locktronics™

Simplifying Electricity

Automotive Electricity

MATRIX

CP4388

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Contents

Worksheet 1

Conductors and insulators

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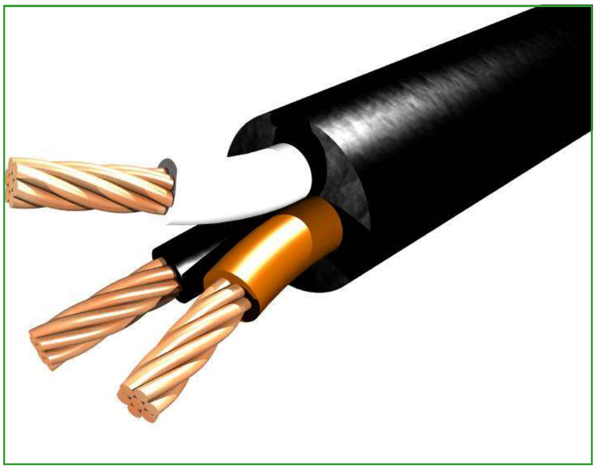
We are surrounded by many kinds of materials. They behave in different ways. For example, some pass electricity while others do not.

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

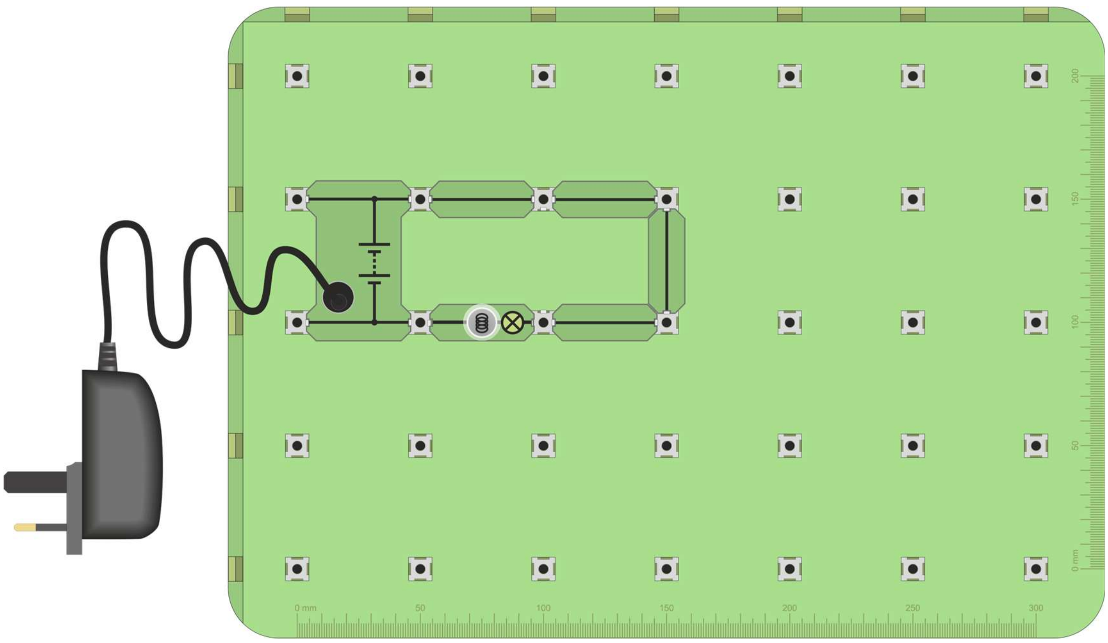
Photograph shows a three core cable



Over to you:

- Build a circuit that makes a bulb light.
- Use a 12V 0.1A bulb. (See the picture opposite!)
- Electric current is measured in ‘amps’ (A).
- The bulb rating shows the voltage and current that the bulb is designed to operate with.
- Set the power supply to 12V.

The picture below shows one way to build this circuit.



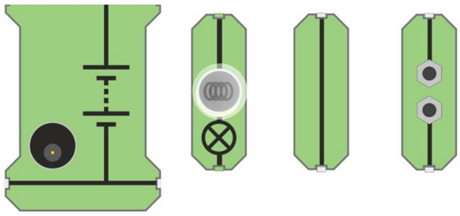
Worksheet 1

Conductors and insulators

Automotive electricity

So what?

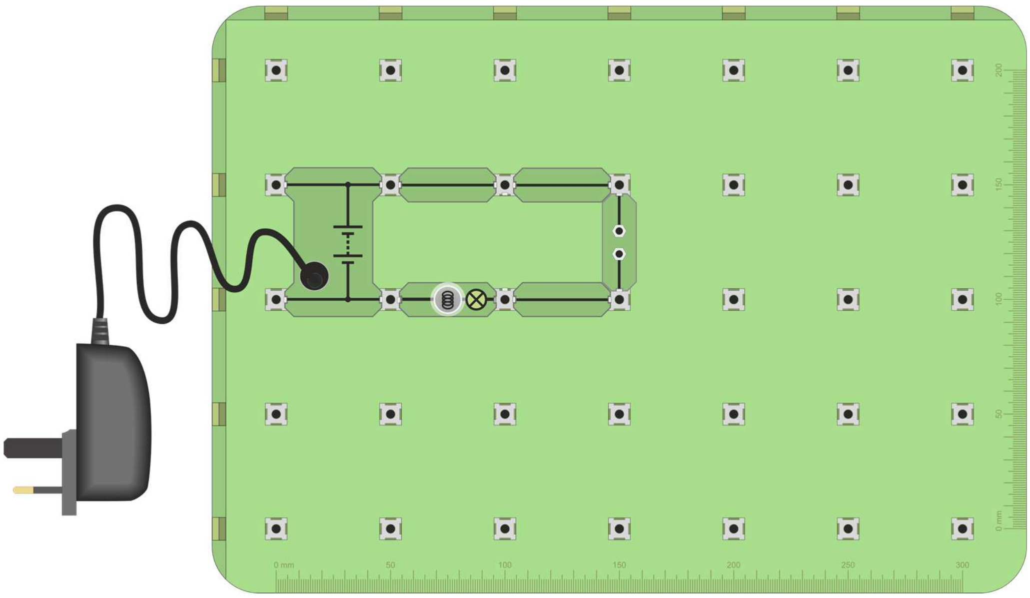
Here are the names of some of the components that you use on the board.



