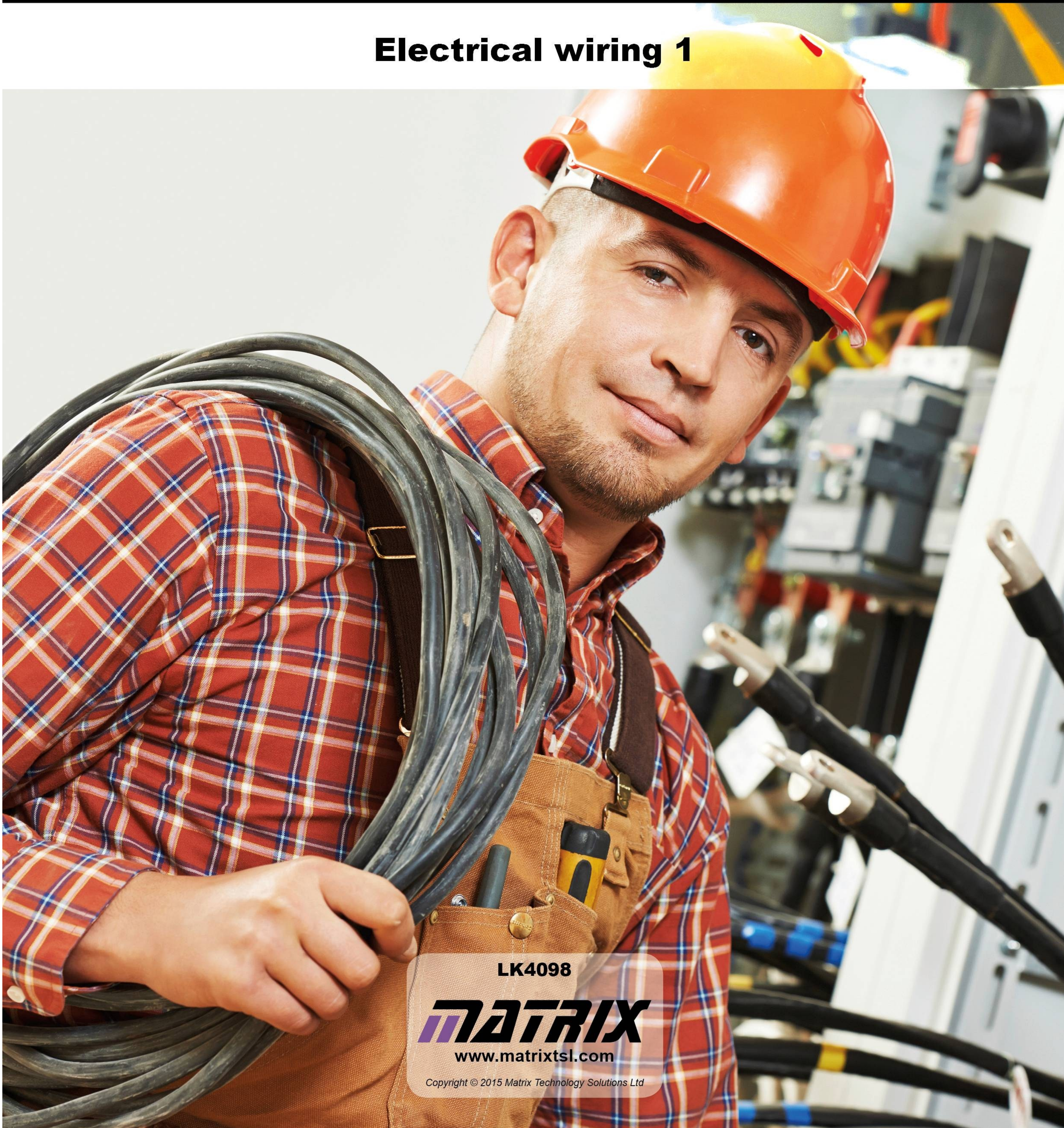
locktronics

Simplifying Electricity

Electrical wiring 1



LK4098

MATRIX

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Contents

Introduction

The course aims to prepare you for Unit 107 - “Electrical Science and Technology” part of the City and Guilds Level 1 Diploma in Electrical Installation qualification. It assumes no prior knowledge of electricity.

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

There are a variety of different tasks, identified by a series of icons.

Icon	Significance
i	Content gives information about electricity, or explains some terminology
	Practical activity
	Relates the current activity to jobs in the industrial / domestic realm
	Open-ended activity where the students designs the activity
!	Health and Safety related issue
X^2	Activity involves a formula or calculation
AC DC AC DC	Power supply flags indicate which type of power supply to use.

For your records:

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

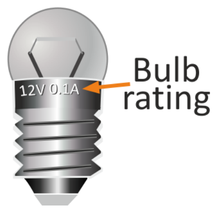
Circuit Training

From the dictionary:

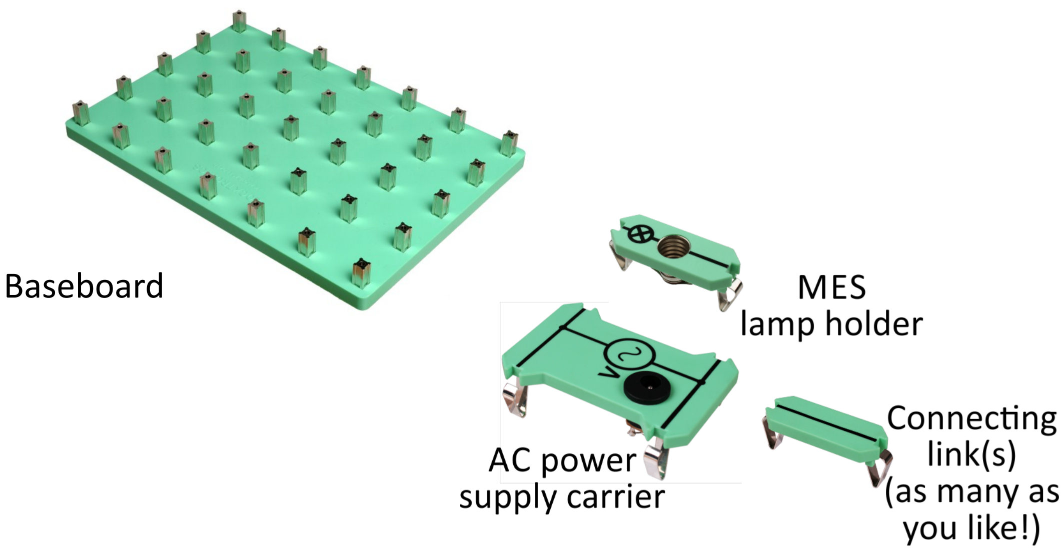
"**Circuit:** *noun*

- a roughly circular line, route, or movement that starts and finishes at the same place."

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



The hardware:



Locktronics	Domestic electricity
Bulb	like a domestic bulb, but designed for lower voltage and current.
Connecting links	the wires.
AC power supply carrier	the consumer unit - where the domestic circuits connect to the National Grid.

Power Supplies

Power supply:

- drives current around the circuit by applying a voltage.
- 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):

- terminals change polarity repeatedly, one positive, the other negative and then they swap;
- ‘two-way traffic’ - current flows clockwise, then anticlockwise around the circuit.

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;
- ‘step-up’ and ‘step-down’ transformers can modify voltage and current to allow more efficient distribution.

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 cells convert light energy into DC electrical energy;
- **dynamo** - a rotating coil of wire near a magnet generates DC provided a ‘commutator’ connects 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 rotated by high-pressure steam in a power station, by wind (wind-generator) or by falling water (hydro-electricity).

AC Versus DC

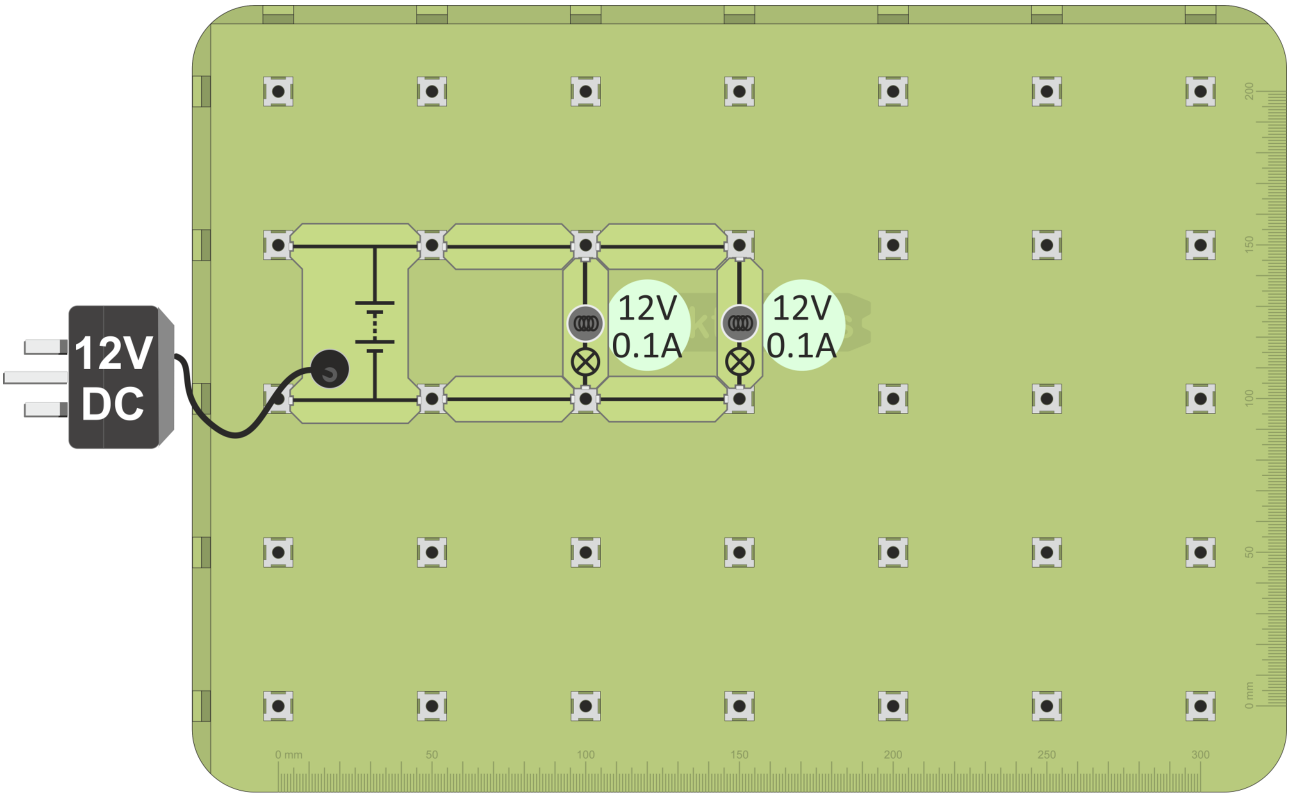
The aim of this and the next activity is to compare the performance of an AC and a DC power supply.

Preliminary experiment - finding two bulbs that have the same brightness

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

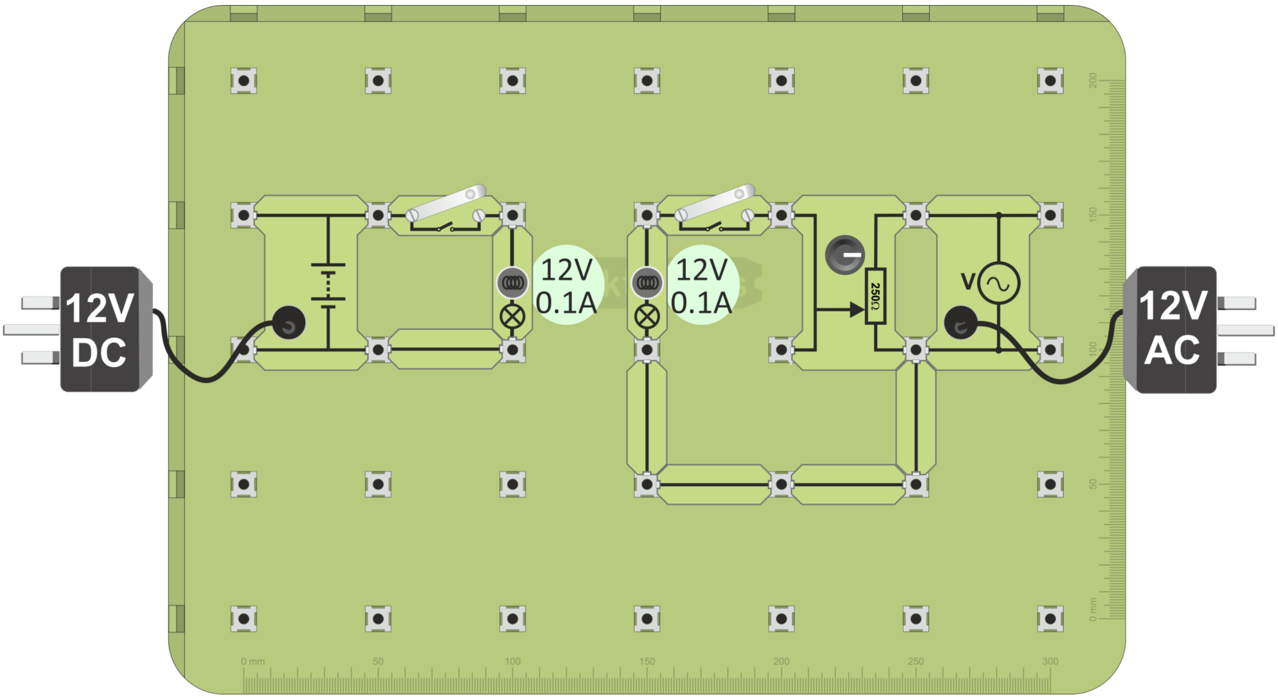
This activity continues the task of comparing the AC and DC power supply.

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.

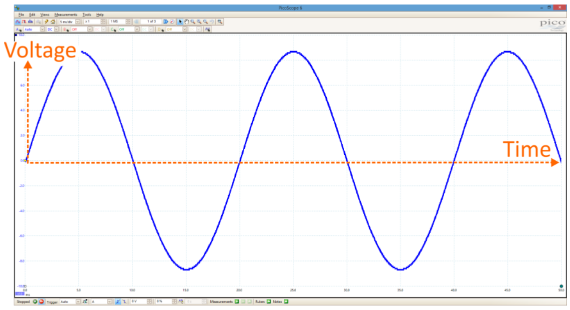
   Now, the AC voltage has exactly the same effect as the DC supply.

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 Handout.

AC and DC Again

Measuring AC signals often calls for the use of an oscilloscope, which produces a voltage / time graph of the signal.

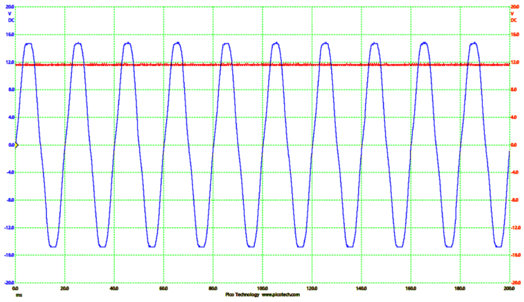


The diagram shows an example - the output of an AC power supply.
Voltage and time axes are shown in orange.

Notice:

- the average voltage is zero - the voltage is positive for half of the time and negative for half of the time;
- it may be described as a peak voltage of 9V, but most of the time the voltage is much less.

So what is the "average" effect of an AC supply? How can we compare AC and DC?
The previous experiment gives the answer - look for the two having the same effect on a device like a bulb. The oscilloscope trace opposite shows the AC and DC power supply signals from that experiment, when the two bulbs had the same brightness.



Notice that the DC supply sits well below the AC peak value. It is called the r.m.s. value of the AC supply - but more of that later!

The symbols shown in the diagram are often used to distinguish between these forms of electrical power. We use both in this course.

- Both have 'plug-top' devices that plug into the AC mains electricity supply.
- The DC supply contains circuits which convert from AC power to DC.
- Some exercises, involving bulbs for example, can use either. Some can not. (The 'energymeter', for example, works only on DC.)
- Each worksheet layout suggests one type of power supply, but the flag shows whether there is an option:

AC supply	DC supply	Either
		

Conductors and Insulators

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

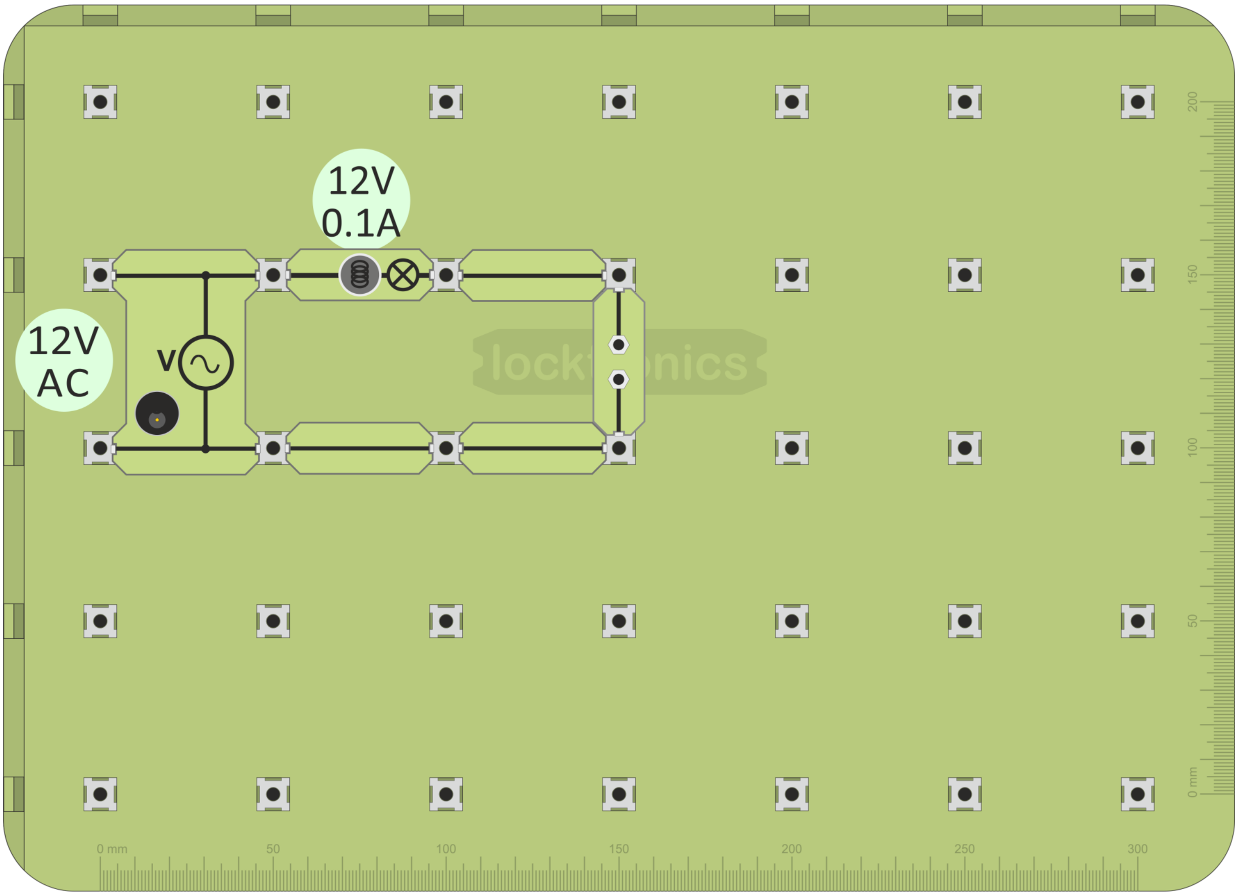
Materials which do not pass electricity are called **insulators**.

The hardware:

Universal component carrier

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

AC DC



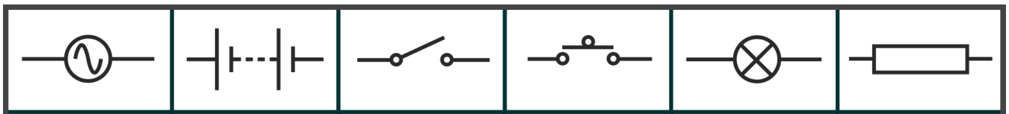
3. Put different materials across the gap in the universal component carrier.
   See if the bulb lights. (We are using the bulb as a simple continuity tester.)
   If it does, the material is a conductor; if not, it is an insulator (roughly speaking).
   Try some of the following:
   kitchen foil (aluminium), 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 Handout with the findings from your experiment and try to answer the question.

