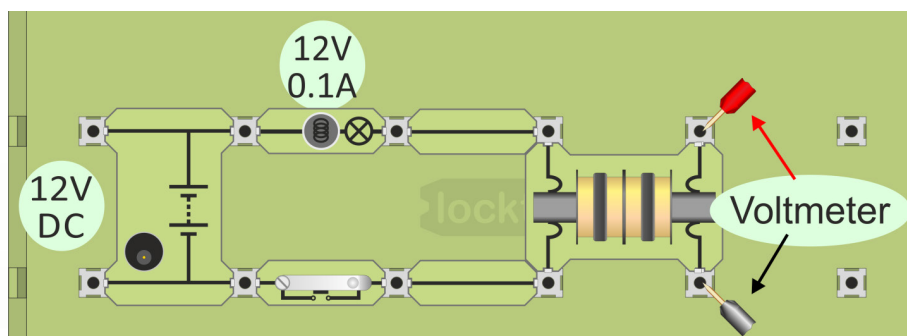
Over to you

1. Build the first layout shown below.



The ferrite rod is not used yet. The left-hand coil is the electromagnet. A voltmeter, connected to the other coil detects any electricity generated in it. If using a multimeter for this, set it on its most sensitive DC range. The 12V lamp shows when a current is present and limits it to protect the coil.

2. At the moment, the voltmeter reads zero. Press and hold down the switch, watching the meter as you do so. You should see a brief pulse of electricity.
3. Now place the ferrite rod in the centre of the coils.



4. Repeat the procedure. Does this generate a bigger voltage?

Transformers - 2

The requirements for generating electricity using electromagnetism are:

- A magnetic field;
- A conductor;
- Relative motion between them.

In the last activity, we succeeded in generating electricity but only in short pulses.

We had a magnetic field and a conductor, but where was the relative motion?

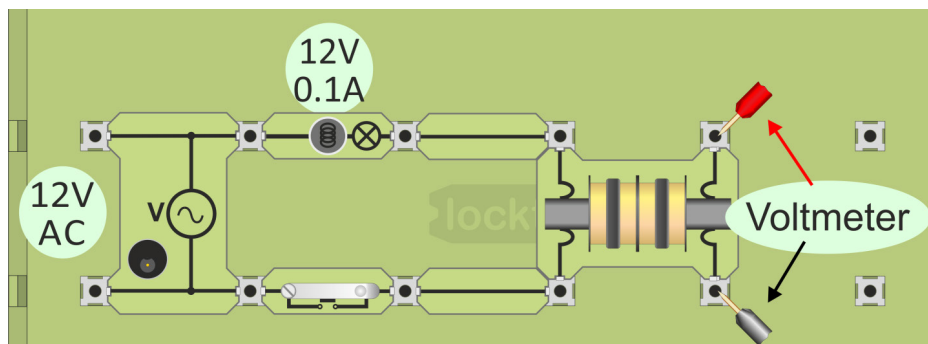
This was provided by the switch. When it was off, there was no magnetic field.

When turned on, a magnetic field built in the coil. It moved through the turns of wire as it built up.

Now we aim to generate a continuous electricity supply, by connecting the electromagnet to AC.

Over to you

1. Build the layout shown below. It is the same as in the previous activity except that it uses an AC power supply. The voltmeter must now be capable of measuring AC. If you are using a multimeter, set it on the most sensitive AC voltage range.



2. As before, press and hold down the switch, watching the meter as you do so. This time, there should be a steady reading on the voltmeter for as long as the switch is closed.

Although we cannot see it, the magnetic field is building up and collapsing in step with the AC current, providing the motion that we need to generate electricity.

The role of the ferrite rod is to intensify the magnetic field in the second coil. Notice that the efficiency of this transformer is very low. The left hand coil, called the primary, is supplied with 12V AC. However, the output from the other coil, called the secondary, is much smaller.

3. Answer the questions in the Student Handbook.

Step-Down Transformer

Let's refine the transformer a little!

The strength of the magnetic field in the primary depends on factors like:

- The number of turns in the primary coil,
- The current flowing through it and so the voltage applied to it.



The voltage generated in the secondary coil depends on factors like:

- The strength of the magnetic field generated by the primary;
- The number of turns of wire in the secondary coil;
- How effectively the magnetic field of the primary links with it.

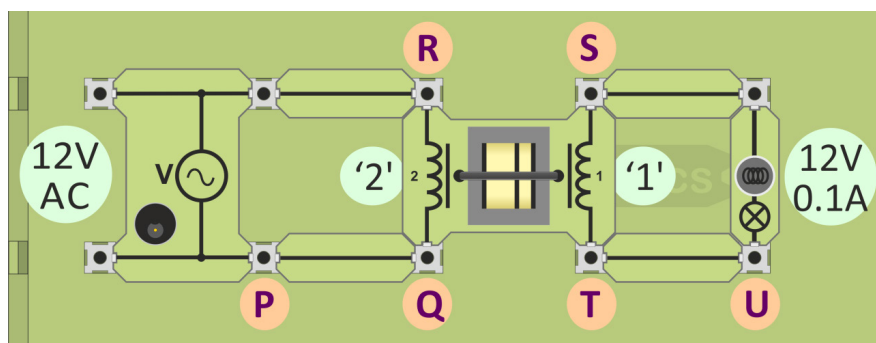
In a step-down transformer, the primary coil, the one supplied with AC power, has more turns of wire than the secondary, the one that generates the output voltage.

In this activity, we use a commercial, but not very efficient, transformer with a turns ratio of 2:1, meaning that one coil has twice as many turns as the other. The primary will be the '2' coil, and the secondary the '1' coil.



Over to you

1. Build the layout shown below.



2. Connect a multimeter, set to measure AC voltage, to points **Q and R** to measure the voltage, V_p , across the primary (the '2') coil.
3. Connect it across points **S and T** to measure the voltage, V_s , across the secondary.
4. Change the multimeter range and connections to read AC currents.
5. Remove the connecting link between points **P and Q** and replace it with the multimeter probes to measure the primary current I_p . Then replace the link.
6. Remove the connecting link between points **T and U** and use the multimeter to measure the secondary current I_s .
7. Record all readings in the table in the Student Handbook.

Step-Up Transformer

In a step-up transformer, the primary coil has fewer turns than the secondary.

The National Grid uses both step-up and step-down transformers. At a power station, the output voltage is stepped up (typically to 11kV or higher). By doing so, a smaller current needed to transmit a given amount of electrical power and so less energy is wasted in the transmission cables. At the substation, a step-down transformer then lowers the voltage, typically to 440V and 240 V.

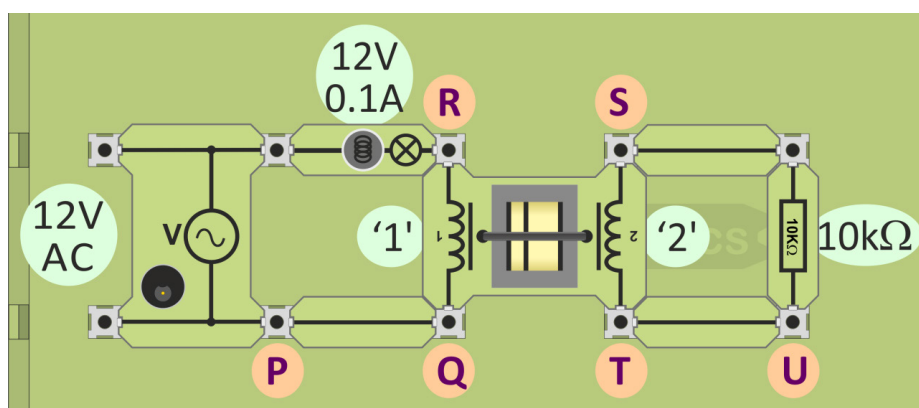
In the home, step-down transformers are common, used as battery eliminators for electronic devices such as computers, televisions, mobile phones (and Matrix Locktronics circuits!) The step-down transformer outputs an AC voltage which then needs rectification to DC and smoothing before being used as a power supply.