Battery Bulb Link Sampler

Over to you:

- Swap one link for the sampler. Your board now looks like the picture below.



- Put different materials in turn across the gap, and see if the bulb lights. Try :
  - kitchen foil (aluminium), a rubber, paper,
  - polythene, copper, air, lead,
  - pencil lead (graphite), glass, wood,
  - a coin, a piece of cloth, a plastic pen
  - any other handy items.

Materials that conduct	Materials that insulate

- Sort the materials into **conductors** and **insulators**.
- Fill in the table in the Student Handout, like the one shown here, with the findings from your experiment.

Worksheet 1

Conductors and insulators

Automotive electricity

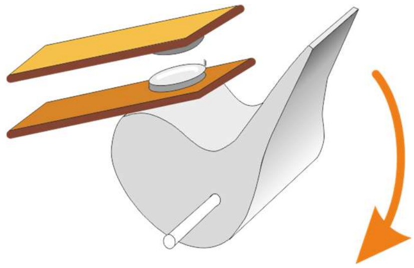
So what?

Answer these questions in the Student Handout.

- Look at the materials that let electricity pass. Which class of substance are they?
- If you had a hard, shiny object that felt cold to touch, would you expect it to be an electrical conductor? Explain your answer to your partner or to your instructor.

Challenge!

- Think of a way to test whether water is a conductor or an insulator. Check your idea with the instructor, and if you get the go-ahead, try your idea out.
- Test pure water, tap water (not the same thing!) and salty water. Is there a difference?

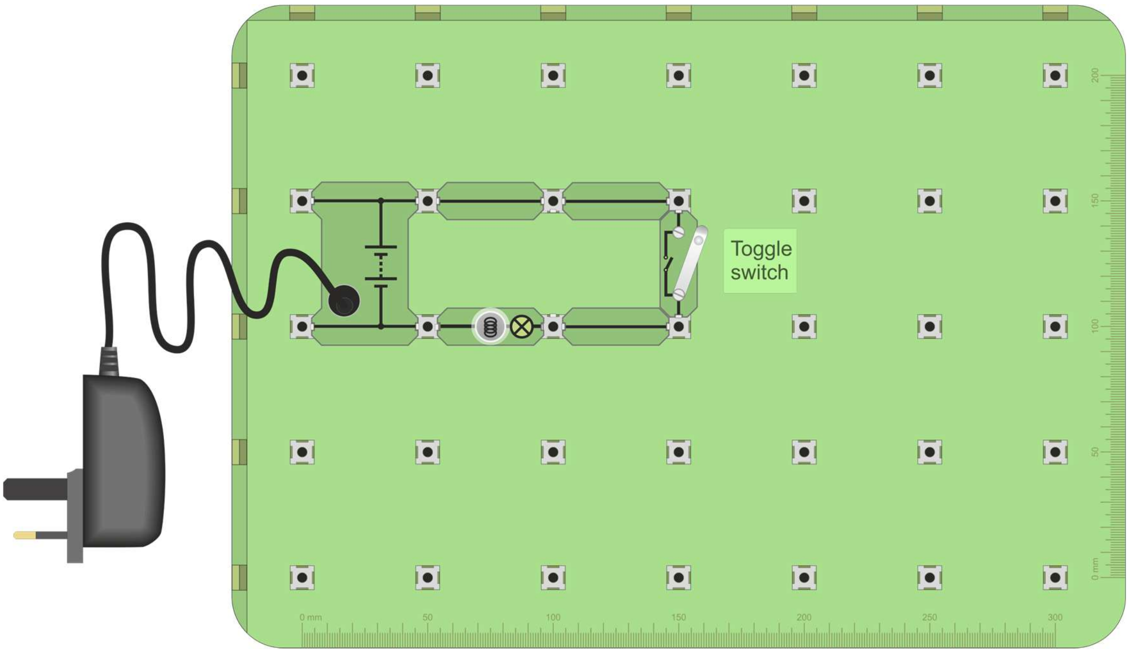


We usually need something to activate our electrical circuits. A switch does just that! It relies on the fact that air is an insulator.

The diagram shows what happens inside a switch. When you press the lever down to switch it on, the two metal contacts of the switch are forced together, 'closing' the switch, making it conduct electricity.

Over to you:

- Set up the arrangement shown in the diagram. It uses a 12V 0.1A bulb.
- Check that power supply is set to 12V.
- Test what happens when you close and open the switch.



So what?

A switch starts and stops the flow of electricity.

Here are the names and circuit symbols for two types of switch:

Push switch

Toggle switch

- A **push switch** is 'on' only as long as you are pressing it.
- When you turn on a **toggle switch**, it stays on, until you turn it off.

Challenge!

- Change the circuit so that there are two 12V bulbs in it and the switch controls both bulbs.
- Now change the circuit again so that the switch controls only one bulb. The other bulb should be lit all the time.
- Does it matter where the switch is placed in the circuit shown above?

  Explain the answer to your partner and then do an investigation to see if you were right.

Worksheet 2

Circuits and symbols

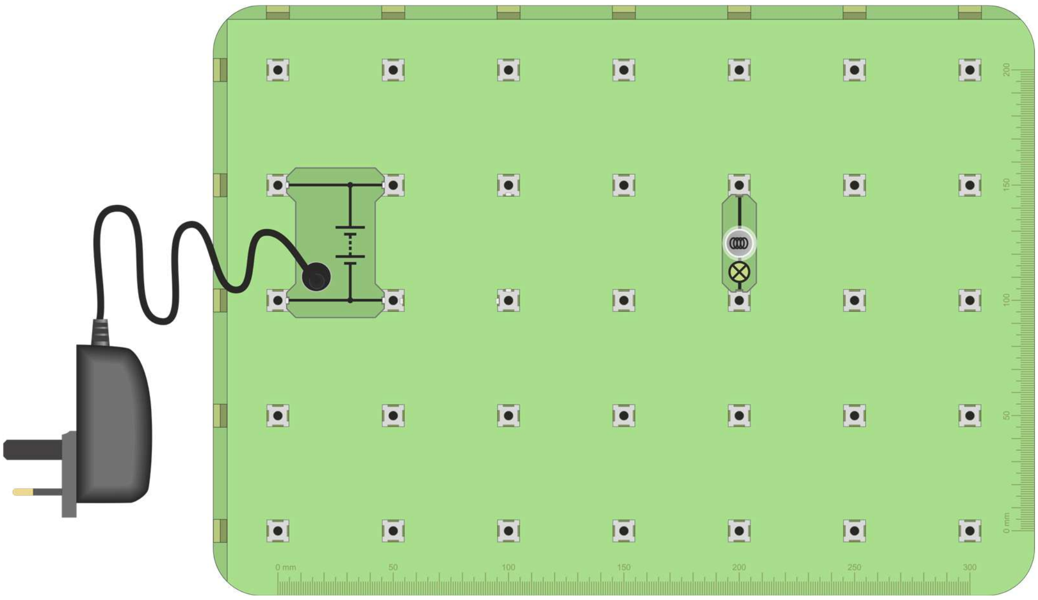
A roller coaster goes round a tracked circuit and finishes at the same place as it starts. Electricity is the flow of invisible particles called electrons. They go round a track of wire.