Circuit Diagrams - 1

i

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

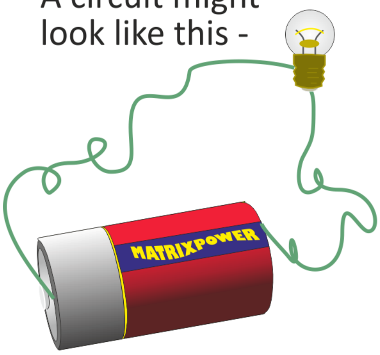
Here is a summary of the ones used so far:



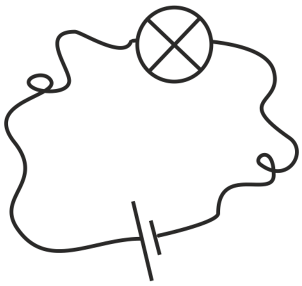
AC power supply	Battery or DC power supply	Toggle switch	Push switch	Lamp	Resistor

The aim is to clarify how a circuit is built, using an internationally recognised format.

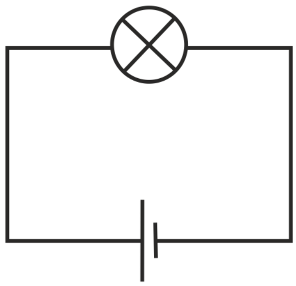
A circuit might look like this -

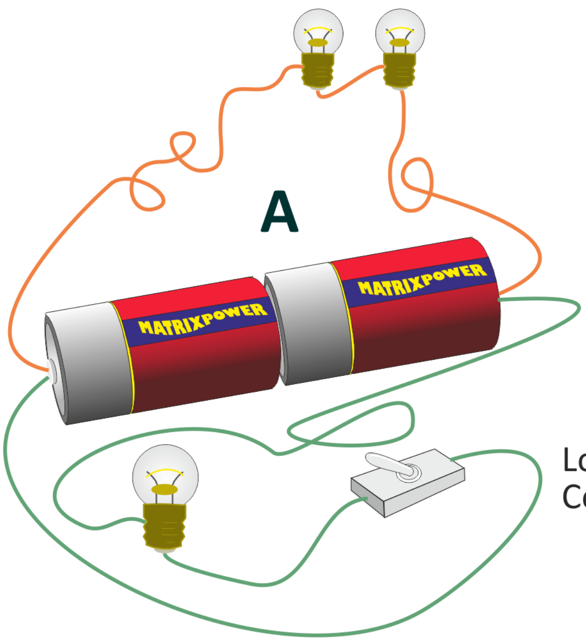


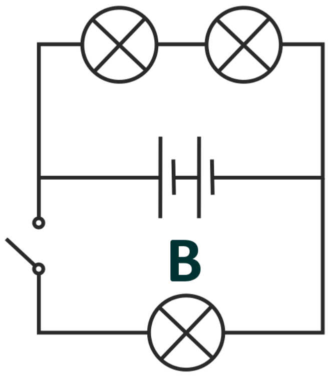
It is simpler to use symbols -



Or better still -



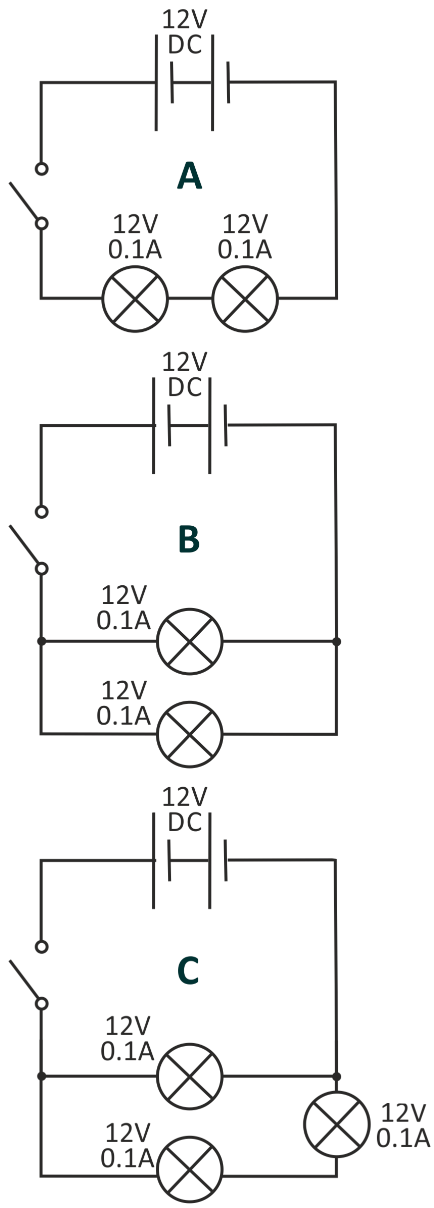




Look at the two circuits, **A** and **B**.
Compare them. Are they the same?

Circuit Diagrams - 2

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 Handout.



DC

Current Path - 1

Power supply:

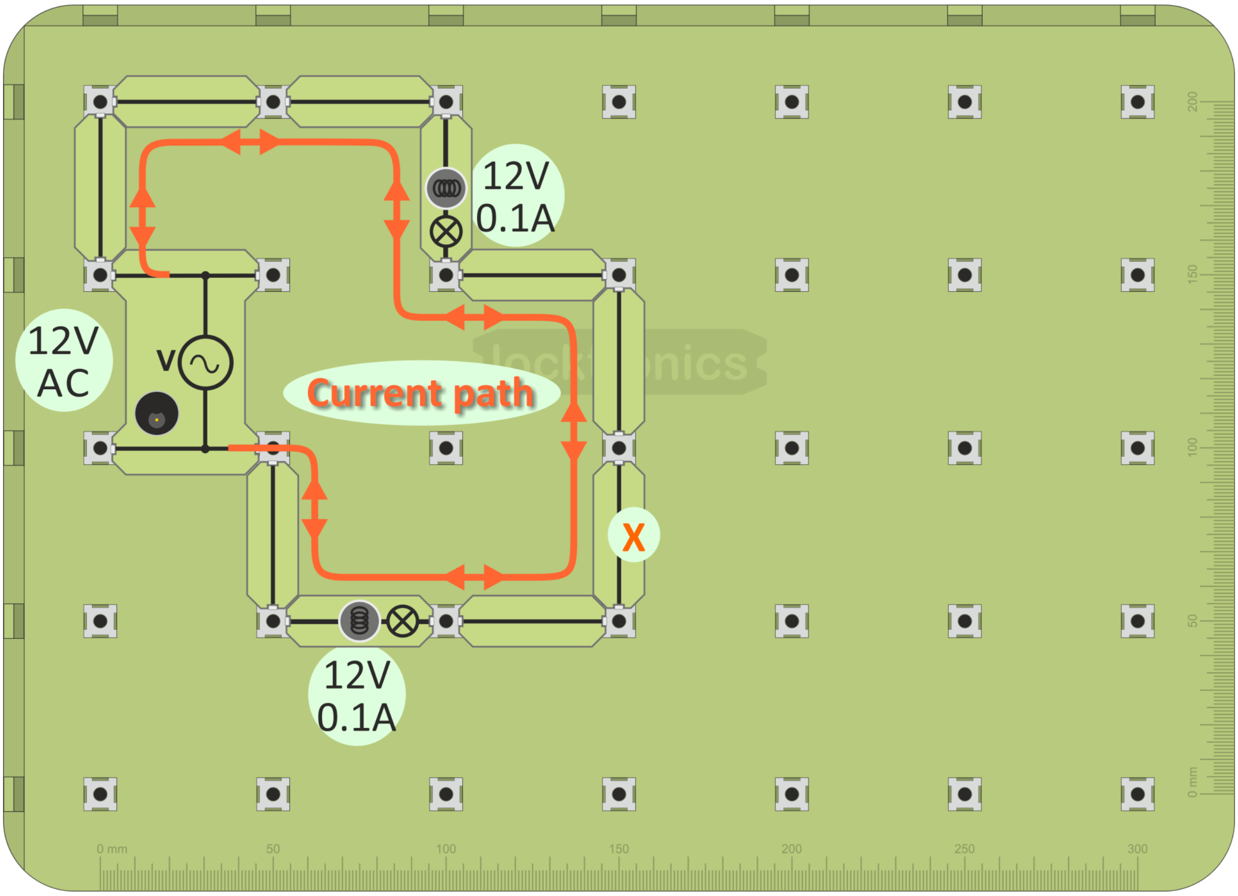
- drives current around the circuit;
- has two terminals (connection points) one 'positive' the other 'negative';
- current flows from positive to negative.

Connecting links: allow current to flow freely.

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

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

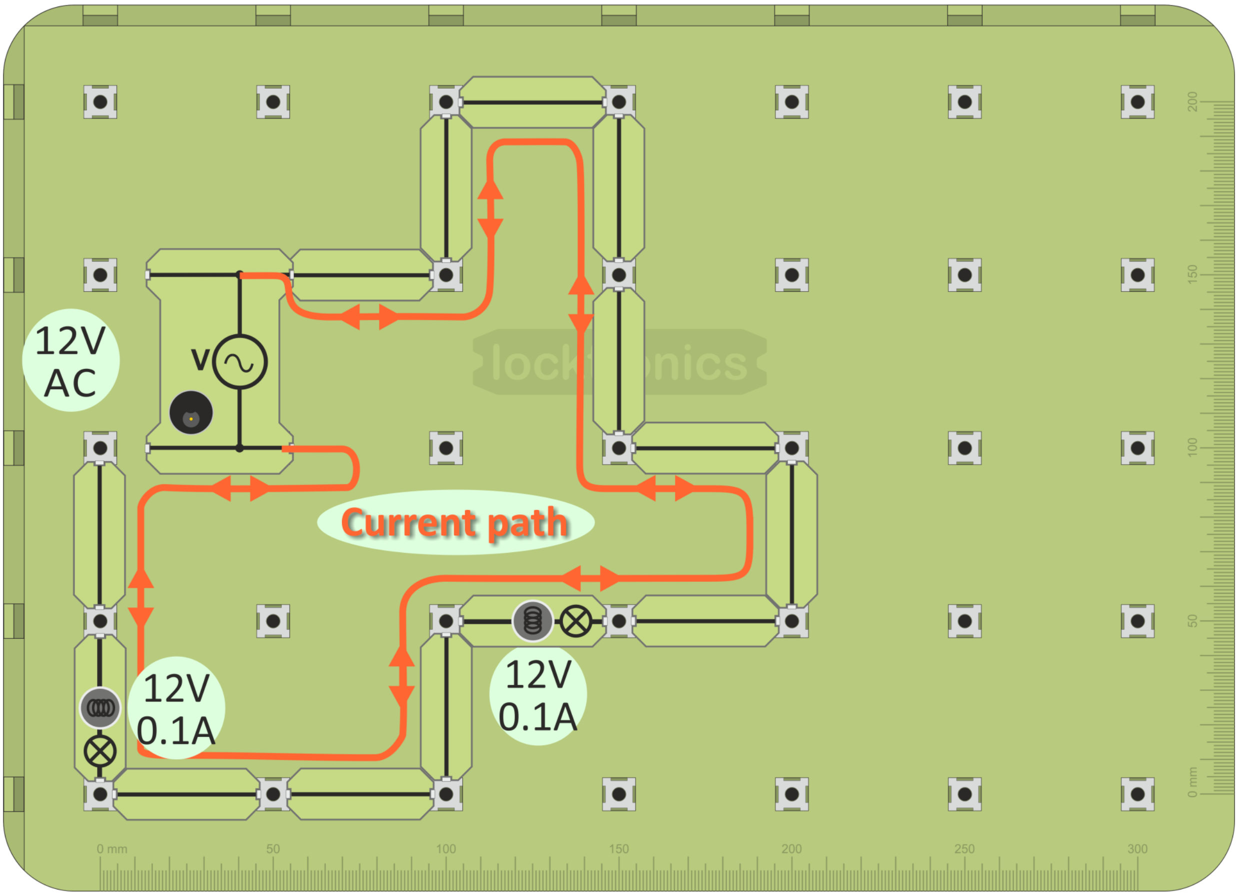
AC DC



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?

Current Path - 2

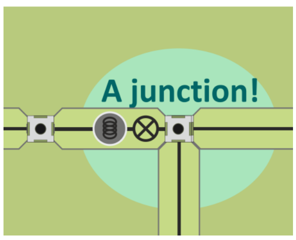
1. Build the layout shown below.
2. Connect the 12V power supply and switch on.



3. This layout has a different shape.
   Does it make any difference to the way the circuit works?

Try other circuit shapes.

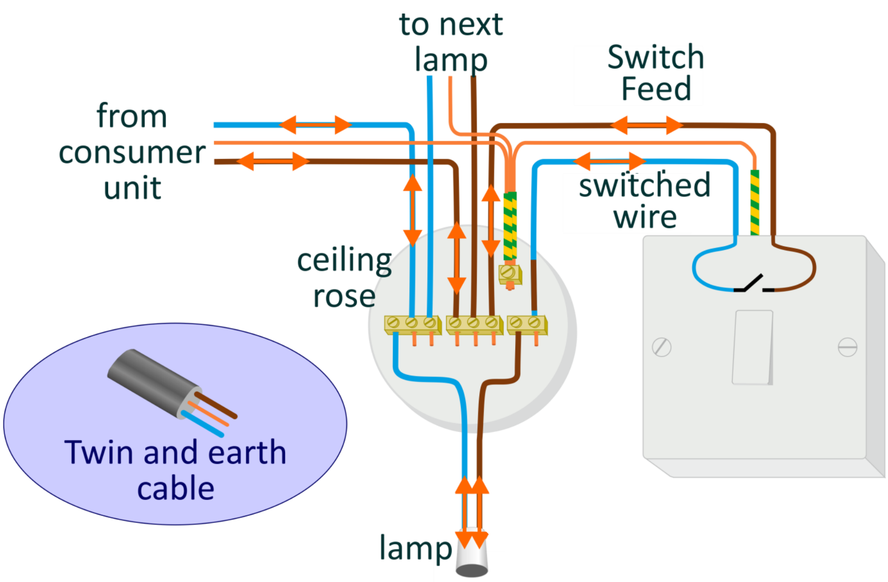
(Make sure that there are no 'branches' (junctions) in your circuits - these are covered later.)



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

Current Path - 3

- 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.



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.

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

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:

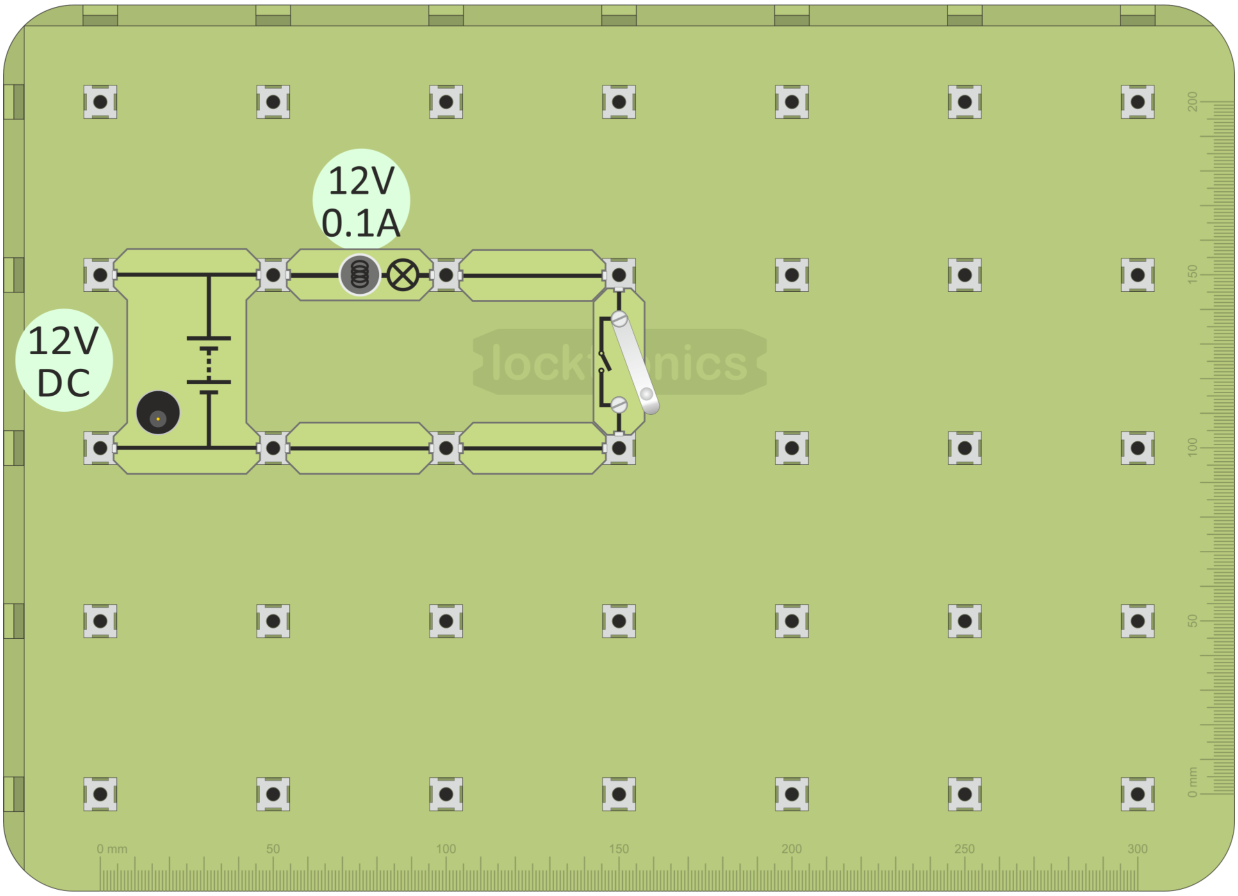
- through the switch,
- through the lamp,
- back to the consumer unit.

Effects of Electric Currents - 1

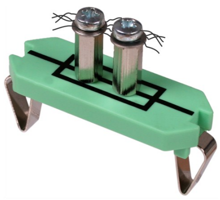
Effect 1 - Heating effect

AC DC

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!

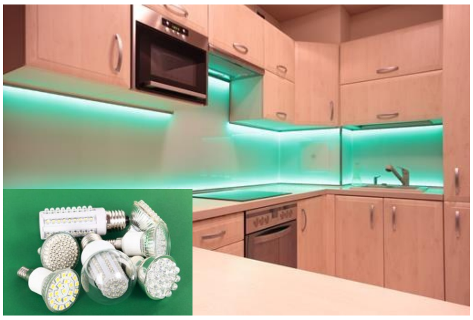


(Take care not to touch the component - it will be extremely hot!)

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 2000^0C, that it glows yellow-hot, giving out light.



Problem - they are very inefficient - typically only ~5% of the electrical energy appears as light. The drive is to higher efficiency lighting. One answer is LED (**L**ight-**E**mitting **D**iode) lighting, which can be 10 times more efficient.

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

An unwanted and harmful aspect of electrical heating is found in short-circuits, where worn or damaged insulation lets wires touch, allowing very large currents and a lot of heat.

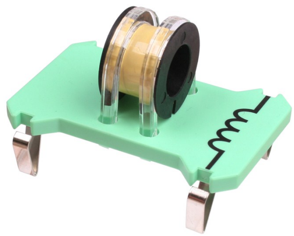
A solution is yet another application of electrical heating, the fuse - a short length of wire made from a metal with a low melting point. It acts as the weak point in the circuit. A large current flowing through it heats it so much that it melts. This breaks the circuit, stopping the current before it causes more widespread damage.

The reverse process takes place in a thermocouple. Two legs made from different metals are connected together. When the junction is heated, it generates a DC voltage. Thermocouples are used to measure temperature.