In this activity we will use the same transformer connected the other way round, so that the primary will be the '2' coil, and the secondary the '1' coil.

Over to you

1. Build the layout shown below. It is similar to that used in the previous activity except that the 12V lamp is used in the primary circuit to reduce the voltage applied to the primary coil. A 10kΩ resistor is used as the load.



2. Connect a multimeter to points **Q** and **R** to measure the primary voltage, V_p .
3. Connect it across points **S** and **T** to measure the secondary voltage, V_s .
4. Change to an AC current range. Remove the connecting link between **P** and **Q** and use the multimeter to measure the primary current I_p . Then replace the link.
5. Remove the link between **T** and **U** and measure the secondary current I_s .
6. Record all readings in the table in the Student Handbook.

Transformer Relationships

The first version of the transformer carrier showed the transformer principles, but was very inefficient.

The second version, the commercial transformer, was a big improvement - two coils sitting side by side, as in the prototype, but now linked by a more elaborate core, which threads through the centre of the coils, and wraps around the outside too. The result is a much more effective magnetic field linkage between the coils.



What the results show:

- The ratio $V_P : V_S$ for both types of transformer is related to the turns ratio.
- The transformer relation says that for an ideal transformer:

$$V_P / V_S = N_P / N_S$$

where N_P is the number of turns on the primary coil;
and N_S is the number of turns on the secondary coil.

In general terms:

- A step-up transformer 'steps up' the voltage (here, virtually doubles it,) but 'steps down' the current - the primary current is much greater than the secondary.
- A step-down transformer 'steps down' the voltage, but it delivers the same secondary current as before for a much smaller primary current.
- For an ideal transformer (100% efficient):

$$P_{IN} = P_S$$

where P_{IN} is the power delivered to the primary,
and P_{OUT} is the power delivered by the secondary;

$$\text{and } I_S / I_P = N_P / N_S$$

Verdict:

There is nothing magical about the transformer. It changes the 'format' of the electricity supply, but at a cost in terms of energy wasted.



STUDENT HANDOUT



Student Handout

Page 4 - Circuit training:

Complete the table, which compares Locktronics components with those used in domestic electricity installations.

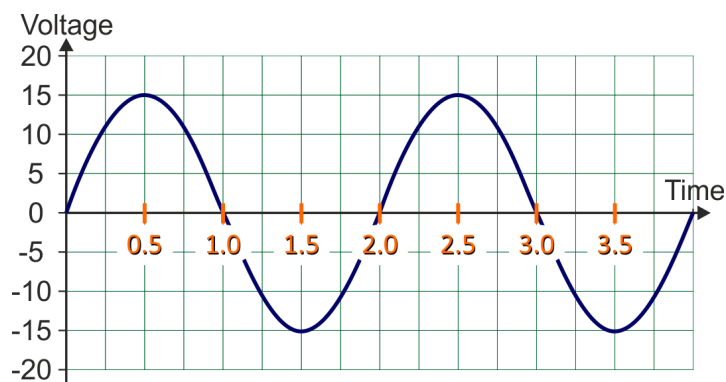
Locktronics	Domestic electricity
	Like a domestic bulb, but designed for lower voltage and current.
Connecting links	
	The consumer unit - where the domestic circuits connect to the National Grid.

Page 8 - AC vs DC - 2:

The 12V AC power supply has a rms voltage of

Page 9 - Measuring AC:

Here is the voltage / time graph for an AC signal.



Complete the following statements about it:

Peak voltage = V

Peak-to-peak voltage = V

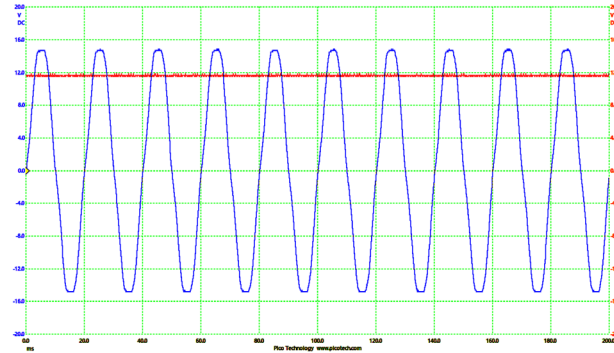
Periodic time = s

Frequency = Hz

Student Handout

Page 10 - AC and DC again:

The graph compares the voltage / time behaviour of the AC and DC power supplies.



Label the r.m.s. value of the AC signal.

In the UK, the AC mains electricity supply has a r.m.s. voltage of 140V.

What is the peak voltage of this supply?

Complete the table to show peak and corresponding r.m.s.voltages.

	Peak voltage	R.m.s voltage
A	10V	
B		14V
C	18V	
D		28V

Which example, **A, B, C or D**, has a peak-to-peak voltage of 40V?

Page 11 - Conductors and Insulators:

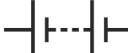
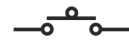
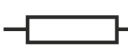
Materials that conduct	Materials that do not conduct

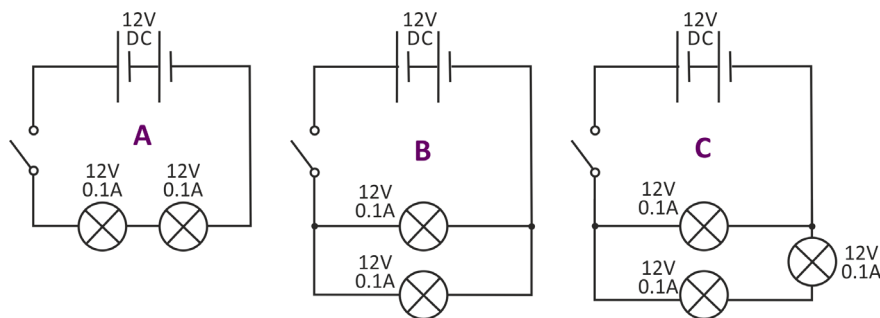
What do you notice about the substances that are metals in this list?

Student Handout

Page 12 - Circuit diagrams:

Common circuit symbols:

					
AC power supply	Battery or DC power supply	Toggle switch	Push switch	Lamp	Resistor



Circuit draws the biggest current from the power supply.

Page 13 - Current path - 1:

Power supply:

- Drives current around the circuit;
- Has two terminals (connection points) one 'positive' the other 'negative';
- Current flows from positive to negative.

Connecting links: allow current to flow freely.

Circuit: continuous length of conductor joining the power supply terminals.