We call these electric pathways - **circuits**.

Photograph shows a rollercoaster ride.

Over to you:

- Set up the arrangement shown.
- Check that the power supply voltage is 12V.
- Now, add connecting links to make the bulb light!

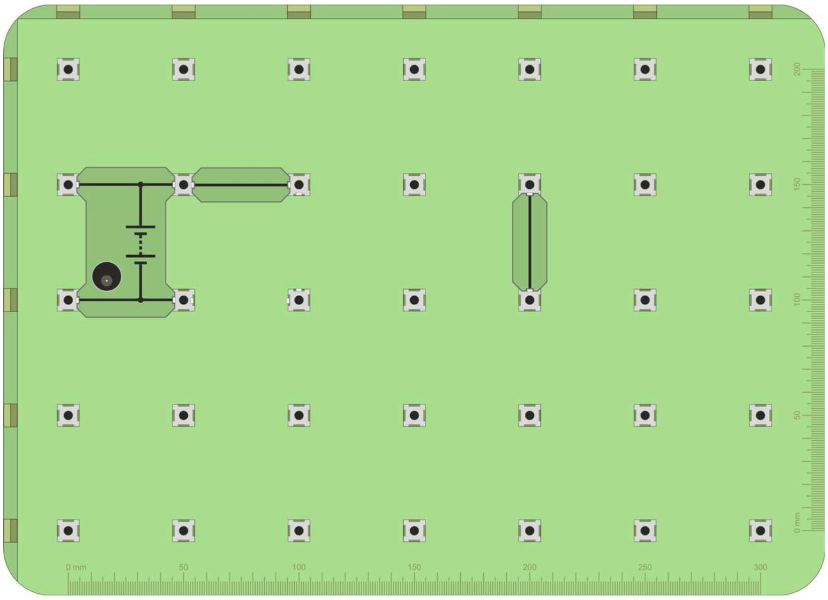


Challenge!

Make other circuit shapes, using extra links, to make the bulb light.

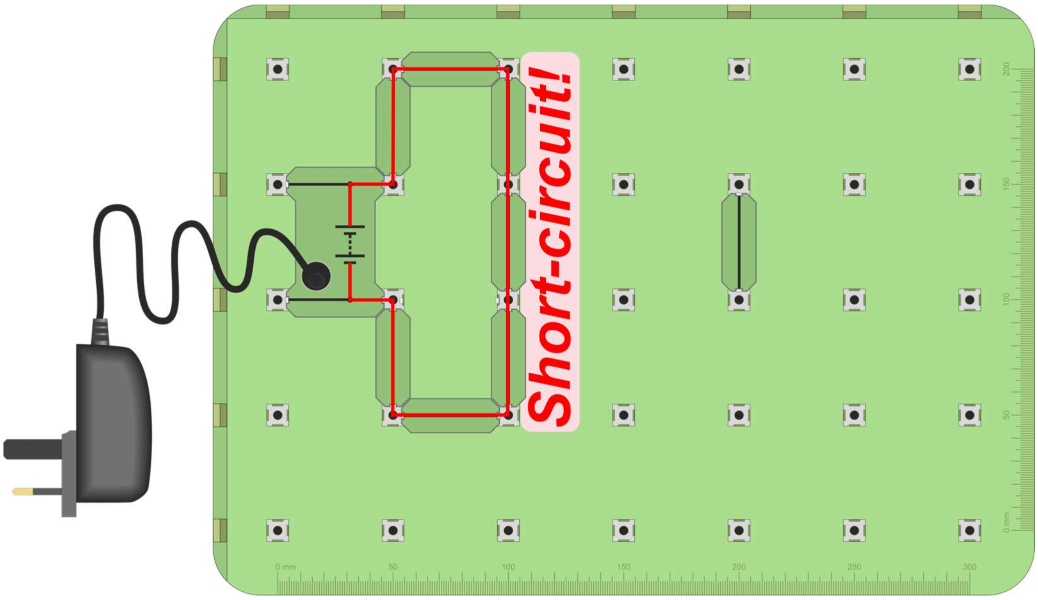
You could try to complete the arrangement shown here.

Does the ‘shape’ of the circuit make any difference?



BE CAREFUL!

Don’t create a short-circuit, where the electricity can get from one side of the power supply to the other without going through the bulb. This might damage the power supply!



The diagram shows an example of a short-circuit.

Worksheet 2

Circuits and symbols

Challenge!

- Can you set up a circuit to make two bulbs light?

There are two ways to do this:

- One makes the bulbs dimmer than when there was just one bulb.
- The other keeps roughly the same brightness as in the one-bulb circuit.

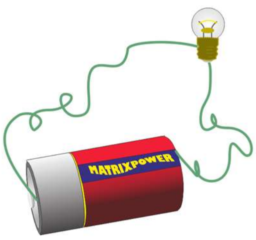
- Can you make both of these circuits?

Circuit symbols

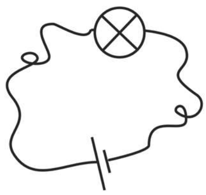
Everyday, you come across **symbols**. They are quicker to grasp than long messages using words!

In this sign, the language may be difficult to understand, but the symbols are not!

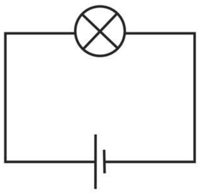
Circuit symbols identify the components used in a circuit and show how they are connected.



A circuit might **look** like this.



It is simpler to describe it using symbols.



Or, better still...!