Effects of Electric Currents - 2

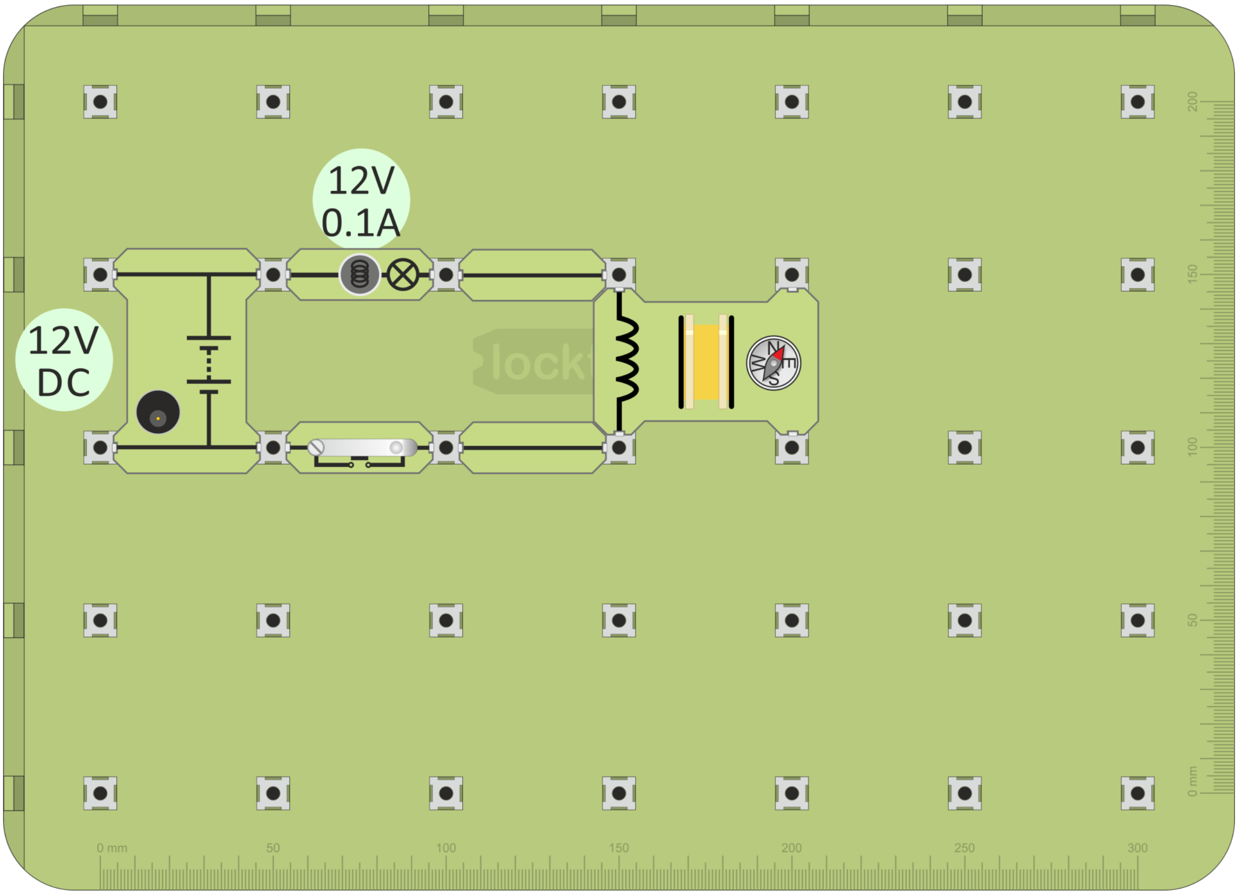
Effect 2 - Magnetic effect

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



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

DC

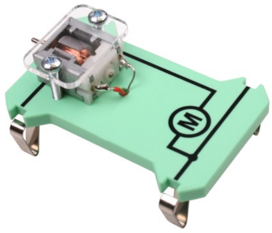


3. Place a magnetic compass next to the coil, as shown above.
4. Close the switch and watch the compass needle as you do so.
5. Now switch off and place a steel nail inside the coil.
6. Close the switch again, watching the needle as you do so.
   Is the effect stronger than before?
7. Wave a magnet near the compass to confirm what is happening.

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.



There are many examples of its use in the home.
(Some involve heating as well as magnetic effects.)



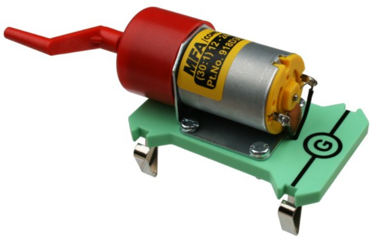


Other applications of electromagnetism include:

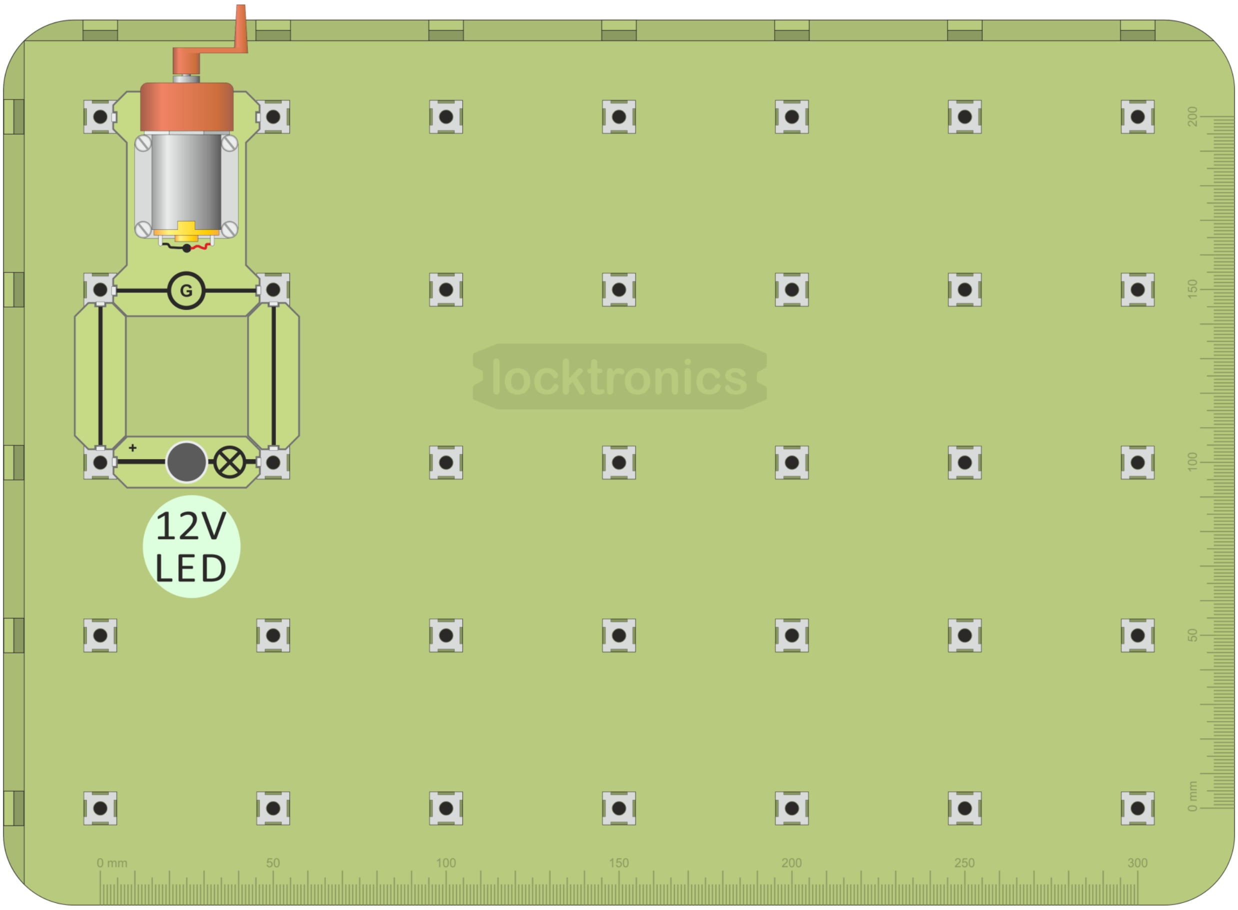
- transformers - in power supplies, such as mobile phone chargers;
- generators - used to power tools or as a stand-by in case of power cuts;
- loudspeakers - in radios, televisions, computers and mobile phones;
- circuit breakers - another protection against current overload and overheating.




The hardware - a hand-cranked generator:



1. Build the layout shown below. 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 the handle in the opposite direction. (The generator outputs DC. The current must flow in the right direction to make the LED light.)

3. Replace the LED carrier with a 12V 0.1A filament lamp. Turn the handle again.

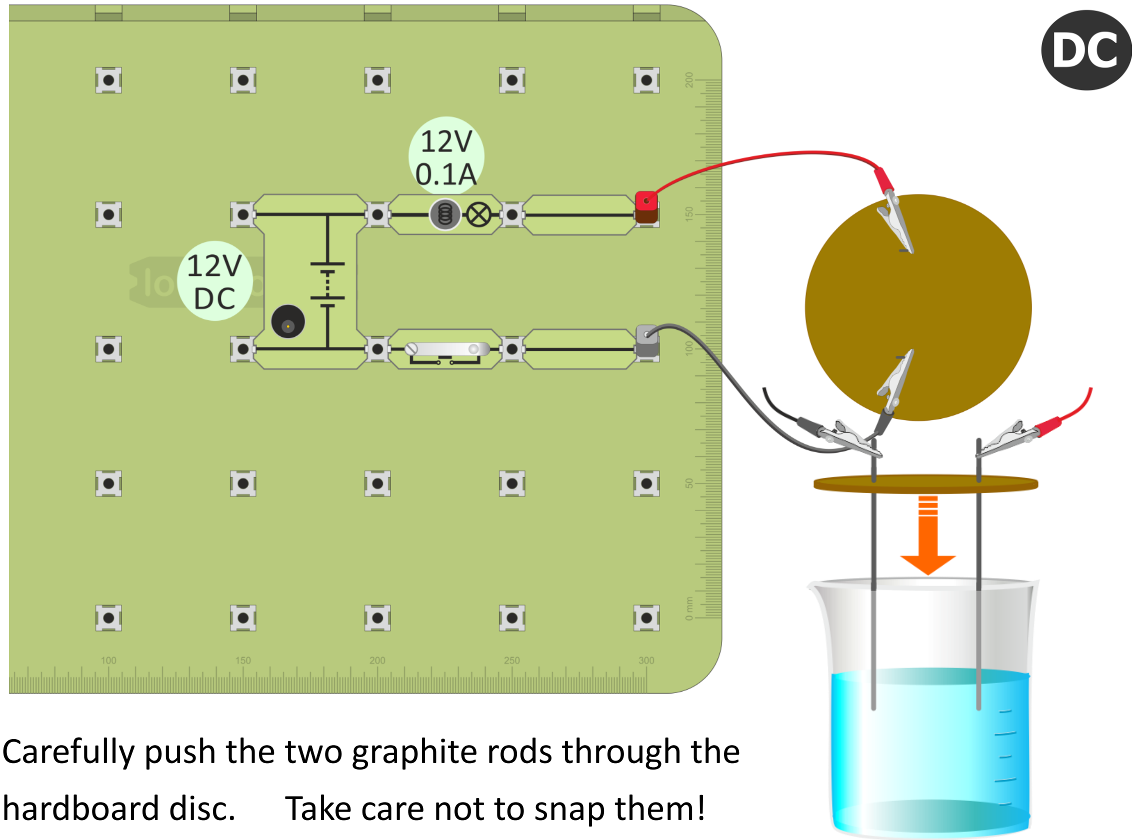
   Which is easier to turn?

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

Effect 3 - Chemical effect

(Optional experiment)

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 - 1

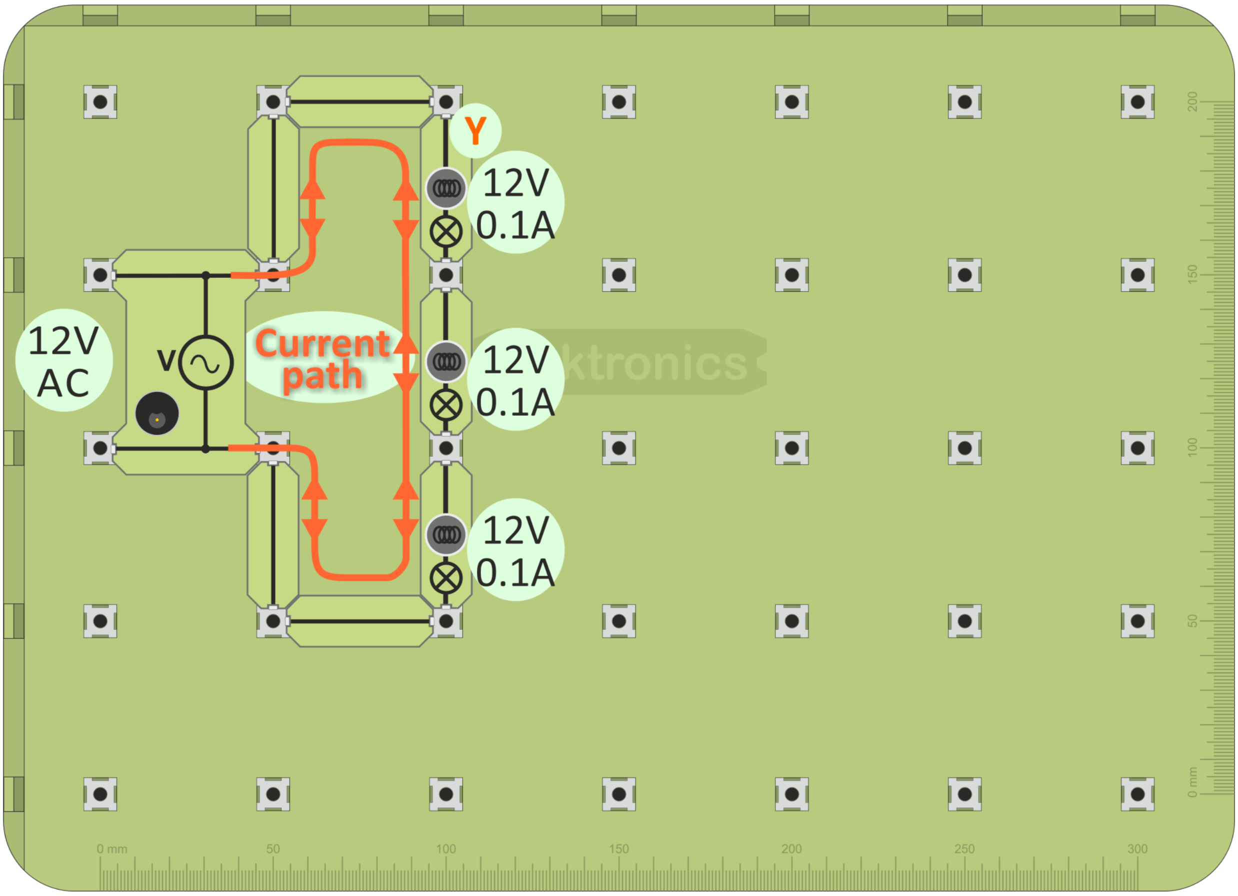
Series:

- 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!

1. Build the layout shown below.
   This is a series circuit - the lamps are connected in a line with no junctions.
2. Connect the 12V power supply and switch on.

AC DC



3. What do you notice about the brightness of the three lamps?
4. What happens if you unscrew one of the bulbs (bulb 'Y' for example)?
5. Write your findings in the Student Handout.

If the lamps are of different brightness, look at

MES bulbs

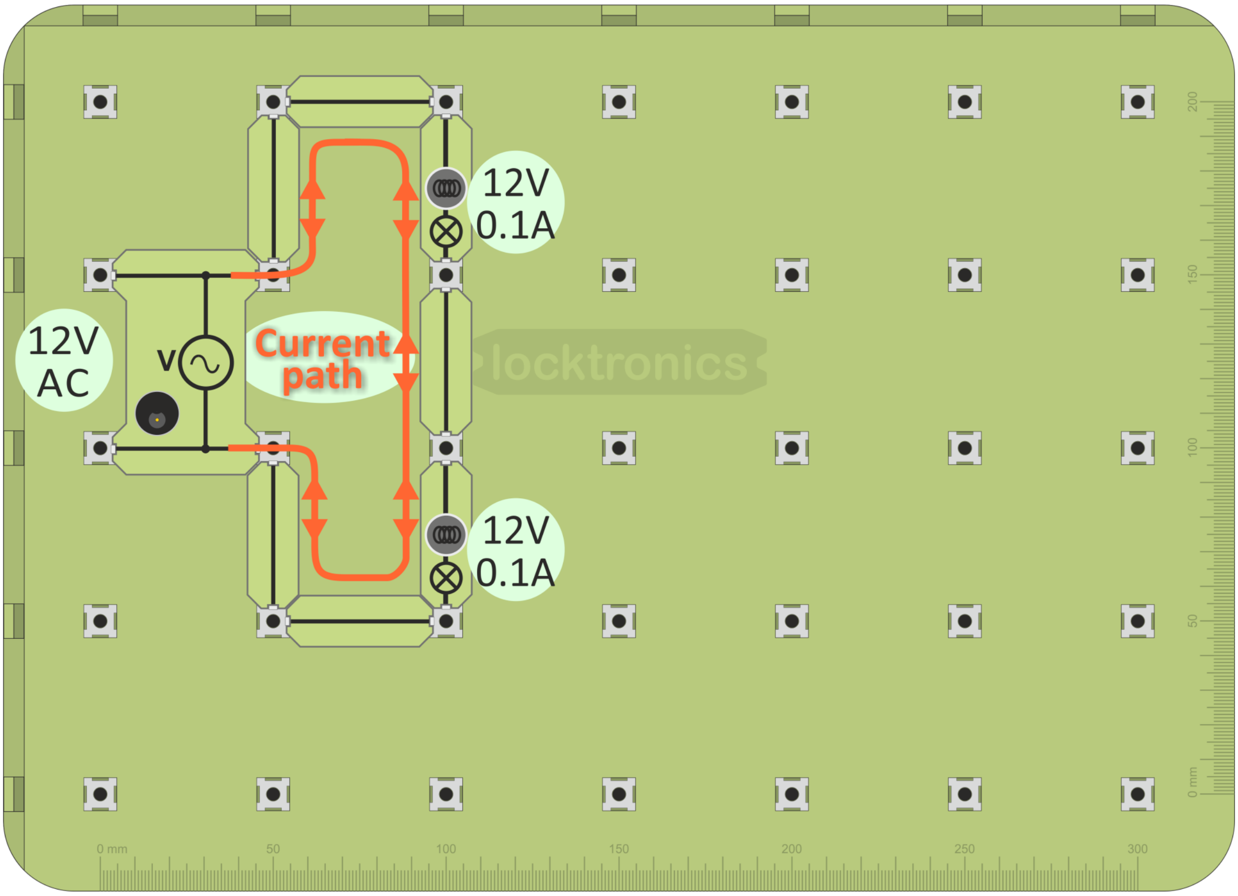
and then come back to the next worksheet!

Connect in Series - 2

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

1. Build the layout shown below.
   This is also a series circuit but this time there are only two lamps.
2. Connect the 12V power supply and switch on.

AC DC



3. What do you notice about the brightness of the two lamps?
4. How does it compare with brightness of the lamps in the previous circuit?
5. What does this show about the current flowing in the circuit?
6. Unscrew one of the bulbs.
   Does this have the same effect as in the previous circuit?
7. Write your findings in the Student Handout.

If the lamps are of different brightness, look at

MES bulbs

and then come back to the next worksheet!