What is the effect of:

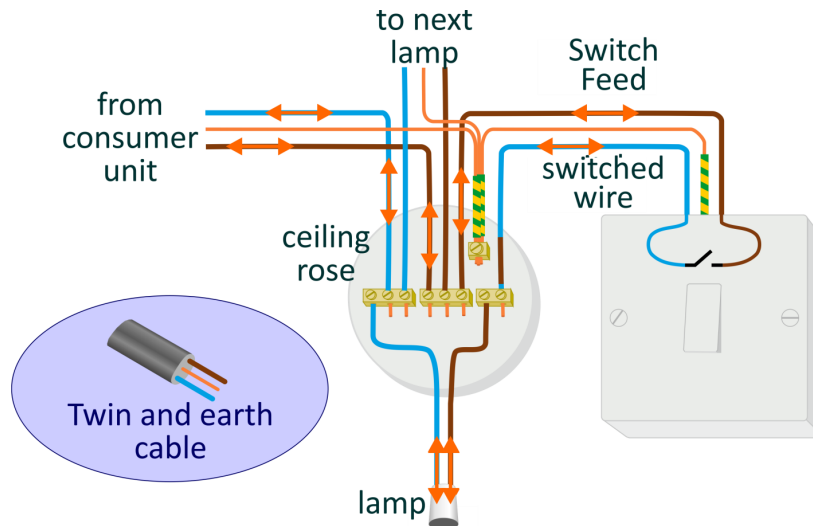
- Changing the shape of the circuit;

- Changing from an AC to a DC power supply?

Student Handout

Page 14 - Current path - 2:

The diagram shows how to wire up a pendant light to a ceiling rose and control it with a switch.



Page 16 - Heating effects:

When an electric current flows, its energy is converted to heat.

In a filament lamp, the filament, usually made from tungsten, is heated to such a high temperature that it glows yellow-hot, giving out light. However, typically only ~5% of the electrical energy appears as light.

Lighting using LEDs (Light-Emitting Diodes) can be 10 times more efficient.

The reverse process takes place in a thermocouple. When its junction of different metals is heated, it generates a DC voltage. It is be used to measure temperature.

Page 18 - Magnetic effects:

An electric current is **ALWAYS** accompanied by a magnetic field.

The principal application of the magnetic effect of electricity is the electric motor, widely used in domestic appliances. Other applications of electromagnetism include:

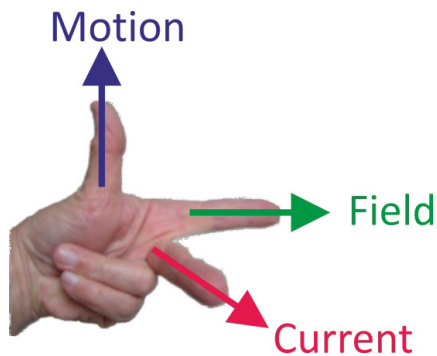
- Transformers - in power supplies, such as mobile phone chargers;
- Generators - used to power tools or as a stand-by in case of power cuts;
- Loudspeakers - in radios, televisions, computers and mobile phones;
- Circuit breakers - protection against current overload and overheating.

Student Handout

Page 20 - Motor effect - 2:

Fleming's Left-hand Rule:

John Ambrose Fleming devised a way to work out the direction a wire will move in (also known as the motor rule):



- Clamp your **left**-hand to the corner of an imaginary box, so that thumb, fore-finger and centre-finger are at right-angles to each other.
- Line up the **Fore**-finger so that it points along the magnetic **Field** (from North pole to South pole,)

- Line up the **Centre**-finger with the direction of the **Current** (from positive battery terminal to negative.)
- The thu**M**b now points in the direction of the resulting **Motion**.

Page 22 - Chemical effects:

An electric current can create/be created by a chemical reaction.

An **electric current** is a flow of electrons, (tiny particles found in all atoms.) A **chemical reaction** involves electrons transferring between atoms.

Batteries illustrate the link between them. In a 'dry' battery, a chemical reaction generates a voltage which can drive an electric current. In rechargeable batteries, this process can be reversed - a current flowing the 'wrong' way can reverse the chemical reaction, storing up energy for later use.

In electroplating, an electric current through a chemical solution deposits a metal on one of the electrodes in order to protect it from corrosion or to improve its appearance.

Student Handout

Page 23 - Connect in series:

In a series connection:

- Devices are connected one after the other in a line;
- There are no alternative routes - no branching;
- Only one path exists for the current through the connection.

What do you notice about the brightness of the **three** lamps connected in series?

What happens if you unscrew one of the bulbs?

How does the brightness of the **two** lamps compare with the previous circuit?

What does this show about the current flowing in this circuit?

Does unscrewing a bulb have the same effect as in the previous circuit?

Page 24 - Connect in parallel:

In a parallel connection:

- Devices have their own separate 'branch-line';
- The ends of a device connect to corresponding ends of all other devices;
- Each device has its own path for the current through the connection.

What do you notice about the brightness of the three lamps?

Student Handout

How does their brightness compare to the three lamps connected in series?

What happens if you unscrew one of the bulbs?

Page 25 - Series / parallel - 1:

What do you notice about the brightness of the three lamps?

What happens when you unscrew bulb 'P'?

What happens when you unscrew bulb 'Q'?

Explain the differences:

Student Handout

Page 26 - Series / parallel - 2:

What do you notice about the brightness of the three lamps?

What happens when you unscrew bulb 'P'?

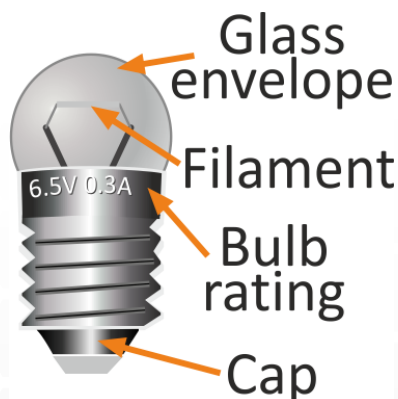
What happens when you unscrew bulb 'Q'?

Explain the differences:

Page 27 - MES bulbs:

MES bulbs are mass-produced to reduce cost. As a result, they are not quite identical. They may have different filament lengths or diameters or experience different heat losses.

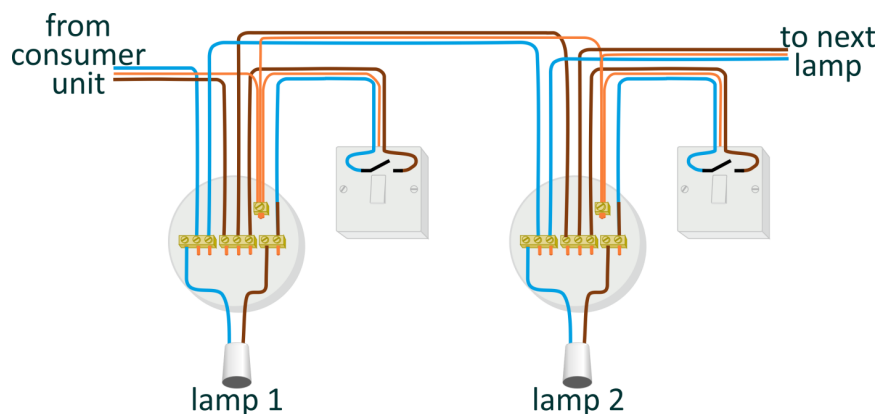
Given identical conditions, they will not give the same brightness.