Worksheet 2

Circuits and symbols

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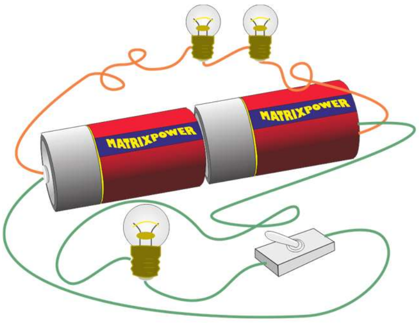
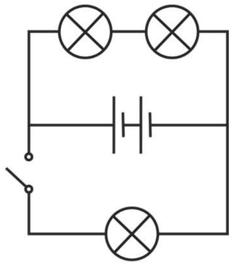
Over to you:

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



A

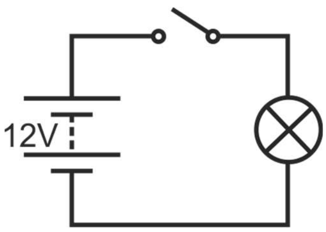


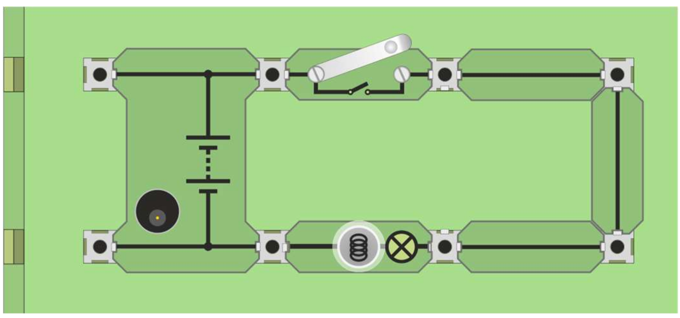
B

More circuit symbols are shown in the table below. You should try to learn them as you use them.

					
Battery	Toggle switch	Lamp	Fuse	Resistor	Sounder
supplies electrical energy	allows a circuit to work	turns electricity into light	a safety device	controls the size of the current	turns electricity into sound

- Build the circuit shown in the circuit diagram below. It uses a 12V 0.1A bulb and a 12V power supply. One possible layout is given.
- Try to remember how bright the bulb glows.
- In the next circuits, you will be asked to compare bulb brightness with this one.



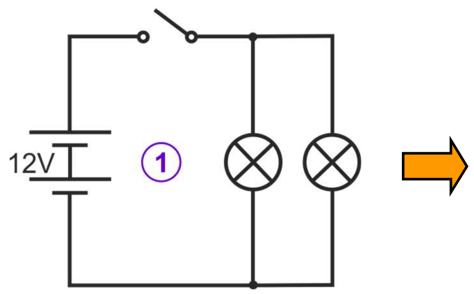


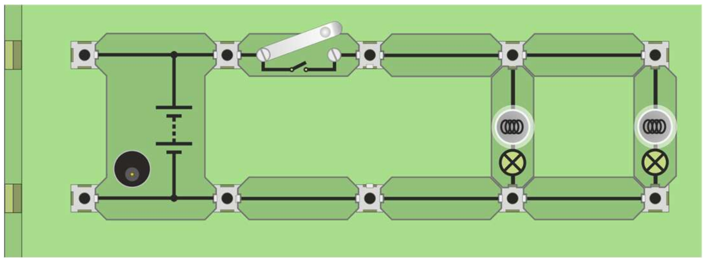
Worksheet 2

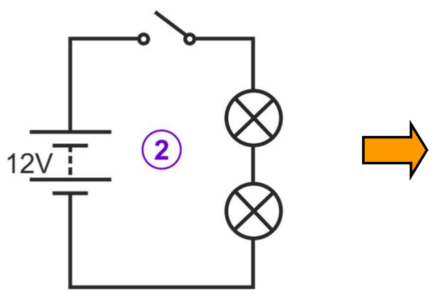
Circuits and symbols

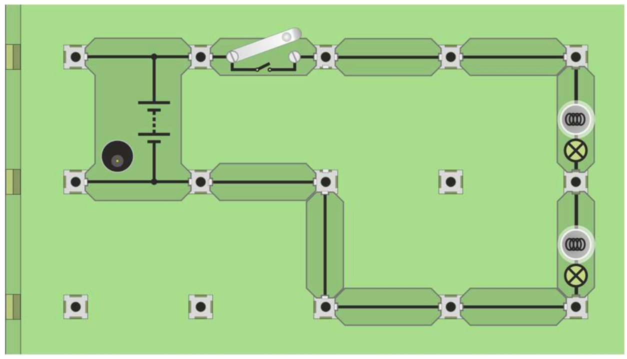
Over to you:

- Build circuits 1 and 2, using 12V 0.1A bulbs and a 12V power supply.

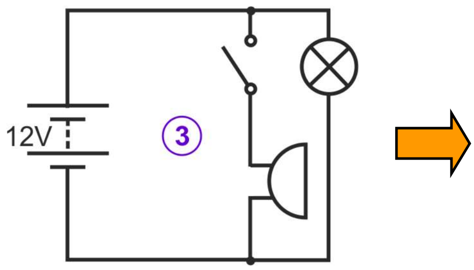


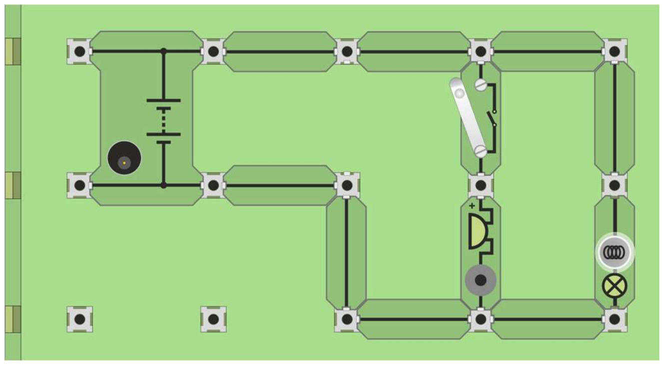






- Compare the brightness of the bulbs in these circuits with that on the previous page.
- Record your answers in the Student Handout.
- Now build circuit 3, using the same bulbs and power supply.





- Which device is controlled by the switch?
- Record your answer in the Student Handout.