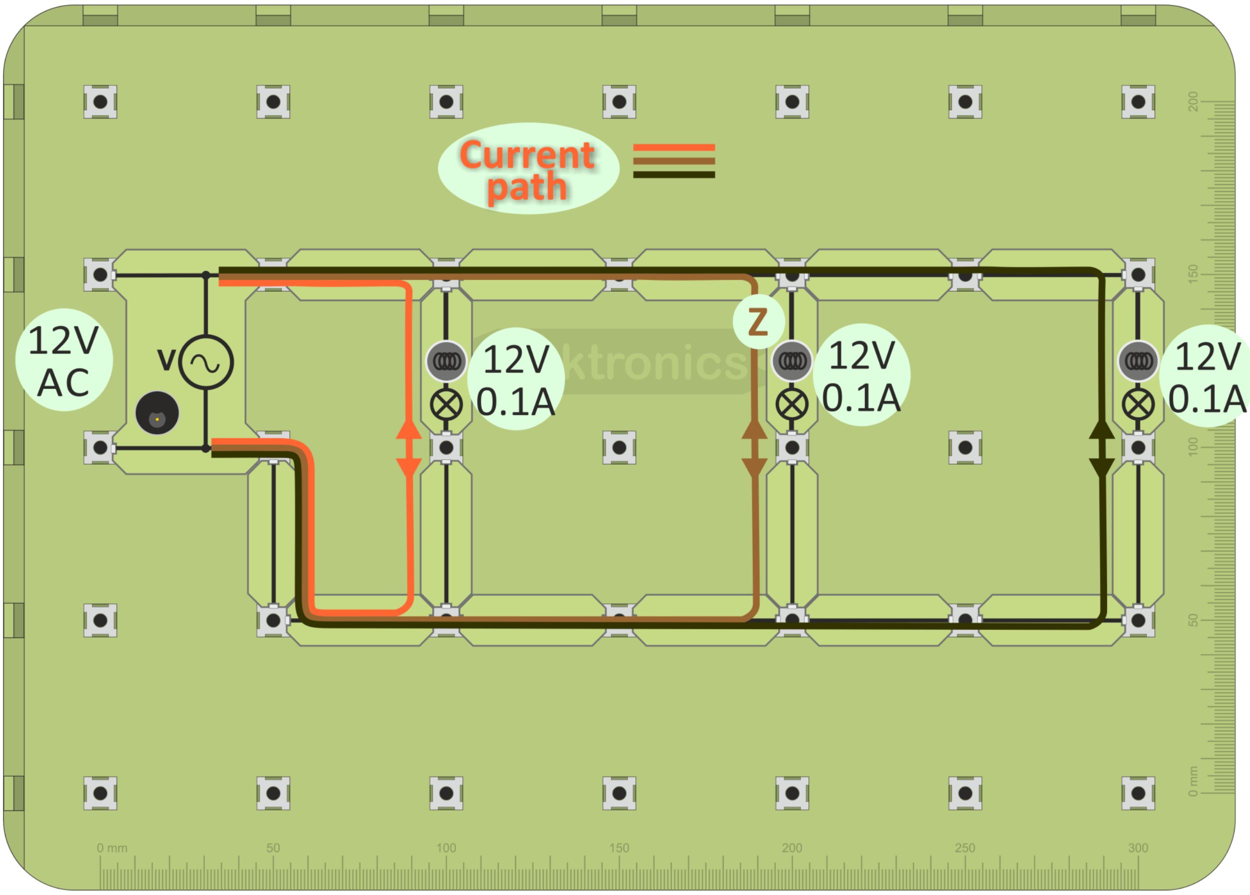
Connect in Parallel

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.

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.

AC DC



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.

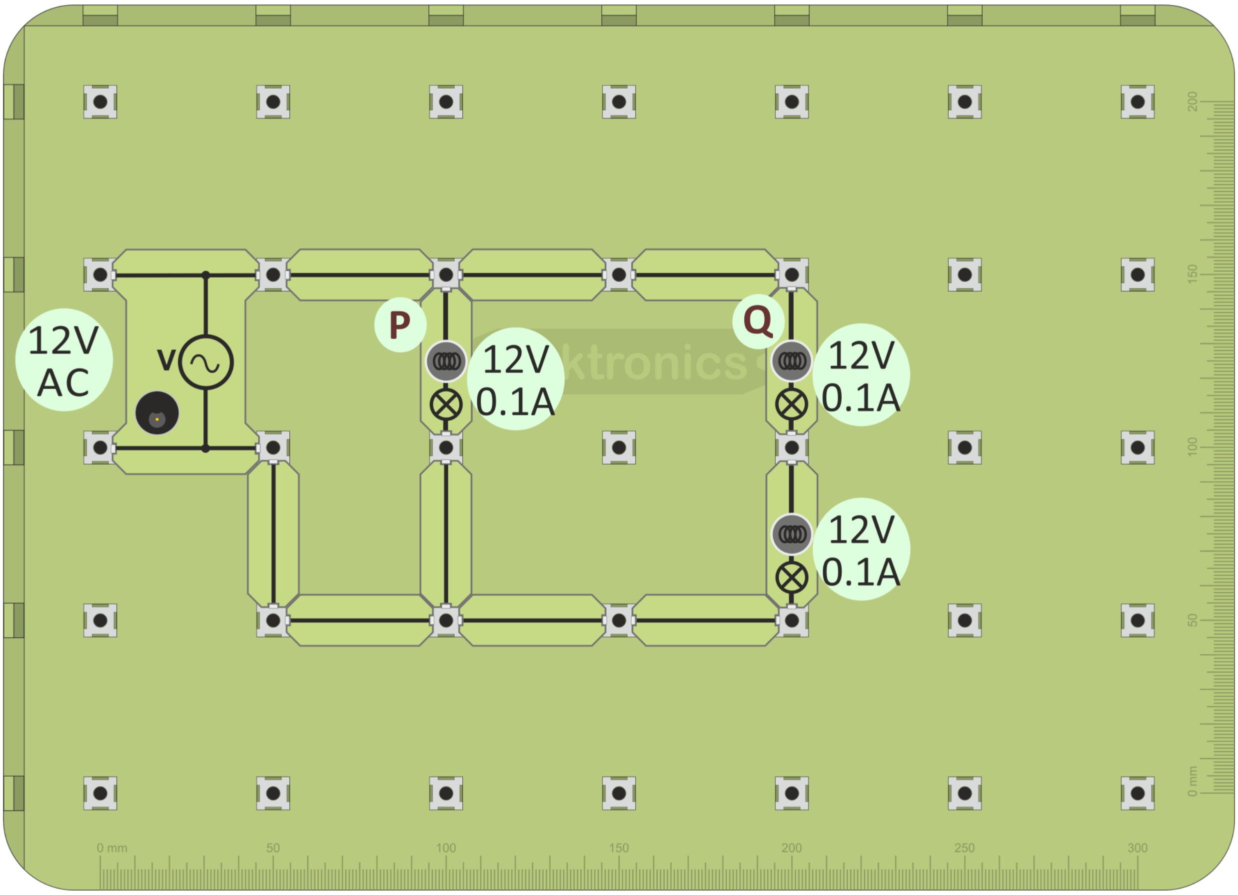
If the lamps are of different brightness, look at
MES bulbs
and then come back to the next worksheet!

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.

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.

AC DC



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

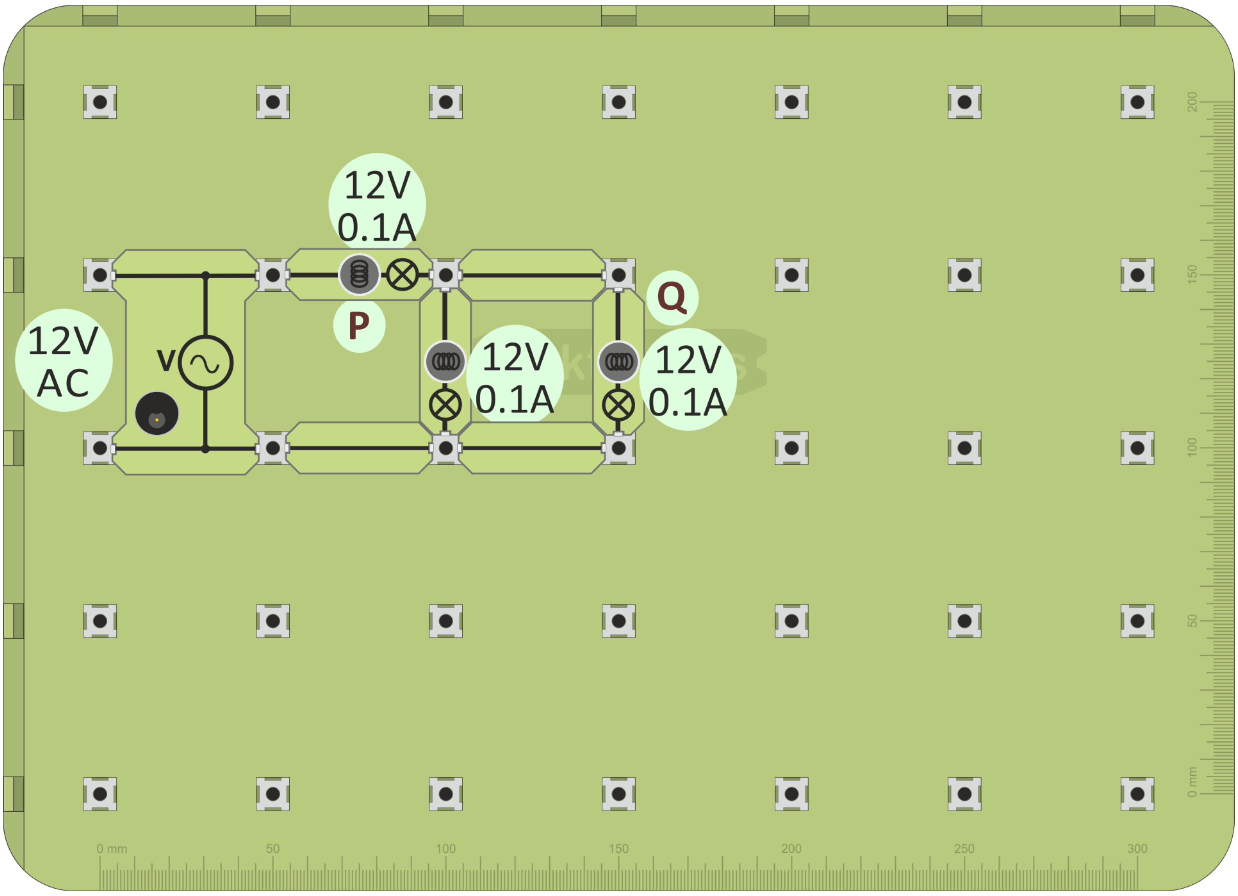
Here is another circuit with a mixture of series and parallel connections.

- 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!

1. Build the layout shown below.

2. Connect the 12V power supply and switch on.

AC DC



3. Compare the brightness of the three lamps? Were you right?

4. Now what happens if you unscrew:

- bulb '**P**';
- bulb '**Q**' ?

5. Try to explain these differences?

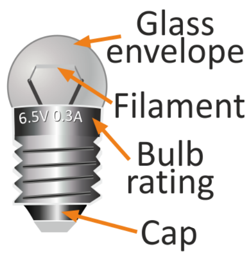
6. Answer the questions in the Student Handout.

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.

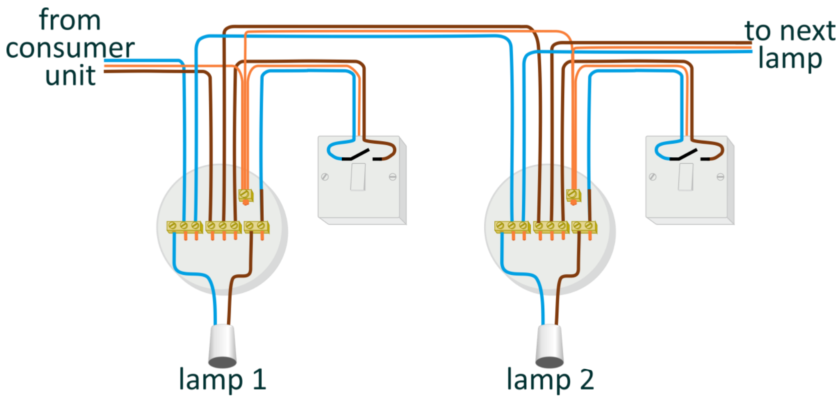
Try the following test:

- 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.

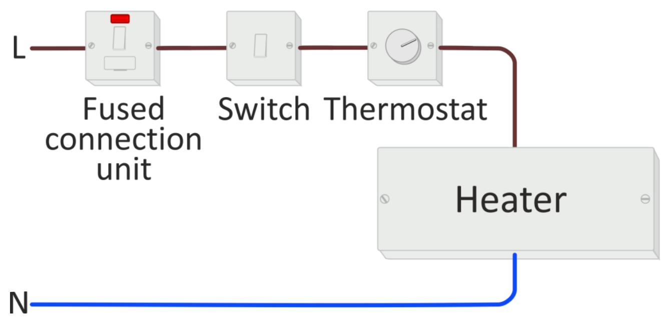
What does your test show?

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.

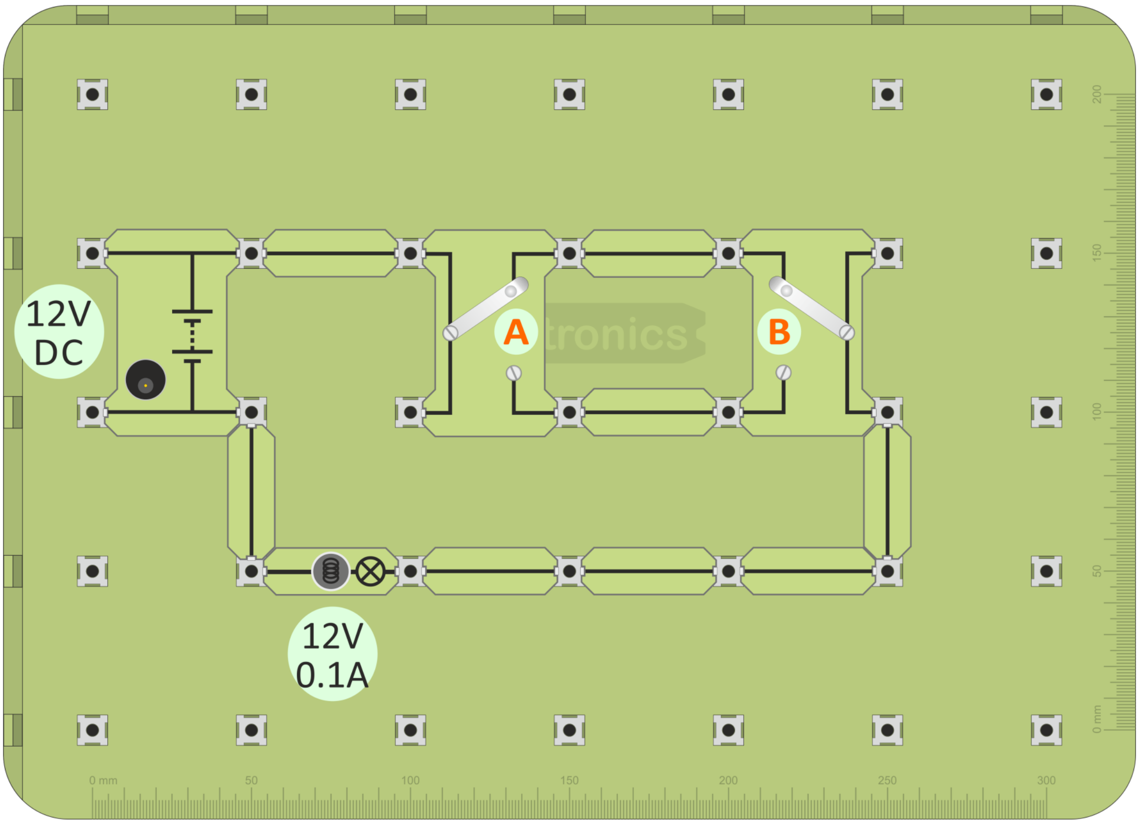


Staircase Circuit - 1

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.

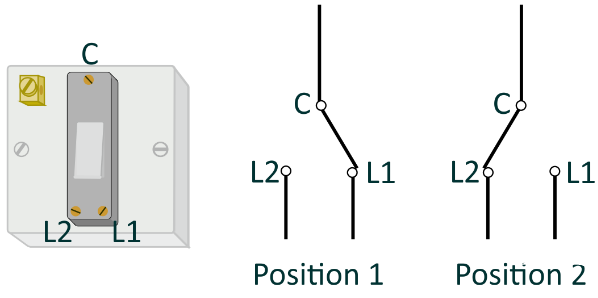
1. Build the layout shown below, using two 'changeover' switches, '**A**' and '**B**'.
2. Connect the 12V power supply and switch on.



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

In practice, the circuit uses two changeover switches like the one shown:

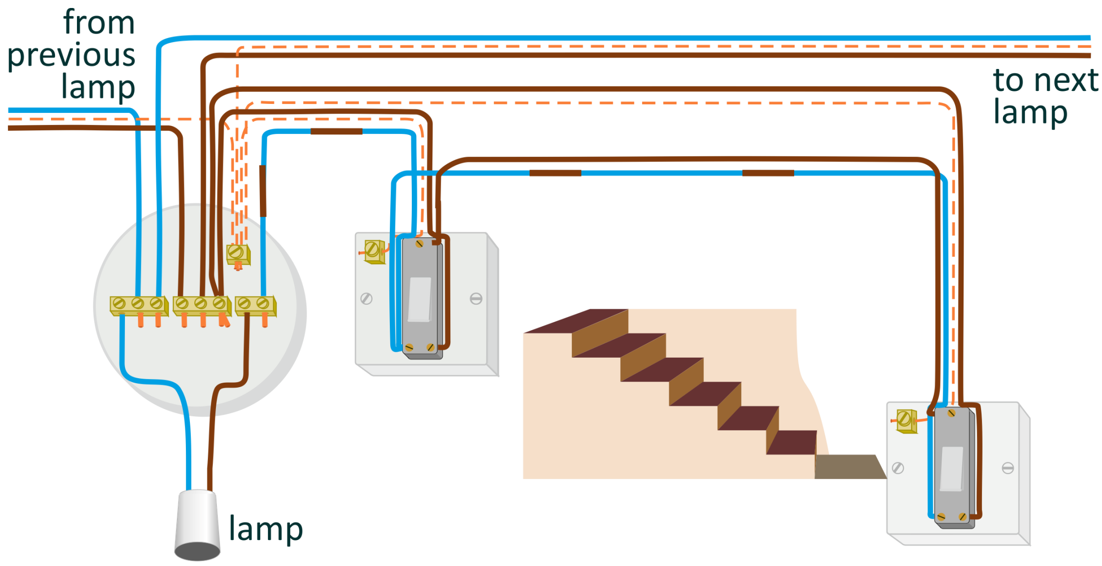


It has three terminals, labelled **C** (for Common), **L1** and **L2**.

Operating the switch connects **C** to either **L1** or **L2**, as shown above.

The two-way switching circuit is shown below.

The earthing connections are shown as dotted lines to make the circuit clearer.



Notice that:

- the **L1** terminals are connected together;
- the **L2** terminals are connected together and to the switched wire to the lamp;
- the **C** terminals are connected together.

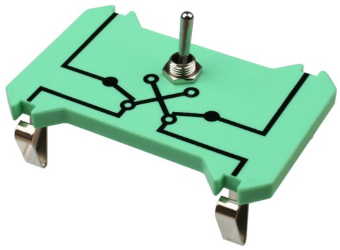
Starting with the incoming 'live' connection (brown) from the previous lamp, trace out the circuit.

- 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.

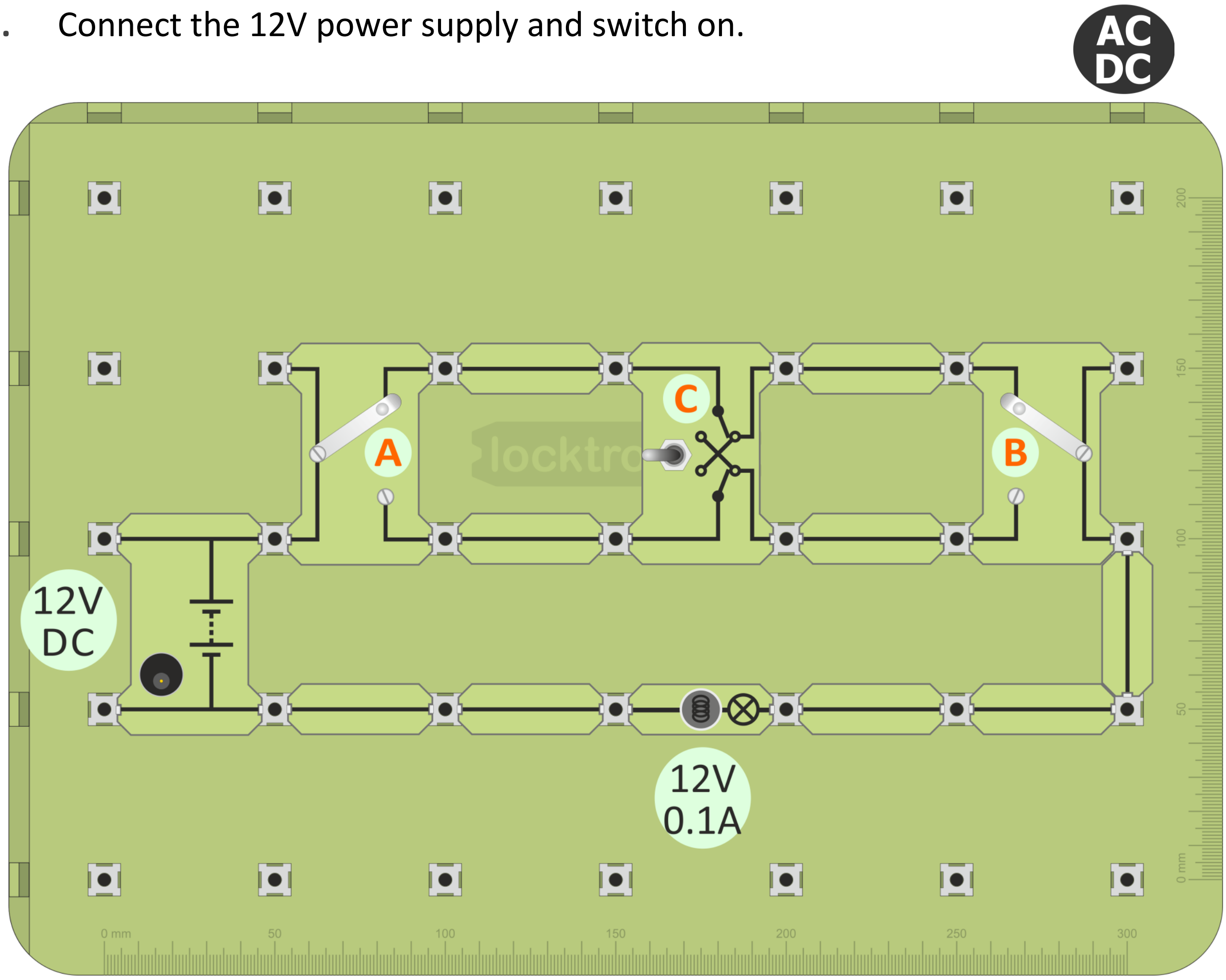
In the same way, trace out the circuit when the switches are in the other positions.