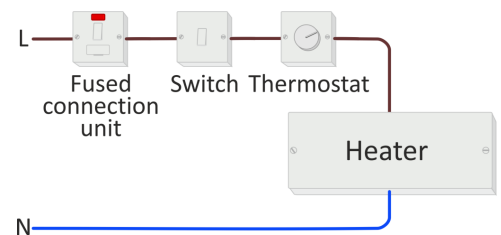
Student Handout

Page 28- Serial / parallel applications:

In domestic lighting, it is important that lamps operate independently especially when one bulb 'blows'. Hence they are connected in **parallel**, as the diagram shows.



Controls, like fuses, switches and thermostats, must be able to 'break' the circuit and stop current flow to the load device, such as a heater. As a result, they are connected in **series** with the load.

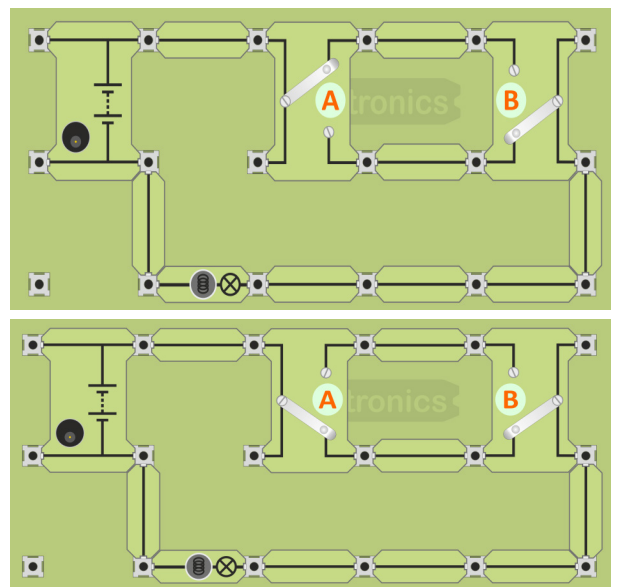


Page 29 - Staircase circuit - 1:

With switch A and switch B in the positions shown, is the bulb lit?

Switch A is moved to the other position, as the next diagram shows.

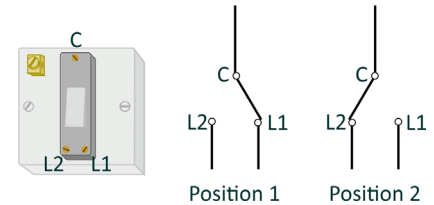
Draw the new current path on the diagram.



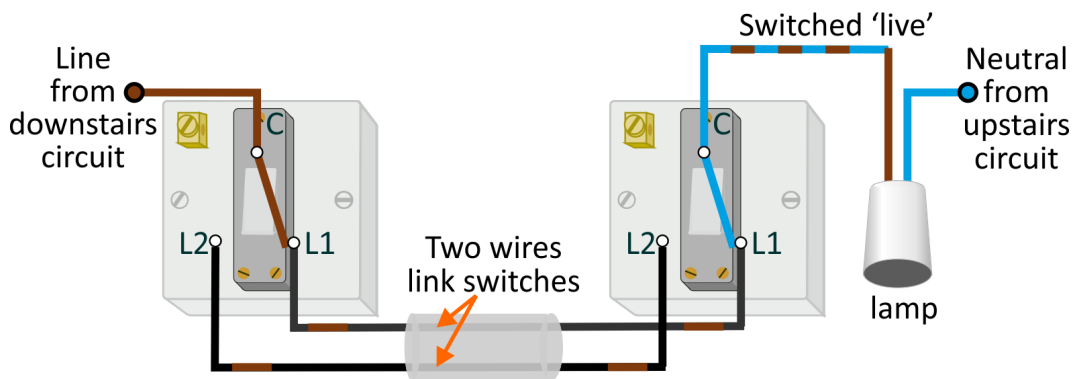
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Page 30 - Staircase circuit - 2:

A changeover switch, also called a SPDT (single-pole-single-throw) switch, has three terminals: **C** (for Common), **L1** and **L2**. Operating it connects **C** to either **L1** or **L2**.



The '2-wire control' system is shown in the next diagram.



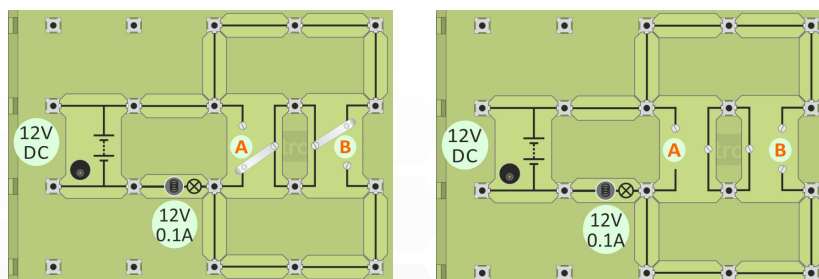
It works **but** there may be safety issues!

- The circuit may take its line connection from one circuit (e.g. downstairs) and its neutral from another (e.g. upstairs.) An electrician working on it might switch off the upstairs lighting circuit and think that the system is safe to work on. However, parts may still be 'live' because the downstairs circuit is still switched on.
- An RCD monitoring the downstairs circuit may trip unnecessarily because line and neutral currents downstairs may be different. Similarly, an RCD looking after the upstairs circuit may be unreliable.

Page 31 - Staircase circuit - 3:

The left-hand diagram shows one set of switch positions which cause the lamp to light. On the diagram, draw the path that the current takes around this circuit.

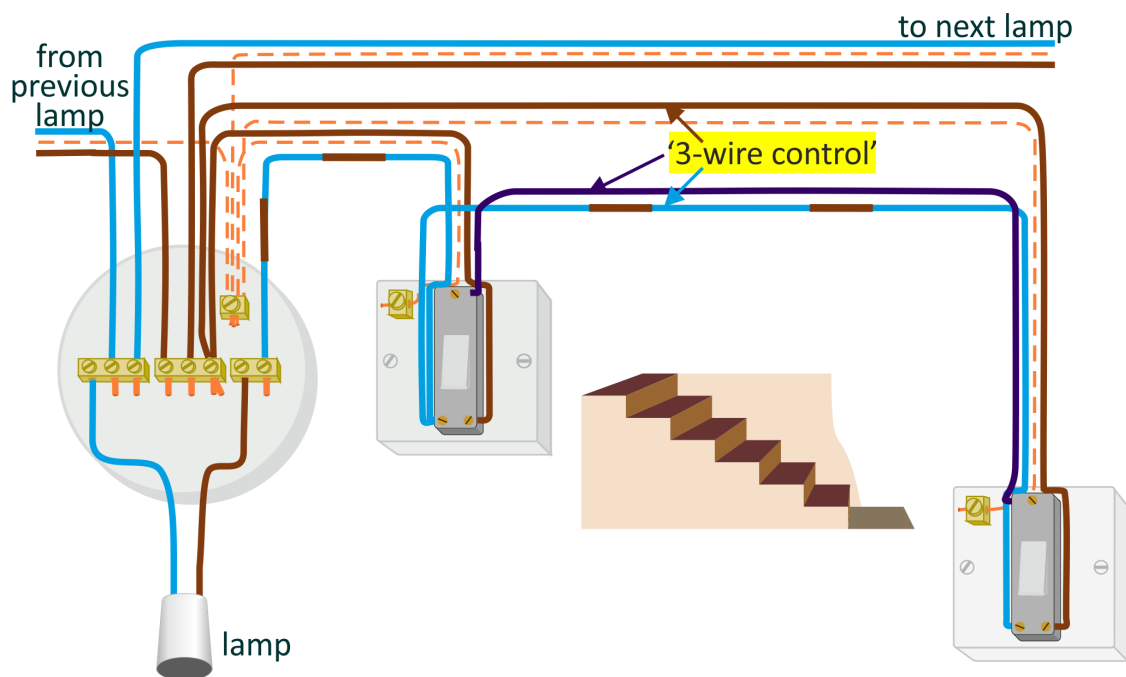
On the right-hand diagram, complete the images of the switches to show another set of switch positions that would cause the lamp to light.