Worksheet 2

Circuits and symbols

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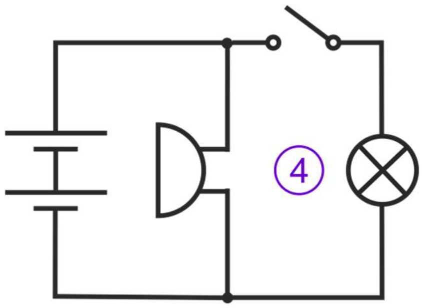
So what?

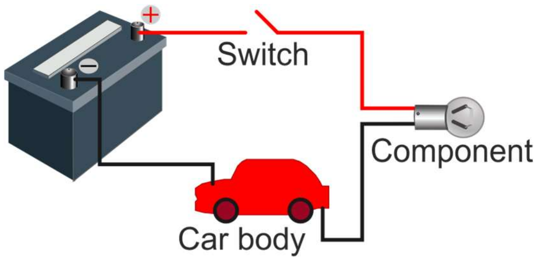
- It is much quicker and easier to describe what is in a circuit by drawing a diagram using symbols. However, you must use the symbols that everyone understands.



Challenge!

Here is another circuit.

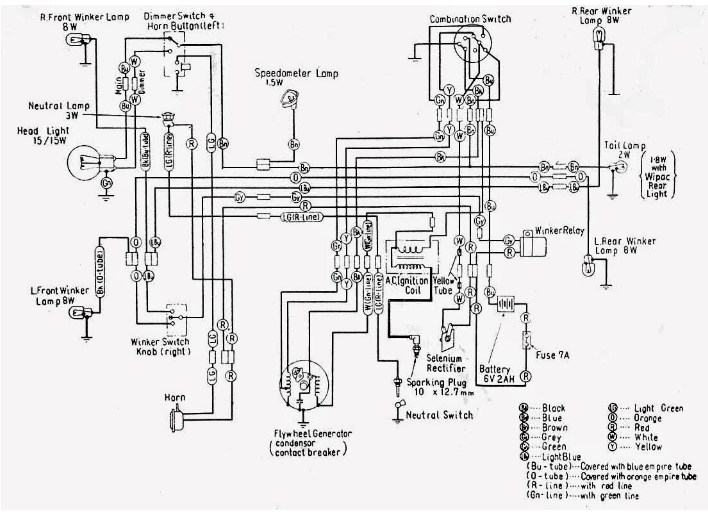
- The increasing use of plastic mouldings in vehicle bodies can cause complications. Explain why!
- Record your answer in the Student Handout.



Other forms of circuit diagram:

There are other types of circuit diagram, such as those used by vehicle manufacturers.

Traditionally, vehicles use 'earth-return' or 'ground return' to complete the electrical circuits. Current flows along a cable from the battery to the component under power. It returns through the car's metal body, which is connected to the battery by a thick cable.



This practice explains why many vehicle wiring diagrams seem to be covered in a multitude of 'earth' or 'ground' symbols.

Using the terms 'earth' or 'ground' in this situation can be misleading. The car is definitely **not** connected to the Earth. It is sitting on rubber tyres. Rubber is an excellent insulator. The use of 'earth' in this context is traditional, rather than factual.

Worksheet 3

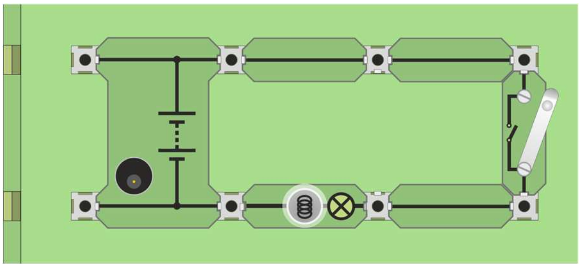
Electric current

We use electricity in many ways, not just for lighting small bulbs. Headlamps, windscreen wiper motors, information screens, electronic control systems - just some of the uses of electricity in the car. It might even drive the car itself!

Photograph shows a modern electric car charging post.

Over to you:

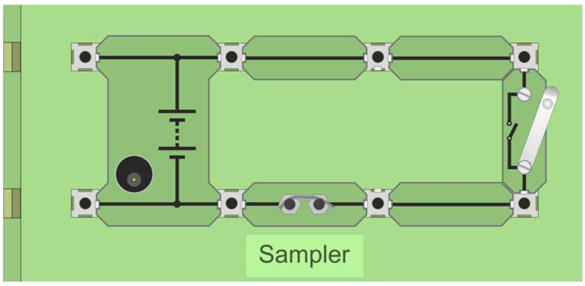
Sometimes useful, sometimes a problem, electric currents always warm up the wires that they flow through. That is the focus of this investigation.



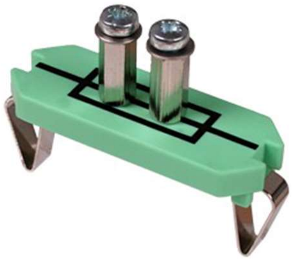
Filament lamp:

- Set up the arrangement shown in the diagram.
- It uses a 12V 0.1A bulb and a power supply set to 12V.
- Switch on by closing the switch.
- Look at the filament. It should be glowing yellow-hot.
- Take hold of the glass envelope of the lamp. Does it feel warm?
- Switch it off.

Wire wool:



- Change the circuit for the one on the right.
- Tease out one or two strands of wire wool from the pack. Carefully clamp them across the gap of the sampler.
- Set up the arrangement shown in the diagram.
- Switch on by closing the switch.
- What happens?



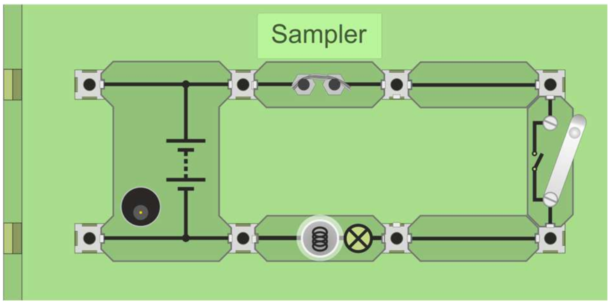
Sampler

Worksheet 3

Electric current

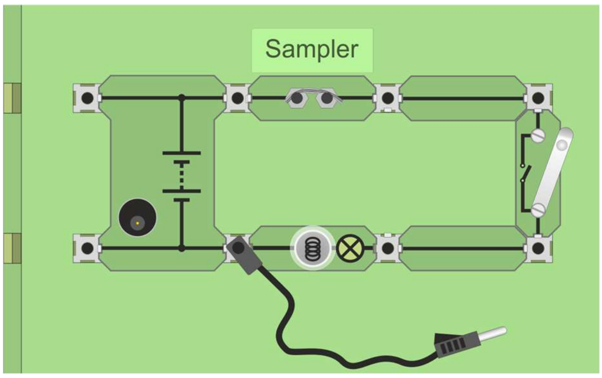
So what?