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**.

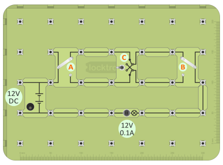


1. Build the layout shown below, using two 'changeover' switches, 'A' and 'B' and an intermediate switch 'C' (or modify the previous circuit by adding 'C' .)
2. Connect the 12V power supply and switch on.

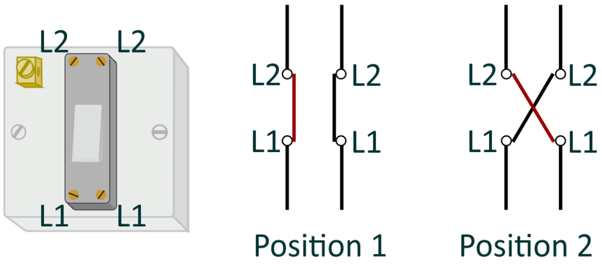


3. Check that the lamp can be controlled by all the switches.
4. For all eight combinations of switch positions, trace out the current paths.
5. Complete the diagram in the Student Handout by adding the current path for the arrangement shown there.

3-way Control - 2



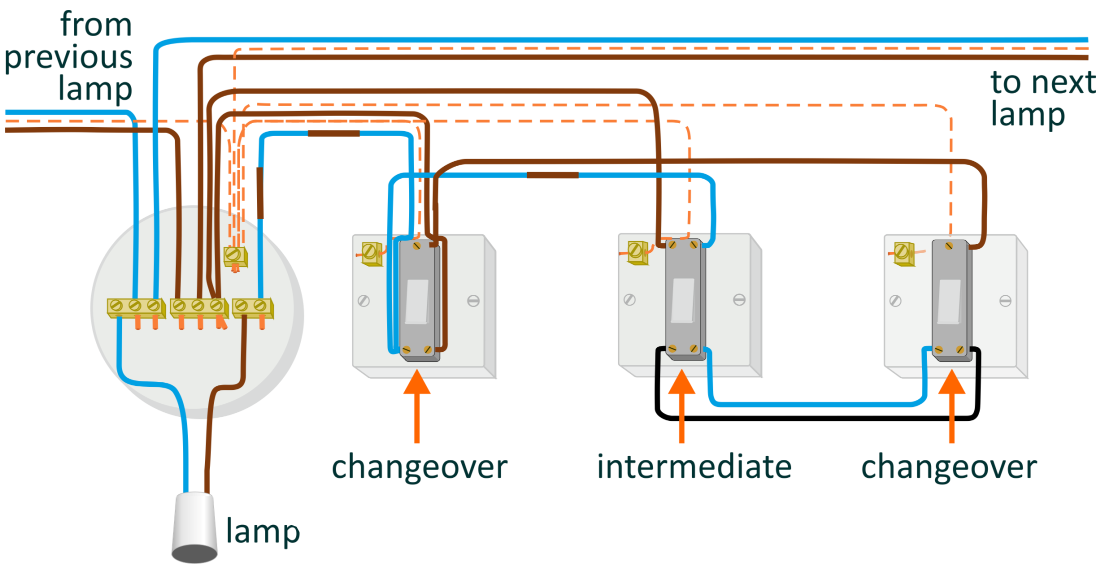
Now, a third switch, an intermediate switch, is added:



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

Operating it makes the connections shown above.

The three-way switching circuit is shown below.



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

Measuring Voltage - 1

i

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, <u>before you switch it on</u>:

- 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.

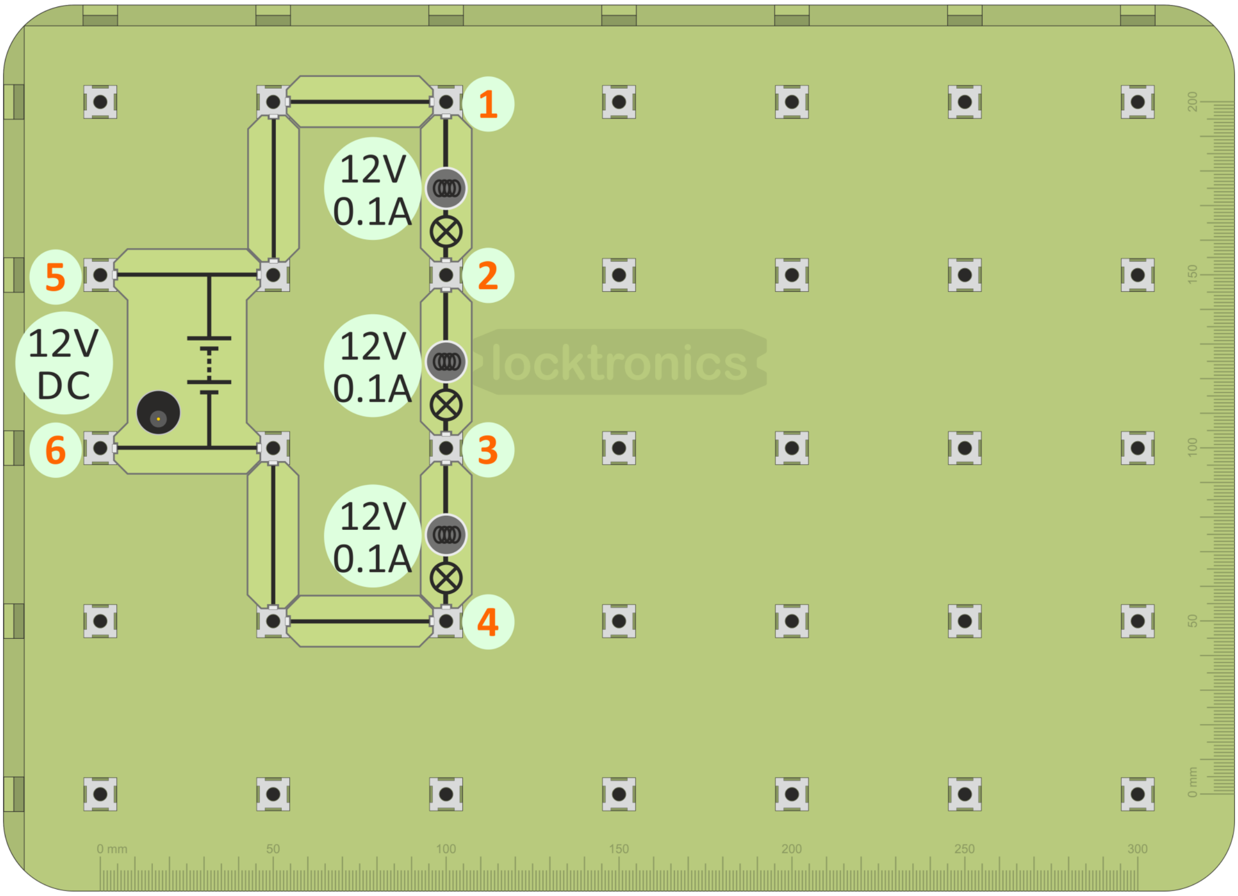
Using a multimeter to measure voltage:

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

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.

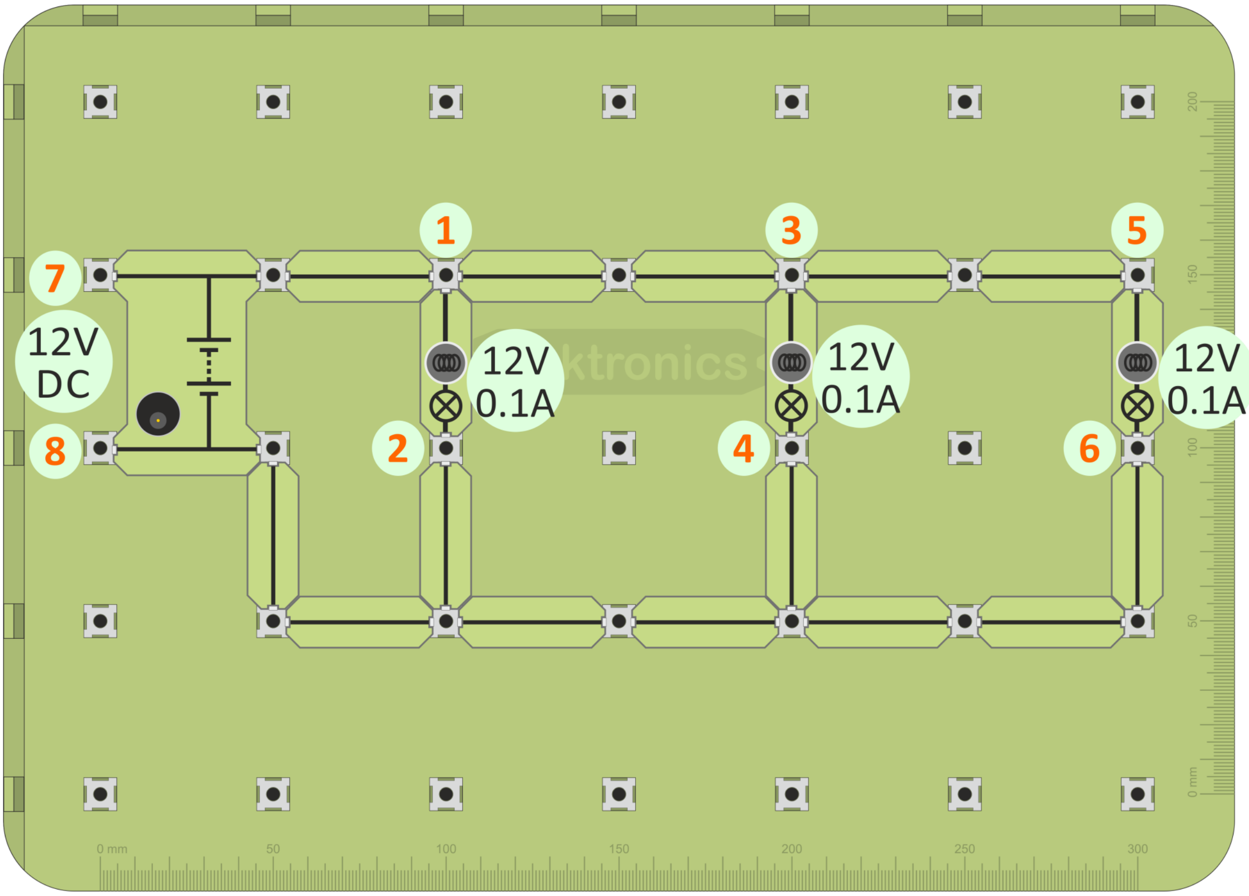


3. Set up the multimeter to read voltages up to 20V DC - see the previous page.
4. Measure the voltage across the top bulb, by plugging the multimeter leads into posts '1' and '2'.
5. Next, measure the voltage across the middle bulb, using posts '2' and '3'.
6. Then measure the voltage across the third 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

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

AC DC

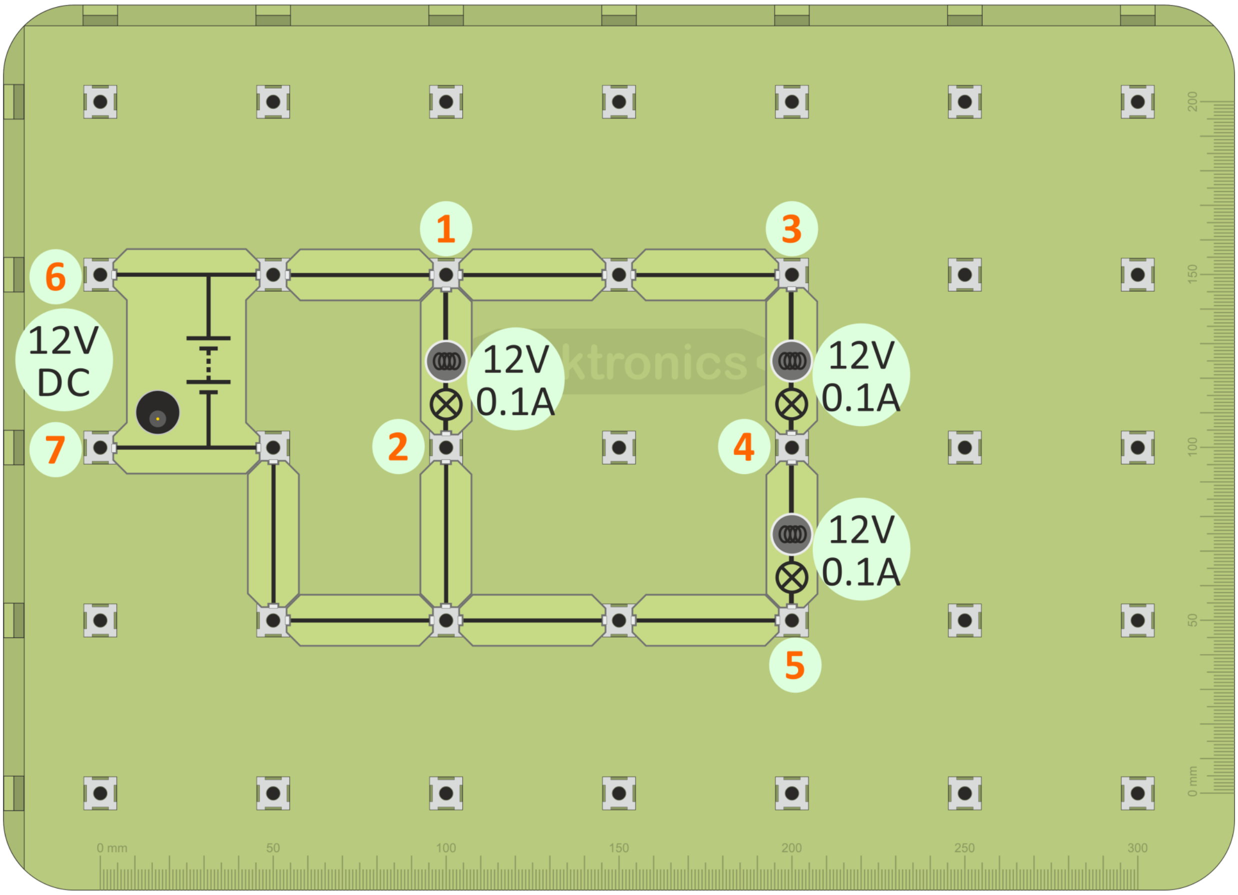


3. Set up the multimeter to read voltages up to 20V DC.
4. Measure the voltage across the first bulb, by plugging the multimeter leads into posts '1' and '2'.
5. Next, measure the voltage across the middle bulb, using posts '3' and '4'.
6. Then measure the voltage across the third bulb, using posts '5' 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.

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.

Investigate the other mixed circuit which you built earlier.

Measuring Current - 1

i

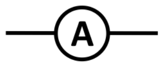
When using a multimeter to measure current, plug the probes into the ’**A**’ and ’**COM**’ sockets, or equivalents.

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.



ammeter

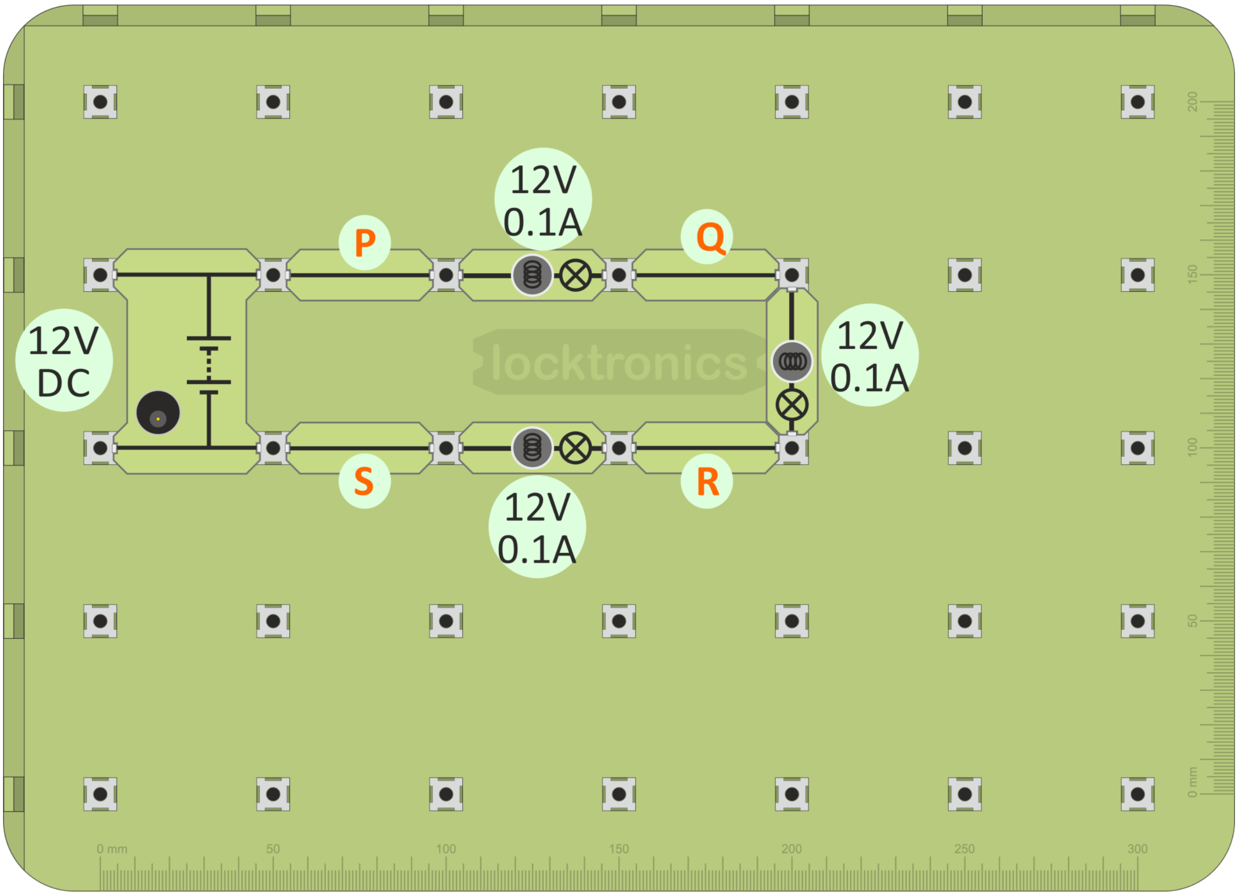
Using a multimeter to measure current:

- 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

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.