Student Handout

Page 32 - Staircase circuit - 4:

The next diagram shows a practical form of the '3-wire control' system, so-called because three wires link the two switches together.

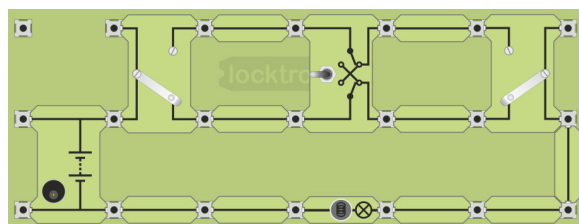


Points to note:

- L1 terminals are connected together and to the incoming 'line' connection;
- L2 terminals connected to each other and to the 'switched wire';
- C terminals are connected .

Page 33- 3-way control - 1:

With a third switch - an intermediate switch, (also called 'reversing' or 'DPDT', (double-pole-double-throw,)) the lamp can be controlled by all three switches. With the switches in the positions shown, and the intermediate switch making the connections shown on the carrier, draw the current path on the diagram.



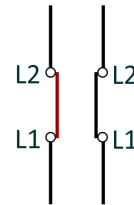
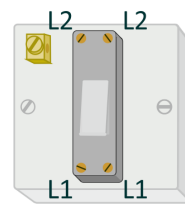
This is another '2-wire control system' and suffers from the same potential problems as the 2-way (staircase) system.

Student Handout

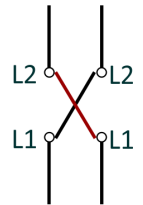
Page 34 - 3-way control - 2:

An intermediate switch has four terminals, two labelled L1 and two labelled L2.

Operating it makes the connections shown.

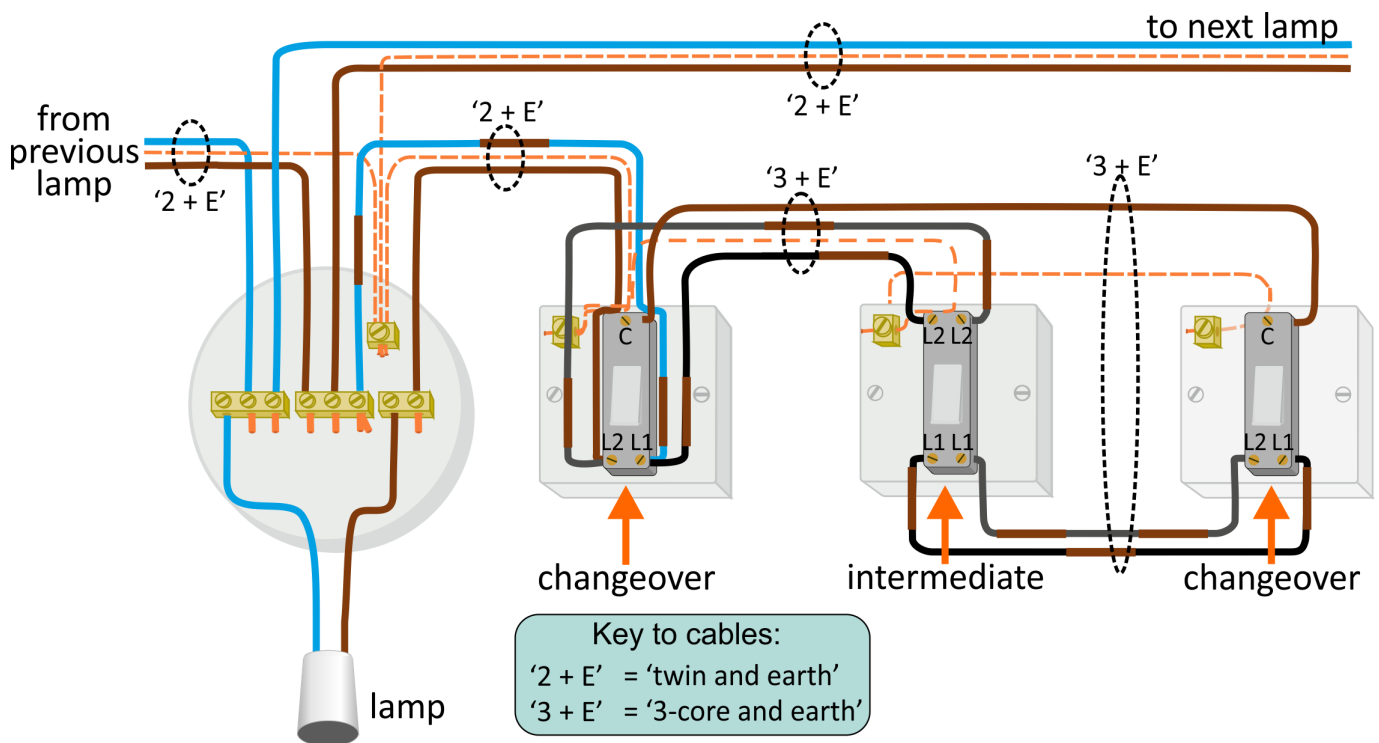


Position 1



Position 2

The three-way switching circuit is shown below:



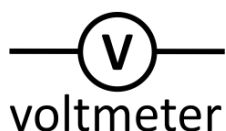
Trace through the connections and compare it with the '2-wire control' system at the top of the page.

Student Handout

Page 35 - Measuring voltage - 1:

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.



- circuit symbol for a voltmeter .

When using a multimeter, **before you switch it on:**

- Take care to plug the probes into the correct sockets;
- Select the correct range.

Using a multimeter to measure voltage:

- Plug a wire into the black 'COM' socket and the second one into the red 'V' socket.
- Select the 20V DC range, (or a range higher than the reading you expect.)
- Plug the other ends of 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!
- Now select a lower range if that is appropriate.



Page 36 - Measuring voltage - 2:

Voltage between points	Reading
1 and 2 (Lamp 1)	
2 and 3 (Lamp 2)	
3 and 4 (Lamp 3)	
5 and 6 (Power supply)	

What do you notice about the sum of the voltages across the three lamps?

Student Handout

Page 37 - Measuring voltage - 3:

Voltage between points	Reading
1 and 2 (Lamp 1)	
3 and 4 (Lamp 2)	
5 and 6 (Lamp 3)	
7 and 8 (Power supply)	

Comment on these results:

Page 38- Measuring voltage - 4:

Voltage between points	Reading
1 and 2 (Lamp 1)	
3 and 4 (Lamp 2)	
4 and 5 (Lamp 3)	
6 and 7 (Power supply)	

Comment on these results:

Student Handout

Page 39 - Measuring current - 1

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.



ammeter

- circuit symbol for an ammeter.