- An electric current can heat things up.
- Some kinds of wire heat up more than others.
- Some wires get so hot that they glow. This is what is happening inside some kinds of light bulb. In terms of power, this kind of light bulb gives out more heat than light!
- You have just seen a rudimentary fuse in action. The electric current was big enough to melt the wire, causing a break in the circuit and stopping any further current.



Over to you:

- Build the circuit shown opposite. It uses the sampler with strands of wire wool clamped across it, as well as a 12V 0.1A bulb and a 12V power supply.
- What happens when you close the switch?
- Build the circuit shown in the second diagram.
- Leave one end of the black lead loose and make sure that it does not touch any part of your circuit.
- Close the switch and make sure that the bulb lights.
- Now create a fault in the circuit - touch the loose end of the black lead onto the right-hand side of the bulb, for a moment.
- You just short-circuited the bulb. What happens?
- Record all your observations in the Student Handout.



So what?

- The fine fibres of steel wool get hotter than the other wires, so hot that they melt.
- That creates an air gap, rather like when a switch is open, stopping the electric current.

Worksheet 4

The electromagnet

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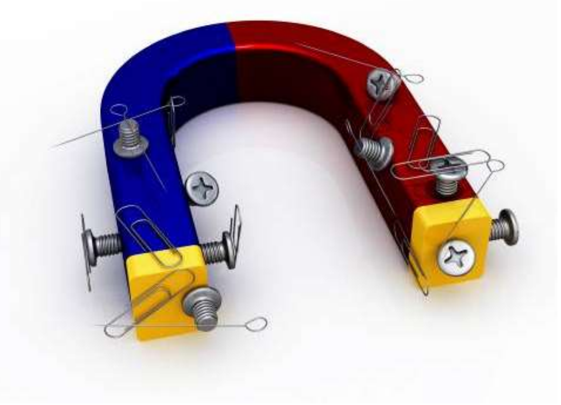
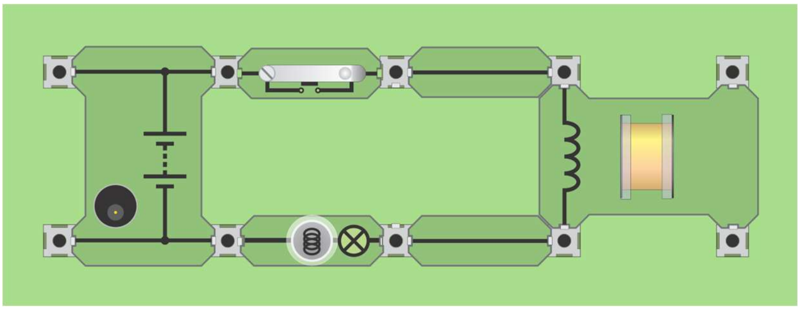
We use electricity in many ways, not just for lighting bulbs. It heats our homes, drives our washers, driers and vacuum cleaners and powers our computers, games and phones.

It can even make wires behave like magnets!

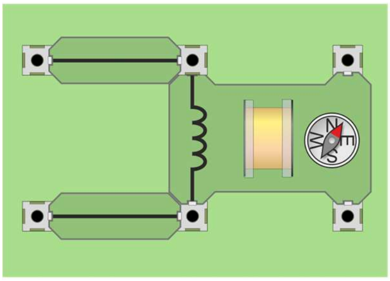
Photograph shows a magnet.



Over to you:

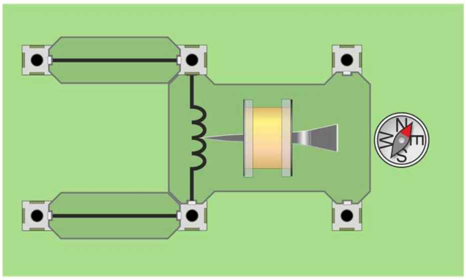


- Set up the arrangement shown in the diagram, using a 12V 0.1A bulb, and the mounted coil .
- Make sure that the power supply is set to 12V.
- Place a magnetic compass next to the coil.
- Turn the board so that the compass needle points across the opening of the coil. The second diagram shows this in close-up.
- Wave a magnet near the compass. What happens?
- Press the switch. What happens?
- Now switch off and repeat this again.
- What does this show about the coil when it was carrying a current? Record all your findings in the Student Handout.



So what?

- An electric current can make the coil behave the same as a magnet.



Challenge!

- Slide a nail inside the coil, as shown in the third diagram. Switch on the power supply and watch the magnetic compass. Is the effect stronger than before? Record your findings in the Student Handout. See if you can make paper clips stick to the nail. How do you think you could make the magnetic effect stronger?

Worksheet 5

The solenoid

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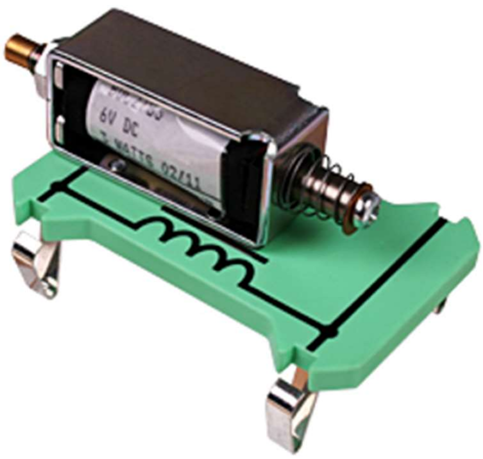
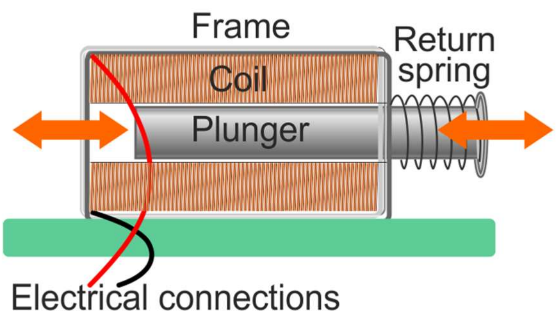
Solenoids have the job of turning electrical energy into mechanical movement. They have a number of uses in vehicles:

- the starter motor - to mesh the starter motor with the engine flywheel;
- fuel injectors;
- central locking systems - to operate doors remotely;
- gearboxes - to select or inhibit gear selection.