DC



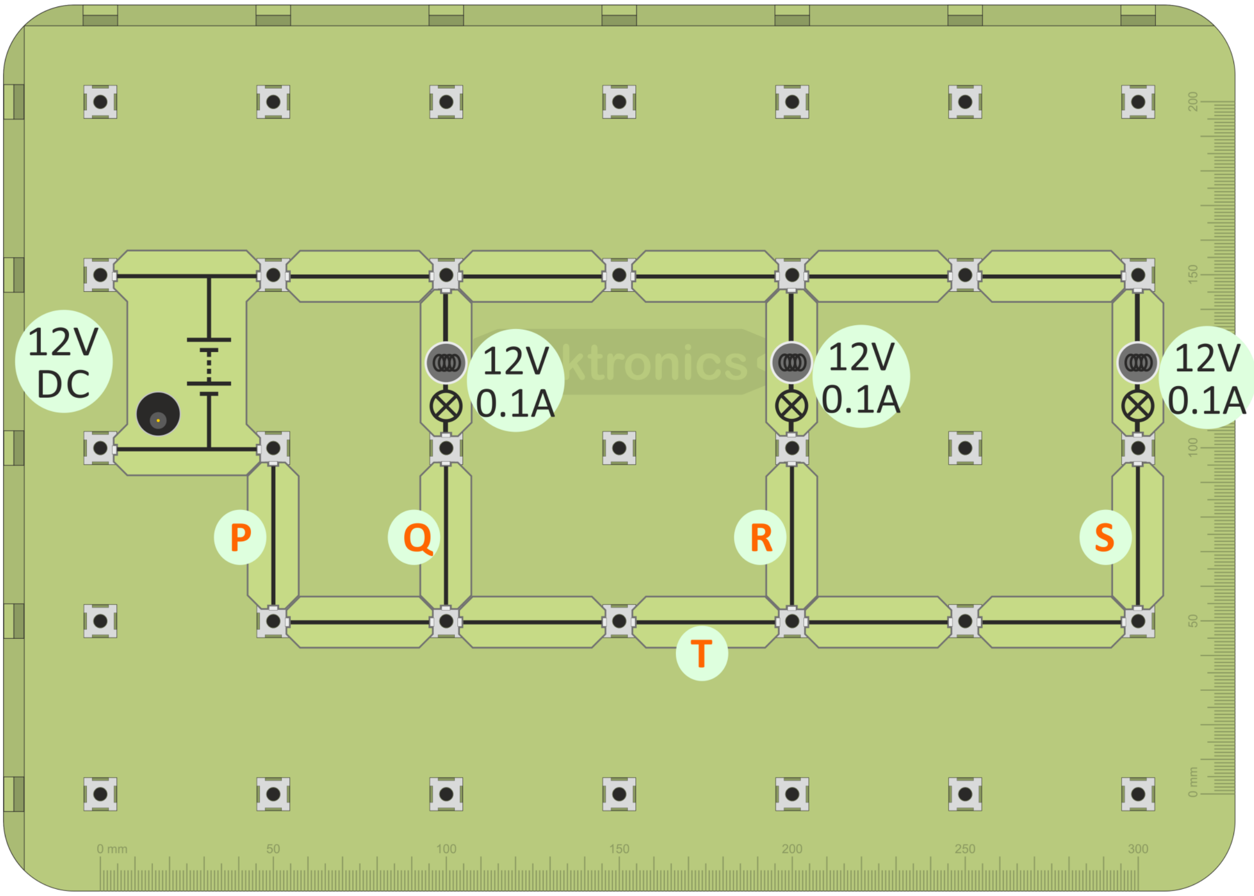
3. Set up the multimeter to read currents up to 200mA DC - see the previous page.
4. Measure the current at point 'P', by removing the connecting link and plugging the multimeter leads into the posts at either end of it.
5. In the same way, measure the current at points 'Q', 'R' and 'S'.

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

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.

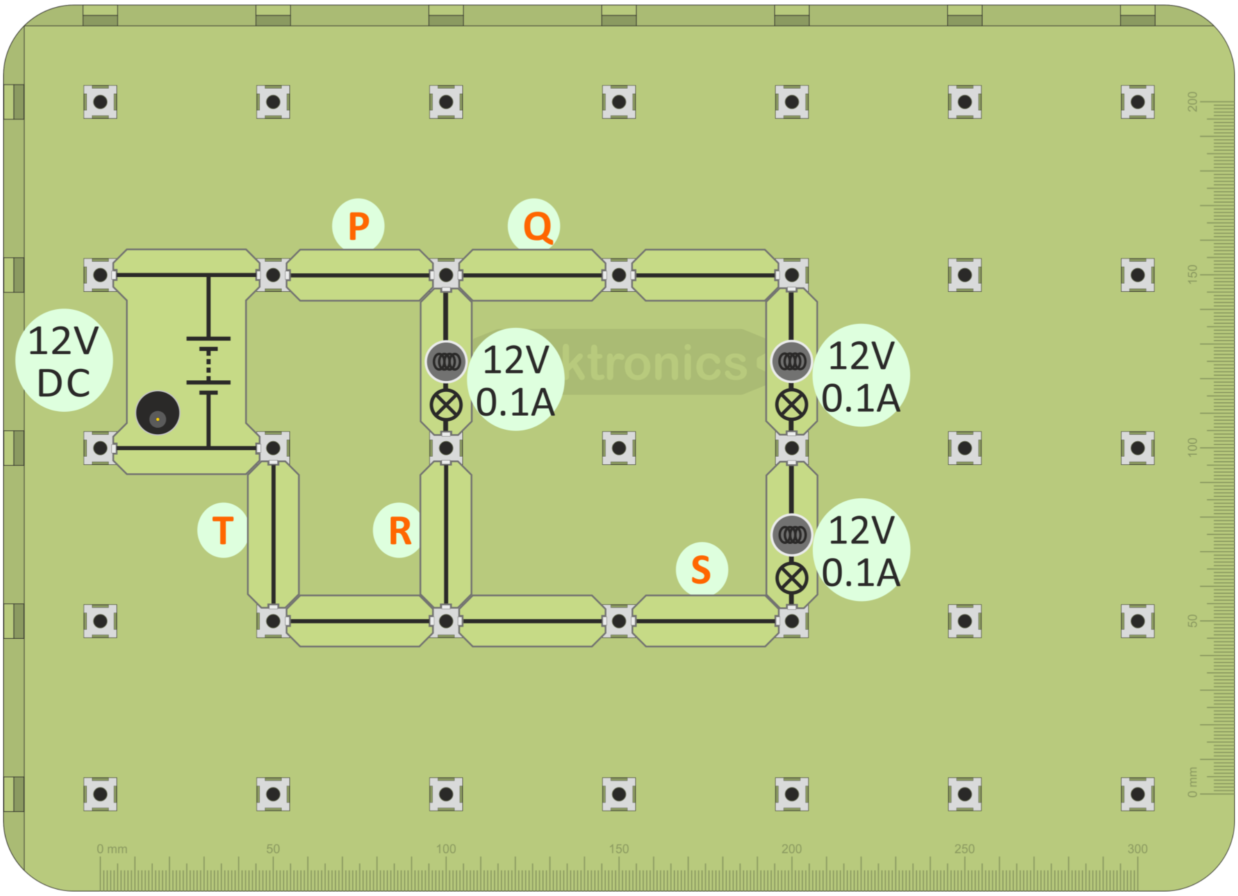
6. Use your results to estimate the current flowing at point ‘T’.
7. Now measure it. Were you correct?
   Write its value in the Student Handout.

Measuring Current - 4

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

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

DC



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?

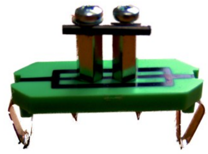
Carry out a similar investigation on the other mixed circuit, built earlier.

Resistance - 1

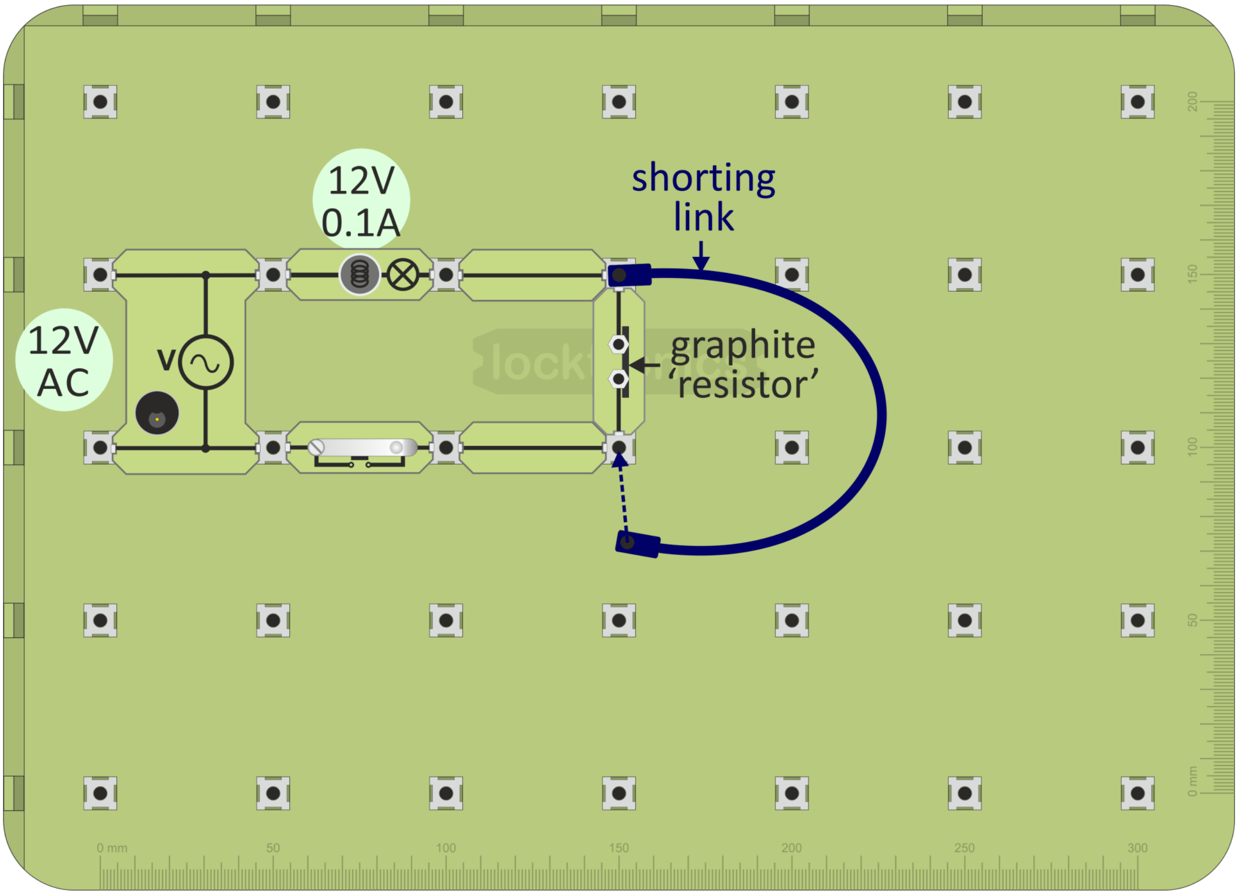
So far it has been on/off control of electric currents, using conductors or insulators. Now we want a more subtle control.

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

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



1. Create your resistor, using a short length of graphite (pencil lead) in the universal component carrier.
2. Build the layout shown below.

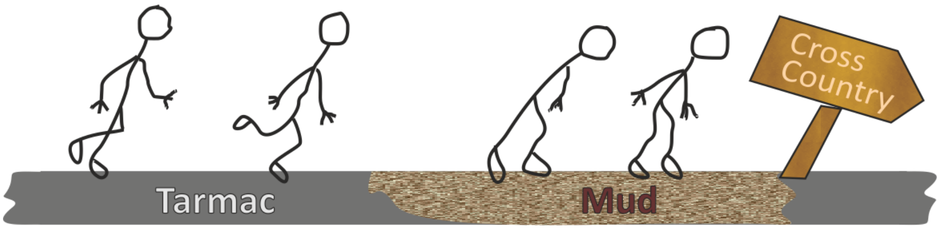


3. Connect the 12V power supply and switch on.
4. Close the switch and notice how bright the bulb looks.
   Remember – the brighter the bulb, the greater the current flowing.
5. Next, 'short-circuit' the resistor by joining both ends with a wire, as shown.
   What do you notice about the bulb?
   What does this tell you about the electric current when you add the resistor?

Resistance - 2

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

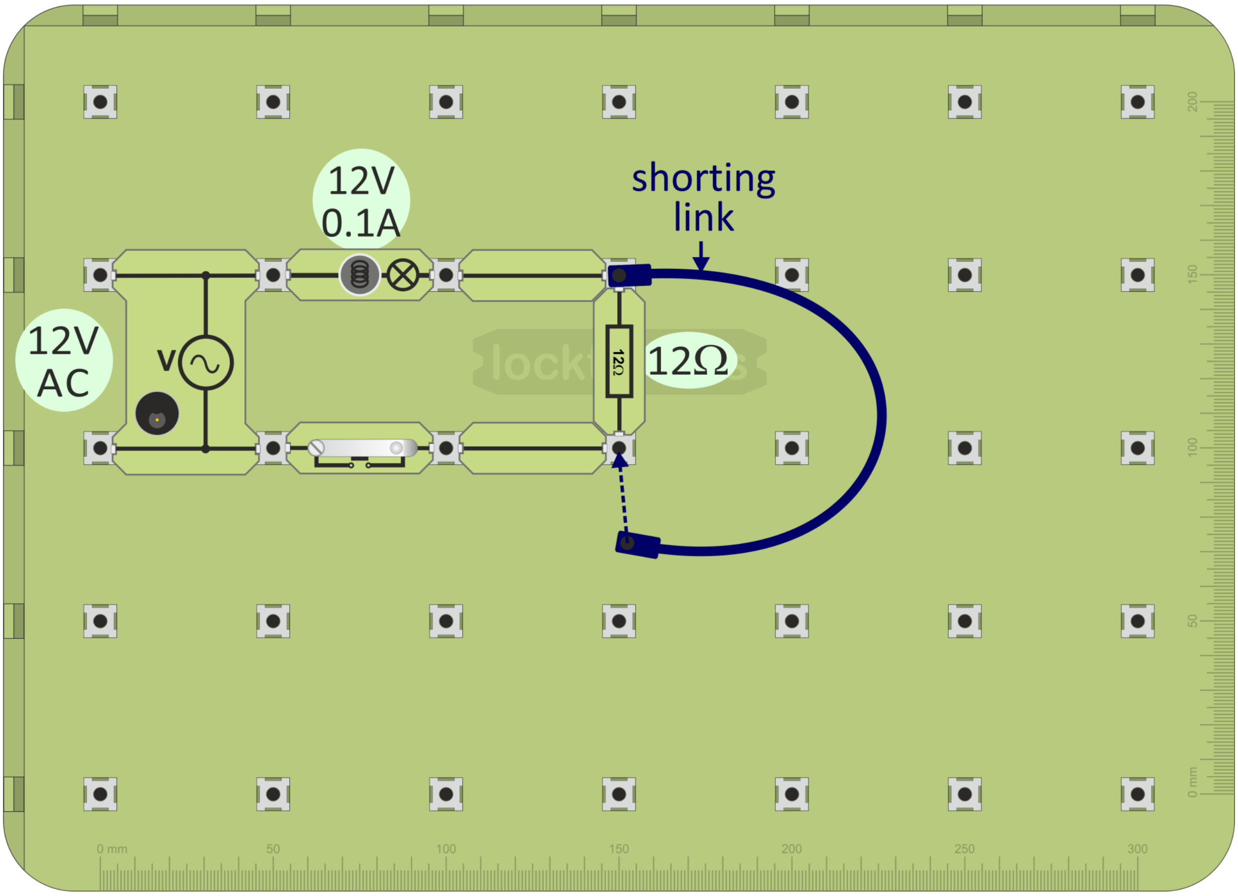
It takes more energy!



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?

Measuring Resistance - 1

i

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

As before, <u>before you switch on</u>:

- 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.)

Ohmmeter

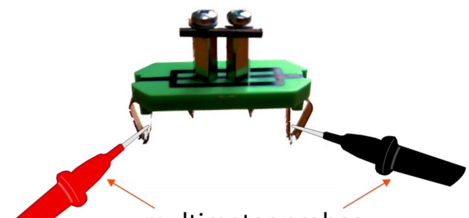
Using a multimeter to measure resistance:

- Plug one wire into the black '**COM**' socket.
- Plug another into the red '**Ω**' socket.
- Turn the dial to select a resistance range, such as 200kΩ. (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.

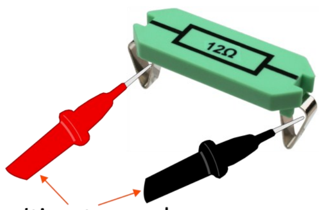
Measuring Resistance - 2

The first task is to measure the resistance of the home made resistor.
We expect this to have quite a low resistance, judging by its effect on the bulb earlier.

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 Handout
6. Next, do the same for the 12Ω carrier.
7. Record its value in the Student Handout as well.



Although we know what answer to expect, the value displayed 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!)

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:

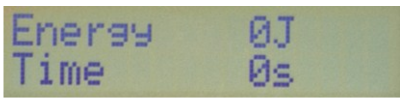
- energy used (or converted) per second;
- measured in watts (W), or kilowatts (kW). (1 kilowatt = 1 000 watts.)

The energymeter:

- 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 opposite.



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.

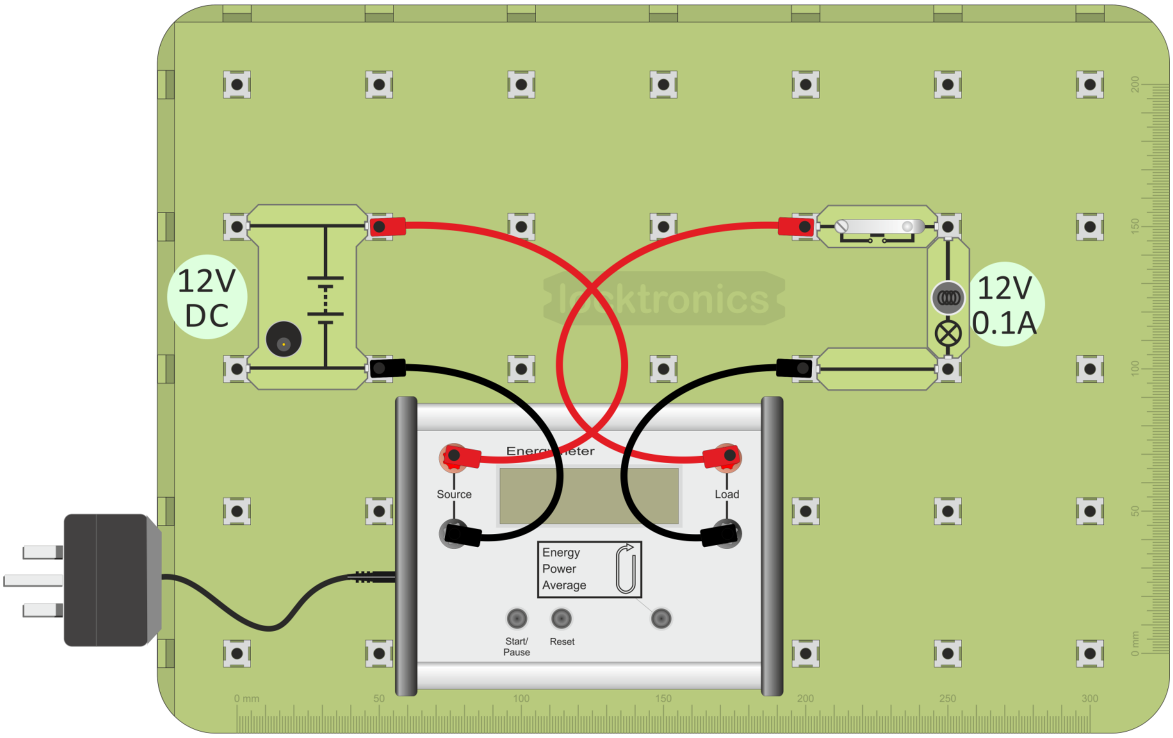
Measuring Power

(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 Handout.

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 Handout.

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:

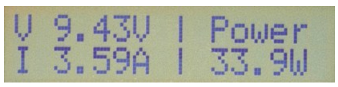
Use the formula: **P = I x V**

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 x 240 = 60W.

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



The power measurement = current x voltage = 3.59 x 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.

Electrical Installation Level 1

Student Handout - For your records

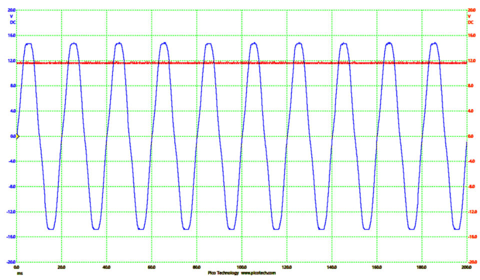
Page 7 - AC vs DC:

The 12V AC power supply has a rms voltage of ………………. .