Using a multimeter to measure current:

- Plug a wire into the black '**COM**' socket and a second into the red '**mA**' socket.
- Select the 200mA DC range, (or a range higher than the reading you expect.)
- Break the circuit where you want to measure the current, by removing a link or component and plug the two multimeter wires in its place.
- Switch on the multimeter when you are ready to take a reading.
- Now select a lower range if that is appropriate.
- Beware - 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.

Page 40 - Measuring current - 2:

Current at point:	Reading
P	
Q	
R	
S	

Comment on these results:

Student Handout

Page 41 - Measuring current - 3:

Current at point:	Reading
P	
Q	
R	
S	

Comment on these results:

Estimate of the current at point T:

How did you obtain this estimate?

Page 42 - Measuring current - 4:

Current at point:	Reading
P	
Q	
R	
S	
T	

Why are the readings at points 'P' and 'T' equal?

Student Handout

Why are the readings at points 'Q' and 'S' equal?

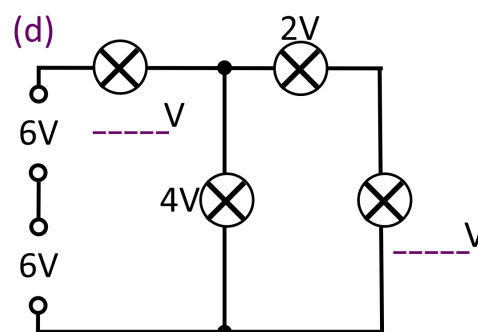
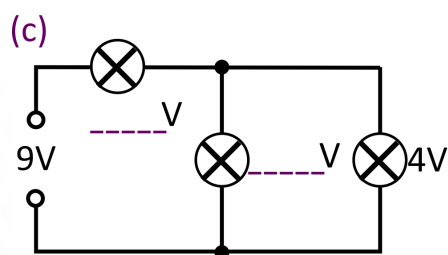
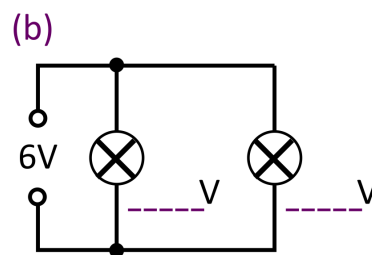
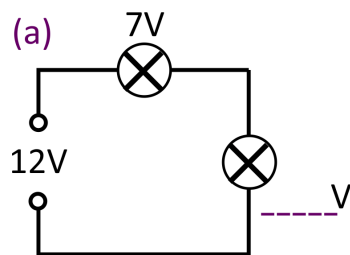
What does this imply for the brightness of the two bulbs between these points?

Which bulb is the brightest?

Page 43 - Kirchhoff's voltage law:

Here are the circuit diagrams for four lighting circuits.

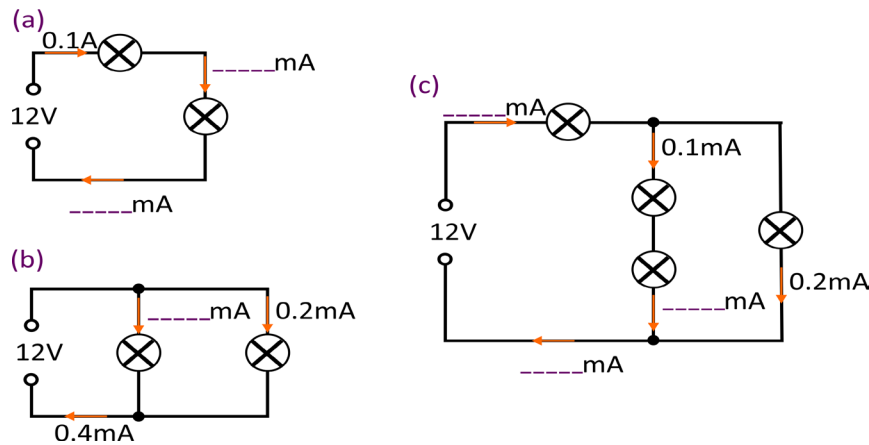
Use Kirchhoff's voltage law to fill in the missing voltages:



Student Handout

Page 44 - Kirchhoff's current law:

In the three lighting circuits shown below, some of the currents are given. Use Kirchhoff's current law to fill in the missing currents.



Page 45- Resistance - 1:

We control the flow of electricity using a **resistor**.

What effect does adding the resistor have on the brightness of the bulb?

What does this tell you about the effect of adding the resistor on the current?

Page 47- Ohm's law - 1:

Ohm's law:

- Relates the current, I , through a resistor, R , to the voltage, V , across it;
- Results in the formula: $V = I \times R$ (or $I = V / R$, or $R = V / I$) using either volts / amps / ohms or volts / milliamps / kilohms;
- Applies only when the temperature of the conductor stays steady.

Component	Power supply voltage	Voltage across component	Current in mA	Resistance in kΩ
1kΩ resistor	12V			
	6V			
12V 0.1A bulb	12V			
	6V			

Write down the resistance of the 1kΩ resistor in ohms _____ Ω.

Student Handout

Page 48- Ohm's law - 2:

Combination of two lamps	Voltage across component	Current in mA	Resistance in k Ω
In series			
In parallel			

With the lamps **in series**, what is the voltage across each lamp?_____ V.

From the previous activity, what is the resistance of a bulb at this voltage? _____ Ω

Comment on the resistance of the series combination compared to this value.

With the lamps **in parallel**, what is the voltage across each lamp?_____ V.

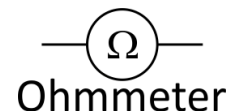
From the previous activity, what is the resistance of a bulb at this voltage? _____ Ω

Comment on the resistance of the parallel combination compared to this value.

Page 49 - Measuring resistance - 1:

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 (k Ω), by an ohmmeter.
(1 kilohm = 1 000 ohms.)



**When using a multimeter to measure resistance,
the component must be removed from the circuit first!**

Using a multimeter to measure resistance:

- Plug one wire into the black '**COM**' socket and the other into the red ' **Ω** ' socket.
- Turn the dial to select a resistance range, such as 200k Ω (or a range higher than the reading you are expecting.)
- Make sure that the component 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.
- Now select a lower range if that is appropriate.

Student Handout

Page 50 - Measuring resistance - 2:

Resistance of Locktronics resistor carrier = _____ V.

Resistance of 'home-made' resistor = _____ Ω

Resistance of 12V 0.1A bulb at room temperature = _____ Ω

What happens to the resistance of the bulb filament as the temperature rises?

Page 51 - Resistivity - 1:

The resistance of a wire depends on three factors:

- Its length;
- Cross-sectional area;
- The resistivity of the material it is made from.

It is measured in units called Ω m (ohm metres).

Page 52 - Resistivity - 2:

Complete the table by adding your resistance measurements:

Sample	Material	Length L in m	Cross-section A in mm ²	Resistance R in Ω
A	Nichrome	0.5	0.075	
B	Nichrome	0.25	0.075	
C	Nichrome	0.5	0.21	
D	Constantan	0.5	0.075	

Comparing A and B :

Resistance _____ (increases / stays the same / decreases) as length increases.

Comparing A and C :

Resistance _____ (increases / stays the same / decreases) as cross-section increases.

Comparing A and D :

Resistance _____ (increases / stays the same / decreases) as resistivity increases.