The solenoid has a structure like that in the diagram here.

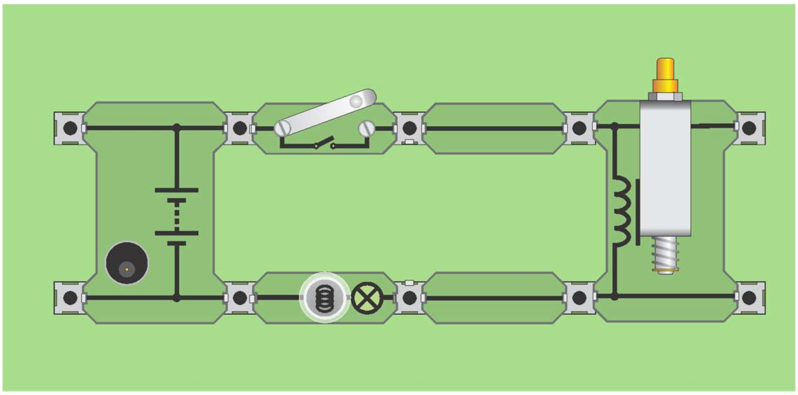


A coil of wire is wound round a cylindrical tube. The plunger, made from magnetic material, is free to slide inside that tube.

When a current flows through the coil, it creates a magnetic field. This pulls the plunger into the centre of the coil, compressing the return spring as it does so. When the current ceases, the spring forces the plunger back to its original position.

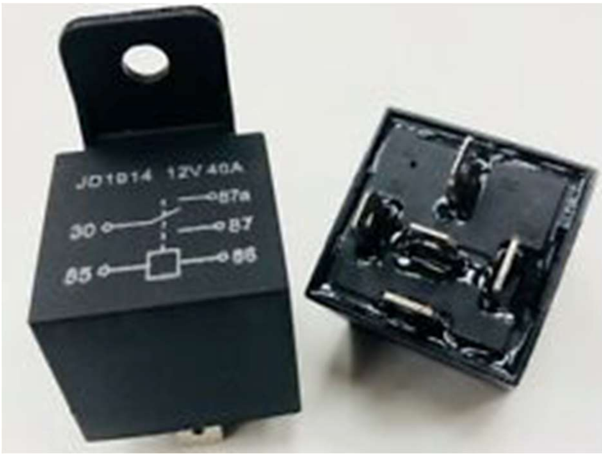
Over to you:

- Build the arrangement shown in the diagram.
- Set the power supply to output 12V
- Test the effect of closing and opening the push-switch.
- Record your results in the Student Handout.

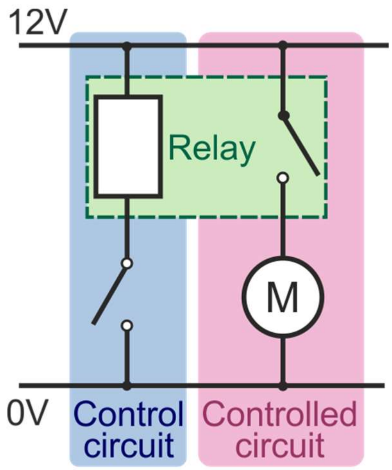


A relay uses a solenoid to activate a switch. This allows one circuit, the control circuit, switches on another, the controlled circuit. Why bother?

- It can save on heavy, expensive copper wire.
- It allows you to switch on a device remotely.
- The first circuit may not deliver enough current to operate the device.
- Photograph shows a typical automotive relay.

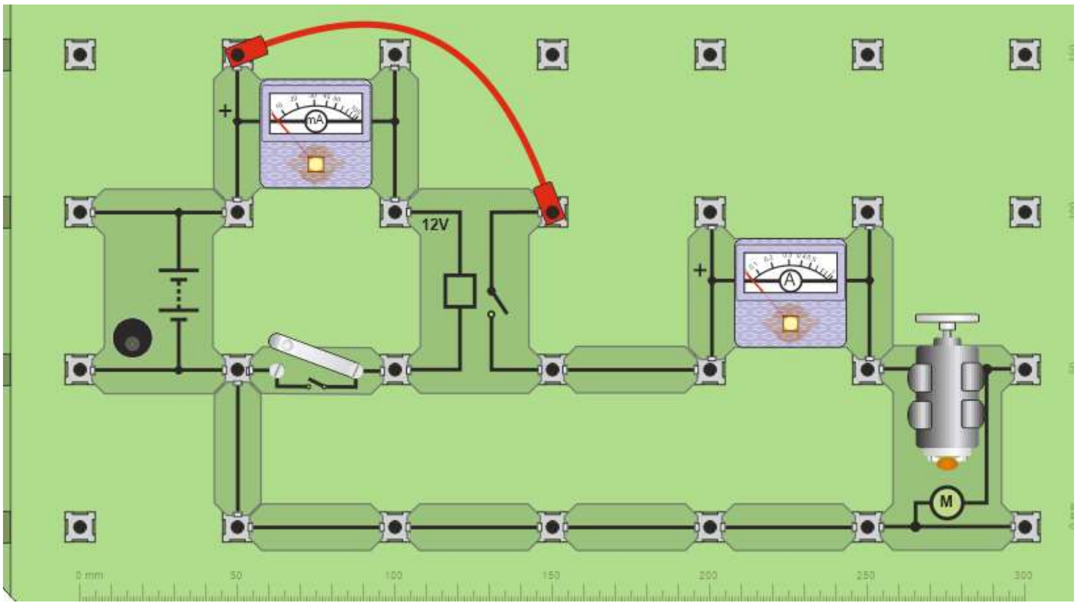


The circuit diagram shows a relay used to control a motor. It is coloured to help identify exactly what is happening. The control circuit contains the relay coil, activated by the switch below it. In the controlled circuit, an electric motor is operated by the relay contacts.