Page 8 - AC and DC again:

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

The symbols shown are used to distinguish between them.



Page 9 - Conductors and Insulators:

Materials that conduct	Materials that do not conduct

What do you notice about metals? ………………………………………………………………………

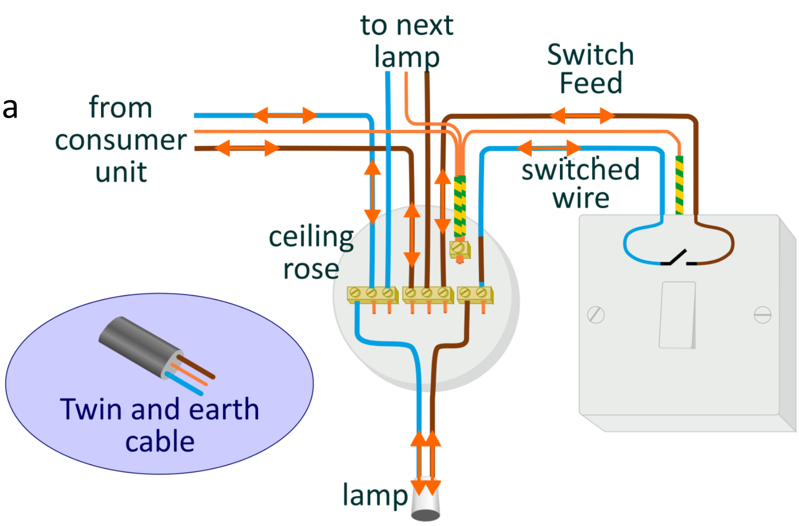
……

Page 11- Circuit diagrams - 2:

Which circuit draws the biggest current from the power supply - **A**, **B** or **C**? ……………….

Page 14 - Current path - 3:

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.

The 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. LED (**L**ight-**E**mitting **D**iode) lighting can be 10 times more efficient.

In a 'short-circuit', where 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 overheating more widespread damage.

The reverse process takes place in a thermocouple. When the junction of different metals is heated, it generates a DC voltage. This can 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 - another protection against current overload and overheating.

Page 21 - 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.

Page 22 - Connect in series - 1:

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?

………

Page 23 - Connect in series - 2:

How does the brightness of these lamps compare with the previous circuit?

………

What does this show about the current flowing in the 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?

………

How does their brightness compare the 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 these differences:

……

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**'?

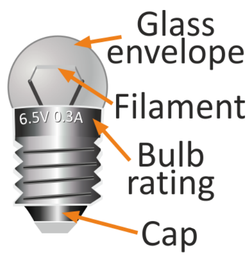
……

Explain these differences:

……

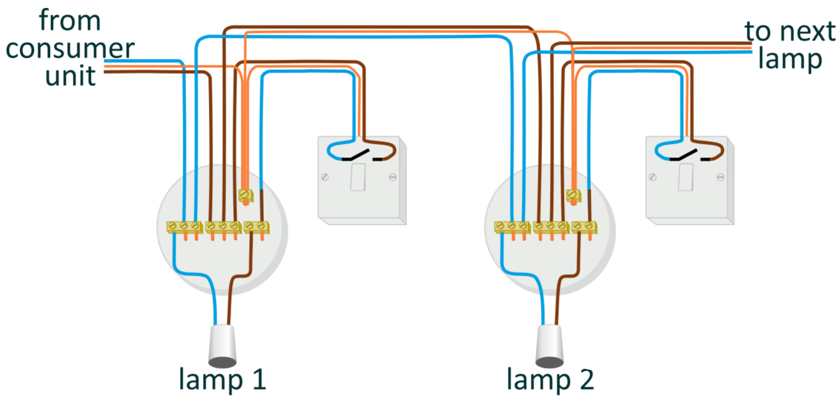
Page 27 - MES bulbs:

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.

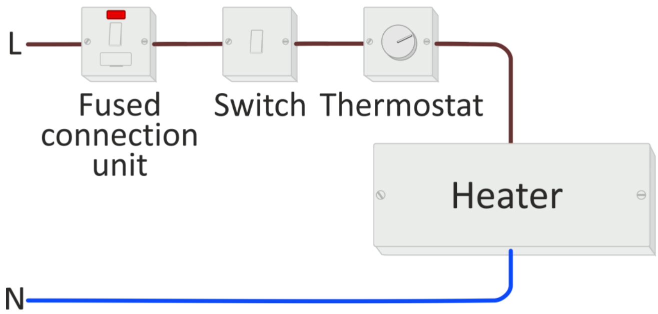


Page 28 - Serial / parallel applications:

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.

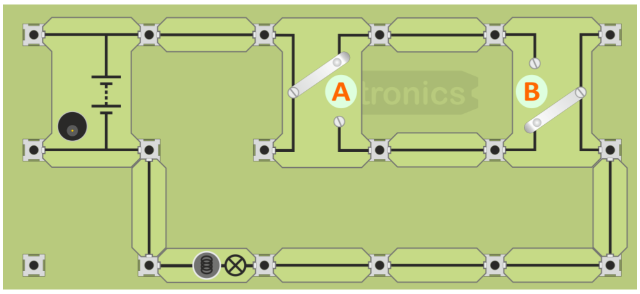


Controls, like fuses, switches and thermostats, must be able to 'break' the circuit and stop current flow to the load device, such as a heater. As a result, they are connected in **series** with the load.



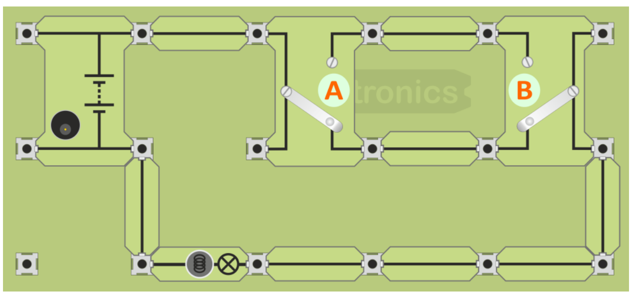
Page 29 - Staircase circuit - 1:

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.

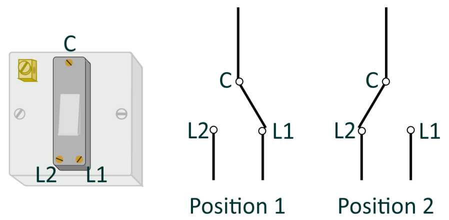
Draw the current path for this arrangement on the diagram.



Page 30 - Staircase circuit - 2:

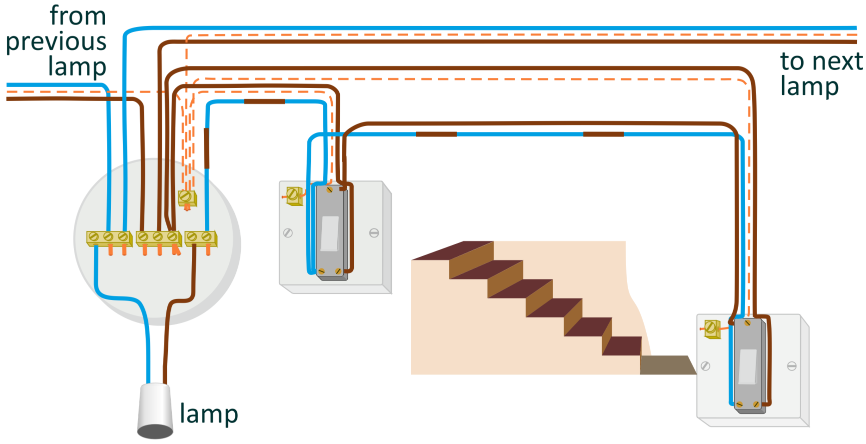
A changeover switch, also called a SPDT (single-pole-single-throw) switch, has three terminals: **C** (for Common), **L1** and **L2**.

Operating it connects **C** to either **L1** or **L2**.



In the 2-way switching circuit:

- **L1** terminals are connected ;
- **L2** terminals connected to each other and to the 'switched wire';
- **C** terminals are connected .



Starting with the incoming 'live' connection (brown) from the previous lamp:

- 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.

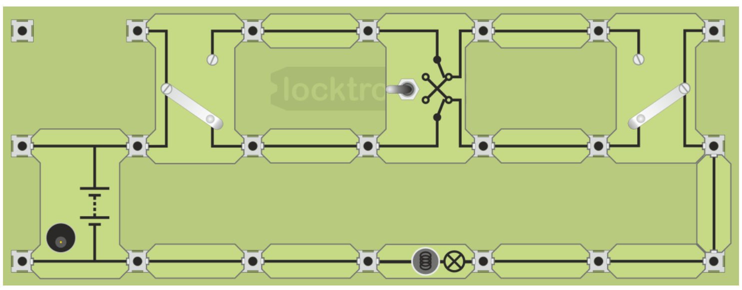
Page 31 - 3-way control - 1:

By adding a third switch - an intermediate switch, (also called a reversing or a DPDT (double-pole-double-throw switch,) the lamp can be controlled by three switches.

The switches are in the positions shown.

The intermediate switch makes the connections shown on the carrier.

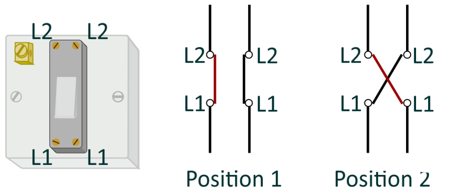
On the diagram, draw the current path.



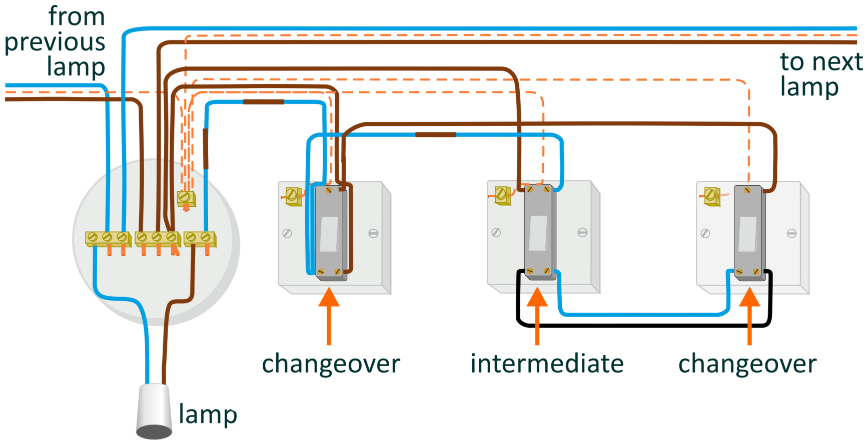
Page 32 - 3-way control - 2:

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

Operating it makes the connections shown.



The three-way switching circuit is shown below:

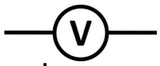


Page 33 - Measuring voltage - 1:

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.

The circuit symbol for a voltmeter is shown opposite.



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

Page 34 - 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?

………

Page 35 - 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 36 - 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:

………

………

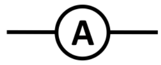
………

Page 37 - 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.

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



ammeter

Using a multimeter to measure current:

- Plug one wire into the black ‘**COM**’ socket and the other 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 38 - Measuring current - 2:

Current at point:	Reading
P	
Q	
R	
S	

Comment on these results:

………

………

Page 39 - 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 40 - Measuring current - 4:

Current at point:	Reading
P	
Q	
R	
S	
T	

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

……

……

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 41 - 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 43 - 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 (kΩ), by an ohmmeter. (1 kilohm = 1 000 ohms.)

Ohmmeter

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 200kΩ (or a range that is much higher than the reading you are expecting.)
- 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.
- Now select a lower range if that is appropriate.

Page 44 - Measuring resistance - 2:

Resistance of 'home-made' resistor = ………………. Ω.

Resistance of Locktronics resistor carrier = ………………. Ω.

Page 45 - 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.

Page 46 - 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 47 - Energy and power:

To calculate electrical power, use the formula: **P = I x V**

(meaning : **power = current x voltage**.)

Example:

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

Power = current x voltage = 0.25 x 240 = 60W.

Instructor Guide

About this course

Introduction

The course is essentially a practical one. Locktronics equipment makes it simple to construct and test electrical circuits. The end result mirrors the circuit diagram, thanks to the circuit symbols printed on the component carriers.

Aim

The course introduces students to the basic concepts used in domestic and industrial electrical installation. It forms the basis for a deeper study of this topic.

Prior Knowledge

No prior knowledge of electricity is needed.
The student should have basic mathematical skills sufficient to calculate a required quantity from a given formula. No manipulation of formulae is expected.

Learning Objectives

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

- build a circuit that makes a bulb light.
- distinguish between AC and DC power supplies;
- carry out an experiment to compare DC and AC power supplies;
- recognise the voltage-time signal for an AC supply;
- name two common sources of DC and AC power;
- state two reasons why AC is preferred for electricity generation;
- test a material to see whether it is a conductor or an insulator;
- recognise standard circuit symbols for batteries, bulbs, resistors, switches and connecting wires;
- build a simple circuit from a given circuit diagram;
- explain the need for a complete circuit in order to allow current to flow;
- identify the path followed by currents in series and parallel circuits;
- relate the behaviour of simple circuits, built on Locktronics kit, to equivalent domestic circuits;
- state that an electric current can cause a heating effect and name three examples of applications;
- describe what is meant by a ‘short-circuit’ and identify fire as the likely hazard;
- describe the use of a fuse and a circuit-breaker in preventing the after-effects of a short-circuit;
- state that an electric current can cause a magnetic effect and name three examples of applications;
- state that an electric current can cause a chemical effect and name three examples of applications;
- recognise and distinguish between series and parallel connections;
- state two reasons why ‘identical’ MES bulbs may have different brightness;
- explain the meaning of the term ‘voltage’ and recognise the circuit symbol for a voltmeter;
- use a multimeter to measure the voltage across a component;
- recognise that the sum of the voltages around a circuit loop equals the supply voltage in that loop;
- recognise that components in parallel have the same voltage across them;
- explain the meaning of the term ‘current’ and recognise the circuit symbol for an ammeter;
- use a multimeter to measure the current through a component;
- identify one cause for failure in a multimeter set to measure current;
- recognise that the same current flows through components connected in series;
- recognise that the sum of currents through parallel components equals that delivered by the power supply;
- explain the meaning of the term electrical ‘resistance’ and describe its effect on current;
- state that resistance is measured in units called ‘ohms’ and convert ‘kilohms’ into ‘ohms’;
- use a multimeter to measure the resistance of a component;
- distinguish between the terms ‘energy’ and ‘power’ and state the units used to measure them;
- use the ‘energymeter’ to measure the power dissipated in a lamp;
- use the formula ‘P = I x V’ to calculate the power dissipated in a component.

What the student will need:

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

1	LK8900	Baseboard
1	LK4100	Resistor - 12ohm,, 1/2W, 5% (DIN)
1	LK5208	Resistor - variable, 250ohm
14	LK5250	Connecting Link
3	LK5291	Lampholder carrier
3	LK2346	MES bulb 12V, 0.1A
1	LK4893	Hand-cranked generator
1	LK6635	LED, red
1	LK6207	Switch, push to make
1	LK6209	Switch on/off
2	LK6208	Switch, changeover, metal strip
1	LK6632	Switch, reversing, toggle
1	LK9998	400 turn coil carrier
2	LK5603	Lead - red - 4mm to 4mm stackable
1	LK5298	Lead - red - 4mm to croc clip
2	LK5604	Lead - black - 4mm to 4mm stackable
1	LK5297	Lead - black - 4mm to croc clip
1	LK5609	Lead - blue - 4mm to 4mm stackable
1	LK7936	Universal component carrier
1	LK8275	Power supply carrier with battery symbol
1	LK2340	AC voltage source carrier
1	LK8591	Energy meter
1	LK9070AP	EMM Accessories Pack
1	LK1110	Multimeter

Using this course:

The experiments in this course should be integrated with teaching to support the theory behind them, and reinforced with practical examples and assignments.

The worksheets should be printed / photocopied / laminated, preferably in colour, for the students' use. They are unlikely to need their own permanent copy of the worksheets, but will need the 'Student Handout' for their records.

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

Time:

It should take students between 15 and 20 hours to complete the worksheets.

It is expected that a similar length of time will be needed to support the learning that takes place as a result.

Instructor Guide

<table>
<tr><th>Page</th><th>Notes for the Instructor</th><th>Timing</th></tr>
<tr><td>3
Introduction</td><td>
The course aims to prepare students for Unit 107 - “Electrical Science and Technology” - part of the Diploma in Electrical Installation level 1 qualification. It assumes no prior knowledge of electricity.
It uses both AC and DC power supplies so that the students is familiar with both and includes an exercise to compare their performance. By default, activities use the AC supply, as in most domestic and industrial installations. At times, the DC power supply is used either because of the instrumentation, or the nature of the investigation.
The layouts show the student how to build the systems and include an appropriate type of power supply carrier, sometimes AC and sometimes DC. Often, this choice is optional and icons are used to identify which type of power supply can be used.
Other icons show the kind of activity being undertaken:
<table>
<tr><th>Icon</th><th>Significance</th></tr>
<tr><td>i</td><td>Content gives information about electricity, or explains some terminology</td></tr>
<tr><td></td><td>Practical activity</td></tr>
<tr><td></td><td>Relates the current activity to jobs in the industrial / domestic realm</td></tr>
<tr><td></td><td>Open-ended activity where the students designs the activity</td></tr>
<tr><td>!</td><td>Health and Safety related issue</td></tr>
<tr><td>x^2</td><td>Activity involves a formula or calculation</td></tr>
</table>
Each activity includes the Learning Objective specified in Unit 107 which it addresses.
</td><td></td></tr>
<tr><td>4
Circuit training</td><td>
The aim of the exercise is partly to build confidence - many people have serious misgivings about anything electrical - they can’t see how it works, worry about electric shocks etc. and partly to impart enjoyment and challenge. It also introduces the Locktronics kit.
Success should be fairly swift and give rapid and positive feedback to the student.
The table at the bottom of the page relates the Locktronics components to their ‘real-life’ counterparts that the students will meet in the work-place. Throughout the course, activities are designed to mirror the tasks and experiences that the students will find in their working lives.
The instructor should add anecdotes from their experience to enrich these activities.
</td><td>15 - 20 mins</td></tr>
</table>

Instructor Guide

Page	Notes for the Instructor	Timing
5 **Power supplies**	This section provides outline information about the role of the power supply, i.e. the plug-top device in these activities but the National Grid in domestic installations. It introduces the two types of electrical power, AC and DC, and justifies the need for both. At this stage, the student needs to know little about the generation process, but the instructor may wish to point out that the alternator, an AC generator, whether driven by steam, water, wind or internal-combustion engine, is usually more efficient than the equivalent DC generator. Transformers, which work only on AC, have the ability to step-up or step-down voltage and current very efficiently. Both of these factors argue in favour of generating electricity in AC form. The remainder of this page looks at common sources of AC and DC power and mentions that each can be converted into the other by using appropriate circuitry. The instructor could support this section using examples of electricity sources - batteries, solar cells, alternators etc.	**10 - 15 mins**
6 **AC versus DC - 1**	The activity shows that DC and AC power supplies can perform the same task - lighting a lamp. This will eventually lead to a discussion of the r.m.s. value of an AC supply, not through mathematical analysis, but as the DC equivalent voltage that produces the same effect. This activity looks at the first part of the task - identifying two bulbs that have the same brightness, i.e. are roughly identical.	**20 - 30 mins**
7 **AC versus DC - 2**	This continues the task spelled out in the previous activity - to show that DC and AC power supplies can perform the same task. The instructor may wish to point out that the average AC voltage is zero - it spends equal times at positive and negative values. The peak value of the AC voltage is similarly inappropriate as a realistic measure of the effect of an AC supply. Most of the time, the AC voltage is smaller than that peak value. Here, one lamp is driven off a 12V DC supply and the other off a variable AC supply (using the 250Ω 'pot' to vary the output of the AC supply.) When the two bulbs are judged to be the same brightness, the outputs of the DC and (variable) AC power supplies are doing the same job.	**20 - 30 mins**
8 **AC and DC again**	The top diagram shows the voltage-time graph of an AC signal. The instructor could demonstrate this on an oscilloscope, though the students themselves are not expected to have any understanding or expertise in using one at this stage. It would make sense for 'electricians-to-be' to focus on activities using AC. However, multimeters often offer more measurement ranges for DC. The 'energymeter' used later for energy and power measurement works only on DC. As a result, both forms of power supply are used within the activities. Sometimes, the activity must use the DC power supply. The icon that accompanies each activity indicates which should be used or where there is a choice.	**10 - 15 mins**