Student Handout

Page 53 - Resistivity - 3:

Voltage, V , across nichrome sample = _____ V

Current, I , through nichrome sample = _____ mA

Resistance of nichrome sample = V / I = _____ $k\Omega$

Resistivity $\rho = \frac{R \times A}{L}$ where R is the resistance of the sample.

Resistivity of nichrome = _____ Ωm

Voltage, V , across constantan sample = _____ V

Current, I , through constantan sample = _____ mA

Resistance of constantan sample = V / I = _____ $k\Omega$

Resistivity of constantan = _____ Ωm

Page 54 - Electrical safety:

Our bodies can sense electric currents as small as 1mA.

A current of 10 mA DC can cause muscle contractions which mean that the victim cannot release the electrified object.

The voltage required to deliver these currents depends on a number of factors including the electrical resistance of the human body.

This, in turn, depends on factors like:

- The presence of sweat on the skin;
- The hydration level of the body - 45 to 70% of the weight of the body is water;
- The body fat content;
- Where on the body the electrical contact occurs;
- Skin has a high resistance unless it has cuts or blisters;
- Current flowing from hand to foot experiences more resistance than current flowing from one finger to the next.

The resistance of the human body is typically between 1k Ω and 100k Ω .

Student Handout

Safety devices :

Fuses and circuit breakers:

Protect the appliance and the wiring connecting it, but **NOT** the user!

A fuse may happily pass a 10A current without 'blowing'.

A human body would not be happy with a current of 10A!

The RCD (residual current device):

Compares the current it supplies **to** the appliance with the current , which **flows** back from the appliance.

An imbalance might indicate a fault, such as an electric current flowing to earth through the user. The RCD 'trips', shutting off the electricity supply to the appliance and the user.

Page 55 - The fuse:

In a 'short-circuit', worn or damaged insulation allows wires to touch, large currents can flow, causing a lot of heat.



One solution is the fuse - a short length of wire with a low melting point, which acts as the weak point in the circuit. A large current flowing through it heats it so much that it melts, breaking the circuit and stopping the current before it causes damage.

In the UK, mains '13A' plugs contain cartridge fuses, with ratings of 3A, 5A and 13A.



Calculating fuse values:

Use the formula $P = I \times V$ (or $I = P / V$) to work out the normal appliance current, I . Then we choose a fuse value just greater than this.

Calculate the normal current and then choose the best fuse rating for the following:

Appliance	Power rating (W)	Normal current (A)	Fuse
Reading lamp	60		
Kettle	2000		
Fire	3000		
Vacuum Cleanser	1200		

Student Handout

Page 56 - The circuit breaker:

The circuit breaker switches off the current when it senses a fault.

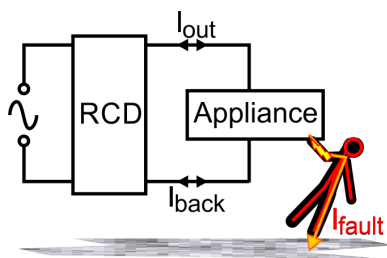
Like the fuse, it protects the appliance and the wiring connected to it.

However, a fuse must be re-wired or replaced before normal operation can resume. The mcb can be reset, usually by pressing a reset button or operating a switch.



Trip current for circuit breaker = _____ A

Page 57 - The RCD:



A faulty electrical appliance might give the user an electric shock, with a current, I_{fault} , flowing to earth through the user. The **RCD** compares the current (I_{out}) flowing **to** with that (I_{back}) returning **from** an appliance. If the difference ($I_{\text{out}} - I_{\text{back}}$) reaches a set value (typically 30mA), the RCD 'trips', shutting off the electricity supply.

The RCD 'trips' when the currents I_{out} and I_{back} differ by around 30mA or more. In this investigation, this comes from allowing some current to bypass the RCD. Explain how this imbalance is created:

The fault current which caused the RCD to trip = _____ mA

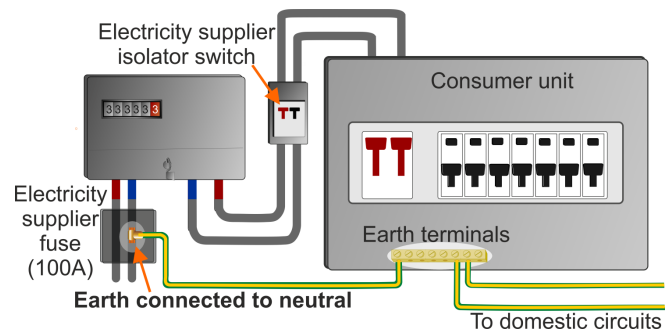
Student Handout

Page 58 - Earthing:

Sometimes, part of an electrical appliance, such as the outer metal casing, can become 'live' (wrongly connected to the mains electricity line cable.) Anyone touching this receives an electric shock which can cause serious injury or death.

'Earthing' is the procedure used to ensure that when part of an appliance becomes 'live', a large current flows causing a fuse to blow, or circuit-breaker or RCD to trip. In this way, the user is protected from electric shock. A cable, the 'earth' lead, connects vulnerable parts of the appliance to the earth, or ground.

The diagram shows one way to do this, called the TN-C-S system. All earth leads are connected to the incoming neutral lead, usually inside the electricity supplier's fuse, where the electricity supply cables enter the building.



Page 59 - The energymeter:

Energy:

- Comes from sources such as fossil fuels, the Sun, nuclear fission;
- Appears in many forms, heat, light, sound, electricity etc.;
- Is measured in units called joules (J) or kilowatt-hours (kW-h).

Power:

- Measures how much energy we use (or convert) each second;
- Is measured in watts (W), or kilowatts (kW). (1 kilowatt = 1 000 watts.)

For example:

- A 100W lamp is much brighter than a 40W lamp - it converts more electrical energy into light each second;
- A 3kW heater generates three times as much heat as a 1kW heater.

Student Handout

Page 60 - Measuring power:

Power consumed by one lamp = _____

Power consumed by two lamps in parallel = _____

Power consumed by two lamps in series = _____

Comment on these results:

Page 61 - Energy and power:

To calculate electrical power, use the formula:

$$\text{Alternatively: } P = I \times V \quad (\text{i.e. power = current x voltage.})$$
$$I = P / V \text{ or } V = P / I$$

Example:

Calculate the power rating of a bulb taking a current of 0.25A from the 240V mains.

$$\text{Power} = \text{current} \times \text{voltage} = 0.25 \times 240 = 60\text{W}.$$

Use this formula to complete the following table:

	Power	Voltage	Current
A		250V	4A
B	750W	250V	
C	48W		4A
D		12V	200mA

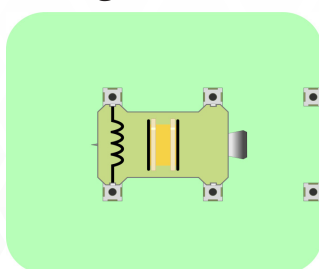
Page 62 - Electromagnetism - 1:

We map magnetic fields using 'lines of force', also called 'flux lines'. The magnetic force is strongest where they are packed most tightly.

A line of force is the path that a free north pole would follow. A free south pole would go in the opposite direction.

In reality, a **single** magnetic pole, whether 'north' or 'south' cannot exist alone. In practice, a plotting compass needle points along a line of force. 'Lines of force' don't exist either - they are just tools used to illustrate features in a magnetic field.