Instructor Guide

Page	Notes for the Instructor	Timing
9 Conductors and Insulators	This activity divides a range of materials into two broad categories - electrical conductors and electrical insulators. This categorisation is too rough, as some materials conduct (or insulate) better than others. However, it is a start! In effect, it uses the lamp and power supply as a continuity tester. It may be worth the instructor pointing this out, as later in the course, students will meet similar devices. If the instructor wishes to streamline this activity, each group of students could be given only three or four materials. The results of all the groups can then later be pooled. The instructor may wish to analyse the results to point out that most metals are good conductors, whereas non-metals are insulators. A good topic for discussion is whether water is a conductor. The key is to distinguish between pure (i.e. de-ionised) water - an insulator - and impure, e.g. tap water or sea water, that definitely conduct.	**20 - 30 mins**
10 Circuit diagrams - 1	The students meet the first of a number of forms of circuit diagram. It is the one in widespread use in the electronics industry and the one used by the Locktronics system. Students should realise the importance of using standard notation for circuit diagrams as a short-hand way to represent wiring installations.	**10 - 15 mins**
11 Circuit diagrams - 2	Continuing the theme of standard circuit notation, this activity tests the student's understanding of circuit diagrams. Each circuit is assembled in turn and then the student uses the brightness of the brightest bulb in the circuit to decide which draws the biggest current from the power supply. Obtaining the right answer does not guarantee that the task was carried out correctly! The instructor needs to circulate to check progress while this task is being carried out .	**20 - 30 mins**
12 Current path - 1	The activity begins with a reminder of some of the vocabulary being used. The aim is partly to continue confidence-building and partly to embed the notion of a complete circuit. The diagram shows the path taken by the current. The use of double-headed arrows indicates AC current. The student sees the effect of 'breaking' the circuit, by removing a connecting link and by unscrewing a bulb, reinforcing the need for a complete circuit. The instructor could contrast this situation with a domestic gas installation, where only one pipe is needed rather than a circuit. Nothing returns to the gas supplier! Unlike electricity, gas is burned! Road traffic offers a number of analogies for 'breaking' the circuit - road works, accidents, congestion. The instructor may wish to expand on these with the class.	**15 - 25 mins**

Instructor Guide

Page	Notes for the Instructor	Timing
13 Current path - 2	This activity extends the work of the previous one. The desired outcome is that the student realises that a complete circuit is needed for current to flow, and that the route taken by the current through the connecting links, the 'shape' of the circuit, is unimportant. The activity invites the student to create other 'shapes' with the caveat that ther should be no junctions. Parallel circuits behave differently, as later activities will show. The instructor should warn about the need to avoid short-circuits In the Locktronics situation, these are of no significance - the power supply simply shuts down for the duration of the short-circuit. In 'real-life' circuits, the consequence could be far more serious - a fire or electric shock.	**15 - 25 mins**
14 Current path - 3	This makes the important link between electrical theory and practice. The previous activity involved circuits made from carriers having single wires, whereas domestic lighting installations use 'twin-and-earth' cables to reduce the number of wires involved (and for mechanical protection of the current-carrying wires). The instructor should check that the students recognise the link between them. The students are given the task of tracing the current route through the circuit. After allowing the students time to do this, it could be summarised as a class exercise. The instructor could have an example wired up so that students can compare the diagram with the 'real thing'.	**15 - 25 mins**
15 Effects of electric currents - 1	The student is required to know the three effects which can accompany an electric current - heating, magnetic and chemical. This activity looks at the first. To begin with, the student feels the glass envelope of a filament lamp. As a later section points out, the filament glows yellow-hot because it is heated to a very high temperature by the current. Next, the student makes an electrical heater by clamping a few strands of steel wool in the universal component carrier. If too many strands are used, the resulting current may be so high that it shuts down the power supply and nothing is seen. If too few are used, then they might heat up sufficiently to burn and melt. Getting the right number is a matter of practice.	**20 - 30 mins**
16 Heating effects	This page highlights some of the applications of electrical heating. This could be the focus of a number of assignments - recent developments in electrical lighting, home heating, electrical safety etc. Although the topic of fuses comes much later, the instructor may wish to focus on it now. The formula for electrical power, P = I x V, is left to the end of this course, but can be introduced here in order to determine appropriate cartridge fuse values for common devices.	**10 - 15 mins**

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17 Effects of electric currents - 2	This activity requires a DC power supply to ensure that the resulting magnetic field is steady. The lamp has two functions - to indicate that a current is present, and to limit that current to a value that does not over-heat the coil or cut out the power supply. If the student notices no effect on the compass needle, it may be that the baseboard is oriented in the wrong compass direction. Rotating the board through 90^0 should cure this. The student waves a magnet near the plotting compass to illustrate that the current-carrying coil has the same effect as a magnet. With the eventual study of transformers in mind, the student tests to see whether a 'core' of magnetic material, the steel nail in this case, intensifies the magnetic field.	**20 - 30 mins**
18 Magnetic effects	The focus here is the electric motor, a widespread application of electro-magnetism. It is present in a host of domestic appliances, some of which also include heaters. Once more, this is a rich source of assignments. Other applications are listed and the instructor may wish to develop themes relating to these or introduce others. Mention of the circuit-breaker can be linked back to work done on the fuse.	**15 - 25 mins**
19 Generating electricity	This activity demonstrates how mechanical energy can be converted into electrical energy - the basis of many forms of commercial electricity generation. The first load to be attached to the output is a LED. As a form of diode, these allow conduction (and so light) only in one direction. Hence, the instructions say that the student should turn the handle gently to begin with, in case the handle is rotated in the wrong direction. The second load is a filament lamp. The contrast between the two, in terms of how easy it is to turn the handle, is quite marked, and can be used to emphasise how efficient LED lighting is compared to incandescent lighting.	**15 - 25 mins**
20 Effects of electric currents - 3	The chemical effect of electricity may not be an easy one for the instructor to access. Hence, the experiment is marked 'optional'. It may be done as a demonstration or made a topic for individual research. The point is made that both chemistry and electrical science rely on the movement of electrons. The link between them is really inevitable. Once again, to make any effect observable, the DC power supply must be used. The lamp indicates the presence of the electric current. Close observation of the beaker shows that chemical changes are taking place.	**20 - 30 mins**

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21 Chemical effects	Chemical effects of electricity are extremely useful. The topic of batteries could occupy the whole course. Rechargeable batteries are found in a huge range of appliances, from mobile phones to electric and hybrid cars. Again, rich assignment territory! Electrolysis and electroplating are a bit more esoteric. The instructor may choose to set these topics for individual research, or use video clips.	**10 - 15 mins**
22 Connect in series - 1	The meaning of 'series' is outlined at the top of the page. The circuit itself is the same as that built when looking at the need for a complete circuit and at current paths. Now the emphasis is different. It is a series circuit and so what does that imply. Perhaps the most significant property is that a break in the circuit anywhere stops the current everywhere. When Christmas tree lights were connected in series, this was the cause of the annual battle to find the faulty bulb. It is one of the reasons why the lights in a house are connected in parallel, but that debate may be better held back for a couple of pages. The page introduces a possible problem. The success of the investigation relies on the bulbs being identical, so that they are equally bright when the currents through them are equal. One of the targets for this investigation is the mistaken belief that the current gets smaller as it goes around the circuit. If that were so, the bulbs would get dimmer the further they were from the start of the circuit. There is an unfortunate possibility that the student may see just this result but because of the structure of the bulbs themselves, not the size of the current. Hence, the note at the bottom of the page! One approach is to tell the students to swap over the bulbs to see if that has an effect. If it does, then the bulbs are not identical, and should be changed	**20 - 30 mins**
23 Connect in series - 2	The focus is still properties of the series circuit. It is important that the student grasps this behaviour and so a second one is included before the parallel connection and hybrid circuits are introduced. This one involves two lamps connected in series. By the end of the course, the student will be able to say that two lamps have less resistance than three and so the current is bigger. For now, it is appropriate that te student sees that this is so without being able to explain it in terms of resistance. Once again, there is a caveat about the effect of mass-production on the performance of the bulbs.	**20 - 30 mins**

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24 Connect in parallel	The meaning of 'parallel' is outlined at the top of the page. The instructor could enlarge on this by discussing traffic flow. Why is a bypass seen as a solution to traffic flow through a black-spot such as an old village? The aim is to contrast the behaviour of this circuit with that of the first series circuit. The procedure is the same, but the results are different. When part of the circuit is broken, the effect applies only to that part of the circuit. In a house, when one bulb 'blows', the others are unaffected. The instructor might point out that each of the three bulbs is connected directly to the terminals of the power supply. Each is unaware of and unaffected by the others. Once again, students need to know that the performance of the bulbs can affect the outcome of the investigation.	**20 - 30 mins**
25 Series / parallel - 1	Very often, some components in a circuit are connected in series and some in parallel. That is the arrangement studied here. The first task for the student is to decide which are in series and which in parallel and to work out possible current paths - these issues are related! Next, the effect of breaking the circuit by unscrewing a bulb is examined. The result depends on which bulb is chosen. There is nothing new here - if it is a parallel connection, the effects are extremely local to the bulb - if in series, the effects can be more widespread.	**20 - 30 mins**
26 Series / parallel - 2	Another example of mixed series / parallel connections! The student needs exposure to a number of these examples to feel confident about them. The approach is slightly different in that the student is asked to predict what will happen and then test that prediction. The instructor may wish to do the first part as a 'brain-storming' session with the whole class. This allows some assessment of how well the class and individuals in it are understanding the work done so far.	**20 - 30 mins**
27 MES bulbs	As pointed out above, the investigations into series and parallel circuits require bulbs with very similar properties. This page explains why this might not be so and gives a test to decide what is going on.	**10 - 15 mins**
28 Serial / parallel applications	As earlier, this section links between electrical theory and practice. The instructor should stress the need for understanding this link and once again could have examples wired up so that students can compare the diagrams with the 'real thing'. At this stage, students probably have some general awareness of fuses and thermostats and do not need detailed knowledge.	**15 - 25 mins**

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29 Staircase circuit - 1	Locktronics makes it easy to set up and study the two-way lighting circuit often used to control hall and staircase lighting in the home. The instructor should allow time and encourage experimentation to strengthen understanding of how this is achieved. Students are asked to trace out the current path for different combinations of switch position. Their work in the Student Handout will inform the instructor on the depth of their understanding. Again, a class demonstration using real components will help cement this understanding. The instructor must judge whether to introduce the term 'SPDT' at this stage.	**20 - 30 mins**
30 Staircase circuit - 2	This section follows up the work done on two-way switching by looking at how this is achieved in practice. Actual examples of changeover switches will help again. The instructor could have a low voltage circuit set up for students to compare with the diagram. The text in the activity guides students through the operation of the circuit. Instructors could ask individual to explain this to the rest of the group to test understanding.	**15 - 25 mins**
31 3-way control - 1	This extends the previous circuit by adding an intermediate switch. The 'Locktronics' layout is quite straightforward and allows experimentation. The real circuit is more complex! The results in the Student Handout allow the instructor to assess a student's level of understanding on this demanding topic. Again, it is for the instructor to decide whether to use the term 'DPDT' for the intermediate switch.	**20 - 30 mins**
32 3-way control - 2	The treatment mirrors that for two-way switching and is equally important, and difficult, for students at this stage in their training. As before, actual examples, such as a low voltage demonstration circuit will help. Class discussion and activities such as wiring up a 'template' and checking its operation using a low voltage supply, will help to identify weaknesses in understanding. Able students, or groups of students, could be asked to create and test a 4-way control circuit using a second intermediate switch.	**15 - 25 mins**

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33 Measuring voltage - 1	The multimeter is one of the most feared of measuring instruments, yet probably the most useful! One problem is that no two models look the same. Another is that it requires knowledge to use it - an understanding of the symbols and appreciation of which sockets to use. The development of the auto-ranging multimeter has both helped and hindered. It reduces the knowledge needed to use it, but masks what is going on. Students need practice in using multimeters and experience of a number of different types, in order to feel confident in their use. It is important that they observe the instruction to select the range and connect to the sockets before they switch on. Most multimeters have an internal fuse to protect the meter when measuring current. This can 'blow' if the student makes a range selection with the meter turned on. Voltage is the simplest electrical measurement to make, but one of the most difficult to explain. Electrical current is easy to visualise - a host of little electrons bobbling along a wire. 'Voltage' is why they flow. It is related to the force that pushes them around the circuit, but isn't that force. It's related to the energy gained or lost by the electrons as they pass through various components in the circuit, but isn't that energy. Hence the phraseology "...is a measure of…" That will have to serve for now. Some texts use 'electro-motive force' ('e.m.f') and 'potential difference' (p.d.) This adds nothing to understanding and increases complexity as the two terms are not interchangeable. For this course, and many others, 'voltage' is fine! Measuring voltage is easy because the multimeter is connected to the two ends of the component being investigated - in parallel with the component, in other words. The guidance given here includes interpretation of the symbols used and identification of the appropriate sockets. Where other types of multimeter are used, the instructor may need to explain these to the students.	**15 - 25 mins**
34 Measuring voltage - 2	A familiar circuit is set up - three lamps connected in series - to introduce voltage measurement. One issue that the instructor may wish to explore is that voltage is a relative measurement, involving two connections. In this regard, it is rather like measuring height. Heights are quoted relative to a known level - "...above sea-level…" "… from the floor…" Sometimes, the base level is not even mentioned as it is obvious. "My height is 1m 53cm." means from the bottom of my feet to the top of my head. It doesn't (usually) mean that I am 1m 53cm above sea level! Some measurements are absolute. My mass is 80kg at sea-level, on the Moon or on the floor of the house! The voltage measurements here can lead to Kirchhoff's Voltage Law, but that's for later. For now, they show that the power supply voltage is shared between the three lamps. It is one factor, among several, that decides how bright they are.	**20 - 30 mins**

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35 Measuring voltage - 3	Measuring voltage is easy because the multimeter is connected to the two ends of the component being investigated - in parallel with the component, in other words. The guidance given here includes interpretation of the symbols used and identification of the appropriate sockets. Where other types of multimeter are used, the instructor may need to explain these to the students. The voltage measurements here show that the voltage across each lamp is equal to the power supply voltage, a result that comes as no surprise when looking at the way the lamps are connected to the power supply.	**20 - 30 mins**
36 Measuring voltage - 4	This exercise is to measure relevant voltages in the mixed series / parallel circuit studied earlier. The student should be able to make sense of the results, bearing in mind the outcomes of the investigations into purely serial and purely parallel circuits.	**20 - 30 mins**
37 Measuring current - 1	As pointed out earlier, current is easy to visualise - hordes of electrons bobbling down a wire. As each electron carries an identical amount of negative electrical charge, current can also be described as the rate of flow of electrical charge past a point. However, measuring current is not quite so straight forward. In order to measure current, it must flow through the ammeter. In other words, the ammeter is connected in series with the component under investigation. That implies that the circuit must be broken to allow the ammeter to be inserted, connected to the two points created by the break. As for measuring voltage, the guidance includes interpretation of the symbols and identification of the sockets. Other types of multimeter may require a briefing by the instructor.	**15 - 25 mins**
38 Measuring current - 2	The circuit has been seen before - three lamps connected in series. In order to accommodate the insertion of the multimeter (ammeter), extra connectors are placed before and after the lamps. The results are predictable. It is a series circuit, so the same current should flow in all parts. Hence it is pointless to say that, for example, the current reading at 'Q' gives the current flowing the second lamp. If the same current does not flow everywhere, then where does the excess current go?	**20 - 30 mins**
39 Measuring current - 3	The process is the same, but applied to a parallel circuit (which includes extra connectors to facilitate taking the measurements.) The analysis is a little more complicated. At any junction, the total current flowing out of the junction is equal to the total current flowing into it. Hence, the current at point 'T' should equal the sum of the currents at 'R' and 'S'. The current at 'P' should equal the sum of the currents at 'Q', 'R' and 'S' etc.	**20 - 30 mins**

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40 Measuring current - 4	Next, the same procedure is applied to a circuit containing both series and parallel connections. The results from the previous two investigations still apply, but only to parts of the circuit. The current at 'P' equals the sum of the currents at 'Q' and 'R'. The current at 'Q' is equal to the current at 'S', and so on. The brightness of each bulb depends on the size of the current flowing through it, so the lamp above 'R' should be the brightest.	**20 - 30 mins**
41 Resistance - 1	This exercise introduces formally the topic of electrical resistance. The universal component carrier is used to make a graphite resistor. Its effect on the brightness of a lamp is seen by inserting it in series, to control the current through the lamp, and then removing it, by short-circuiting it with a connecting wire.	**20 - 30 mins**
42 Resistance - 2	The introduction likens the effect of electrical resistance on electrons to running in mud for us. There is an increased 'friction' - electrons colliding with and losing energy to surrounding atoms - resulting in the generation of heat. The experiment follows the same procedure as the previous but this time uses the 12Ω resistance carrier. The actual resistnce used is not important except that if it is too big, it will cut the current to such a low value that the bulb will not glow. Then the student has no way of distinguishing this situation from a break in the circuit.	**20 - 30 mins**
43 Measuring resistance - 1	The introduction offers a view of the meaning of electrical resistance but does not define it! It is important that students can manipulate prefixes like 'kilo' and 'milli'. The important aspect of measuring resistance is spelled out at the top of the page - the component under investigation must be disconnected from the circuit first. (Otherwise you might be measuring the resistance of other components in the circuit as well.) As for other measurements using the multimeter, it is important that the range is selected and the probes attached to appropriate sockets before the multimeter is switched on.	**20 - 30 mins**
44 Measuring resistance - 2	This activity uses the multimeter to measure the resistance of the home-made resistor and of the Locktronics resistance carrier. In a way, we are cheating in saying "Choose the 200Ω range…" because in this instance we have a good idea what the resistance is. In general, the rule is - 'Start on the biggest range and work down.' The measurements follow the procedure outlined on the previous page. Measuring the resistance of the 12Ω resistance carrier may seem strange, as the answer looks obvious. However, in part, it reassures the student that they are doing it properly. Also, the measurement will vary a little from the expected. Students should be aware that: • components are mass-produced to a tolerance; • meters are not 100% accurate. Both factors are probably at play here.	**20 - 30 mins**

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45 **The energymeter**	This section starts by distinguishing between the terms energy and power, often confused by students. Energy is a very difficult concept to pin down. We know when we've got it, and when we haven't got it. We pay for it on a regular basis - when we fill up the car with petrol, when we buy a battery, when we pay a gas bill etc. Power measures how quickly we are going to 'use' energy, (convert it to a different form, to be precise). A powerful car engine probably uses more petrol than a frugal one. A high-power light bulb 'uses' more electricity than a low power one. To add to the confusion, the units commonly used sound similar. Officially, energy is measured in joules and power in watts. Often, devices have a power rated in kilowatts (kW) and electrical energy is measured in kilowatt-hours (kW-h). (A kilowatt-hour is the energy used in one hour by a device with a power rating of 1kW.) The energymeter is a device designed to allow measurement of energy and power at low voltage. Bearing in mind the formula for electrical power, P = I x V, it is not surprising that the meter can also display current and voltage readings. With an internal timer, it uses the power reading and elapsed time to calculate energy consumed.	**15 - 25 mins**
46 **Measuring power**	This exercise uses the energymeter to measure the power rating of one lamp and then several. The wiring needed is straightforward - the source is connected to the two terminals on the left, allowing the meter to measure source voltage - the load is connected to the terminals on the right because the current must flow through the meter in order to be measured. From those two readings, the power is calculated. The student is challenged to measure the combined power of two lamps, first in parallel and then in series. The instructor can use the results on the Student Handout to assess that the task was carried out correctly.	**20 - 30 mins**
47 **Energy and power**	The page begins by expanding on the outline given earlier on energy and power. The important part of this page is the power formula. Many students have a blind-spot for formulae and will need this spelling out in fine detail, using words as well as symbols and numbers. Although only two examples are given in this section, many more may be needed before this formula makes sense to some students. 'Smart' meters are becoming commonplace in domestic and industrial electricity installations. One of their functions is to display the same information as the energymeter, for individual devices or for the full system. This allows the consumer to make informed decisions about electrical energy usage. This could be the basis for an assignment or a piece of individual research by the student.	**20 - 30 mins**