Use the your results to sketch the magnetic field around the electromagnet.



Student Handout

Page 63- Electromagnetism - 2:

When a magnetic field moves across a conductor, it generates a voltage.

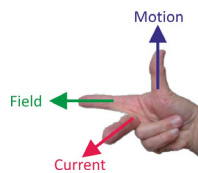
It can be shown that this voltage:

- Has a **size** that depends on the speed of movement and the number of turns of wire in the coil;
- A **direction** that depends on the direction of motion.

Fleming's Right-hand Rule (also known as the dynamo rule):

Predicts the generated current direction, using the **right**-hand to produce the gesture shown:

With the **F**ore finger in the direction of the magnetic **F**ield (i.e. North pole to South pole,) and the **th**u**M**b in the direction of the **M**otion, the **C**entre finger points in the direction of the resulting **C**urrent.

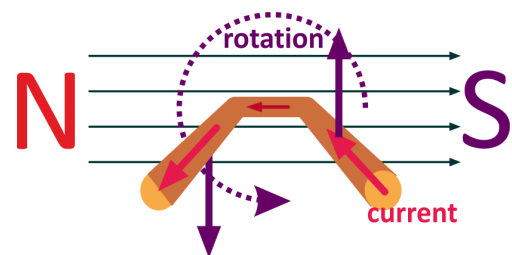


Page 64- Generating electricity - 1:

The requirements for generating electricity using electromagnetism are:

- A magnetic field;
- A conductor;
- Relative motion between them.

The diagram represents a single coil of wire, rotating in a magnetic field. As one side moves up, the other side moves down, but both in the same magnetic field.



The currents induced in the two sides flow in opposite directions, one into the paper, the other out of it. In other words, the induced current flows around the coil. Apply Fleming's Right-hand rule to check the current direction in the two sides of the coil.

Electrical connection to the rotating coil can be made in two ways using:

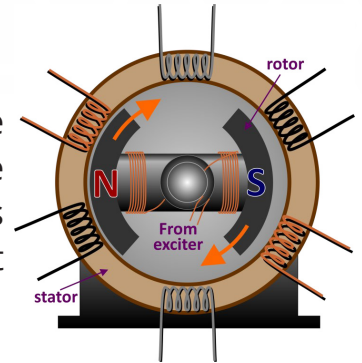
- A commutator to produce a DC output;
- Slip-rings to give an AC output.

Explain the difference in the construction of slip-rings and commutators.

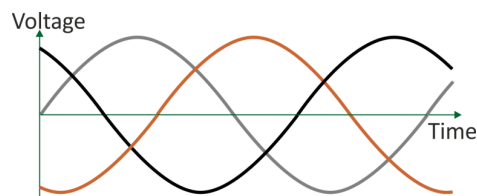
Student Handout

Page 65- Generating electricity - 2:

Most electricity is generated by a rotating magnetic field inside a stator containing coils of wire. This magnetic field could be produced by rotating a magnet. However, more often it is produced by a rotating electromagnet, using a small DC current from an 'exciter'.



The diagram shows the basics of a three-phase alternator, which generates three AC outputs, out of step with each other, as the graph shows.



Page 66 - Transformer - 1:

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

Page 67 - Transformer - 2:

In the primary coil (electromagnet), the magnetic field builds up and collapses in step with the AC current. This provides the motion needed to generate electricity in the other coil, called the secondary.

What is 'ferrite'? _____

What is the role of the ferrite rod in this activity?

Is the voltage generated in the secondary AC or DC? _____

Student Handout

Page 68 - Step-down transformer:

The strength of the magnetic field in the primary depends on factors like:

- The number of turns in the primary coil,
- The current flowing through it and so the voltage applied to it.

The voltage generated in the secondary coil depends on factors like:

- The strength of the magnetic field generated by the primary;
- The number of turns of wire in the secondary coil;
- How effectively the magnetic field of the primary links with it.

In a step-down transformer, the primary coil, the one supplied with AC power, has more turns of wire than the secondary, the one that generates the output voltage.

Record your measurements in the following table:

Use them to answer these questions:

What is 'stepped-down' in this transformer? _____

What is 'stepped-up' in this transformer? _____

Step-down results	
V_p	
V_s	
I_p	
I_s	

Use the formula $P_{IN} = V_p \times I_p$ to calculate the power supplied **to** the transformer:

$P_{IN} =$ _____

Use the formula $P_{OUT} = V_s \times I_s$ to calculate the power supplied **by** the transformer:

$P_{IN} =$ _____

Does the transformer step-up power? _____

Student Handout

Page 69 - Step-up transformer:

In a step-up transformer, the primary coil has fewer turns than the secondary.

The National Grid uses both step-up and step-down transformers. At a power station, the output voltage is stepped up (typically to 11kV or higher). By doing so, a smaller current needed to transmit a given amount of electrical power and so less energy is wasted in the transmission cables. At the substation, a step-down transformer then lowers the voltage, typically to 440V and 240 V.

In the home, step-down transformers are common, used as battery eliminators for electronic devices such as computers, televisions, mobile phones (and for Matrix Locktronics circuits!) The step-down transformer outputs an AC voltage which then needs rectification to DC and smoothing before being used as a power supply.

Record your measurements in the following table:

Use them to answer these questions:

What is 'stepped-up' in this transformer? _____

What is 'stepped-down' in this transformer? _____

Step-up results	
V_P	
V_S	
I_P	
I_S	

Use the formula $P_{IN} = V_P \times I_P$ to calculate the power supplied **to** the transformer:

$P_{IN} =$ _____

Use the formula $P_{OUT} = V_S \times I_S$ to calculate the power supplied **by** the transformer:

$P_{IN} =$ _____

Does the transformer step-up power? _____

You should find that neither type of transformer increases power. That would amount to creating energy from nothing, which the laws of physics do not allow! They change the format from high-voltage-low-current to low-voltage-high-current, or vice-versa, to suit the application.

Student Handout

Page 70 - Transformer relations:

The commercial transformer was a big improvement over the first transformer.

The two coils sitting side by side are linked by a more elaborate core, which threads through the centre of the coils, and wraps around the outside too.

This results in a much more effective magnetic field linkage between the coils, between the secondary coil, and the magnetic field generated in the primary.

What the results show:

- The ratio $V_p : V_s$ for both types of transformer is related to the turns ratio.
- The transformer relation says that for an ideal transformer:

$$V_p / V_s = N_p / N_s$$

where N_p is the number of turns on the primary coil;
and N_s is the number of turns on the secondary coil.

In general terms:

- A step-up transformer 'steps up' the voltage (here, virtually doubles it,) but 'steps down' the current - the primary current is much greater than the secondary.
- A step-down transformer 'steps down' the voltage, but it delivers the same secondary current as before for a much smaller primary current.
- For an ideal transformer (100% efficient):

$$P_{IN} = P_s$$

where P_{IN} is the power delivered to the primary,
and P_{OUT} is the power delivered by the secondary;

and

$$I_s / I_p = N_p / N_s$$

Verdict:

There is nothing magical about the transformer. It changes the 'format' of the electricity supply, but at a cost in terms of energy wasted.

[illegible]

A blank sheet of white paper with horizontal ruling lines and a decorative hexagonal pattern at the bottom.

ELECTRICAL INSTALLATION 2

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