Over to you:

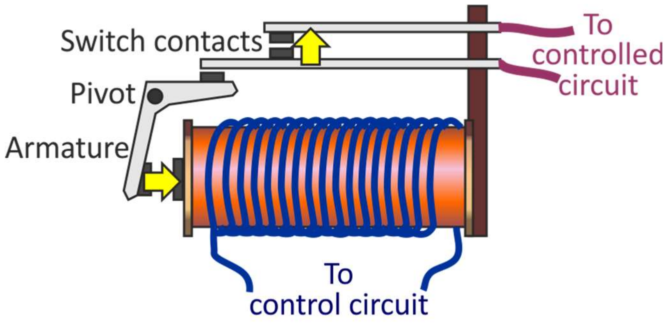
- Set up the circuit shown in the layout diagram.
- Make sure that the power supply is set to 12V.
- The circuit uses two ammeters: the milliammeter measures the current in the control circuit. The ammeter measures the current flowing in the motor (controlled circuit.)
- Energise the relay by closing the switch in the control circuit. The motor should start to spin.
- Measure the currents flowing in the control and controlled circuits.
- Record the values in the Student Handout and comment on them.



Worksheet 5

The relay

So what?

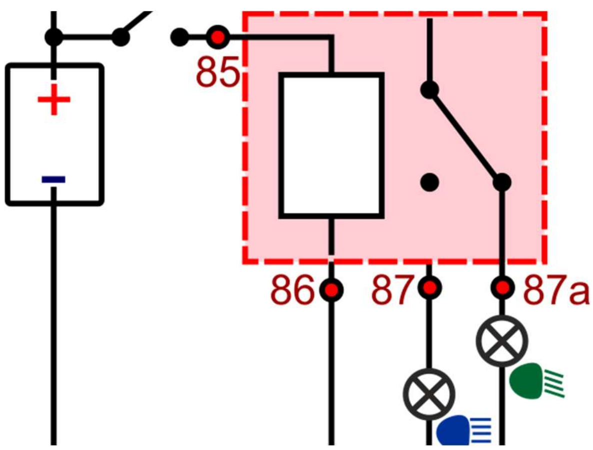


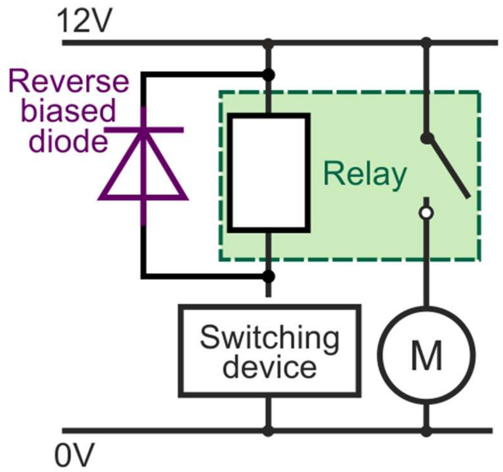
- The diagram illustrates how a relay works.
- An electric current flowing around the coil creates a magnetic field which pulls the armature towards the core inside the coil.
- In doing so, it pivots and pushes the switch contactstogether, closing the switch and operating the device connected in the controlled circuit.
- A relay turns low current signals into high current signals. In a car, it operates devices such as the starter. The starter **motor** takes an enormous current and must be linked to the battery by low resistance cables, i.e. thick copper cables. Using a relay, the starter **switch** is connected with thin wires, as the current it draws is very small. The result - much less copper needed!
- The relay on the previous page is known as a '4-pin' relay. It uses two connections for the
- relay coil in the control circuit, and two for the controlled circuit, one to the power supply and one to the motor. It is also known as a 'make-and-break' relay - a simple on / off switch in the controlled circuit.

4-pin relay

5-pin relay

- The '5-pin' relay also has two connections to power the relay coil.
- However, it has three connections for the controlled circuit, allowing it to act as a changeover relay, to switch from one device to another.
- The diagram below shows a 5-pin relay used to switch a headlight between full beam and dipped beam. It also shows the standard pin numbering for this type of relay.

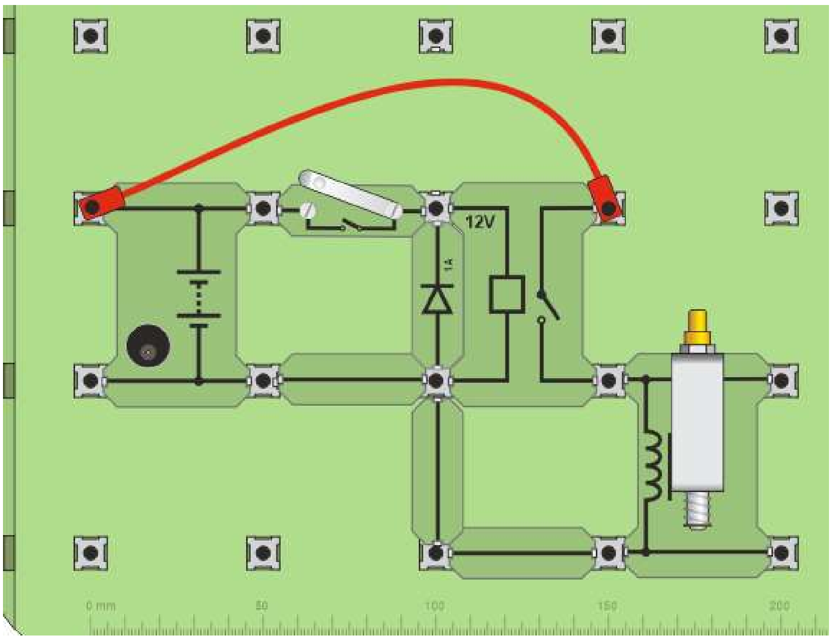




- Although not needed in this investigation, a silicon diode is often connected in reverse bias across the relay coil to avoid damage to the driver, e.g. transistor, when the coil is turned off.
- This is shown in the following circuit diagram.
- The problem is that the magnetic field in the coil collapses when the current is switched off.
- As it collapses, it can generate a high voltage, called a 'back e.m.f.' which risks damaging semiconductor switching devices like the transistor. The diode ensures that the back e.m.f. never gets above 0.7V.

Challenge!

- Use the relay to operate the solenoid from a push-switch.
- One way to do this is shown in the layout below.
- Complete the circuit diagram for this circuit, and answer the questions in the Student Handout.



Worksheet 6

Series and parallel

Automotive electricity

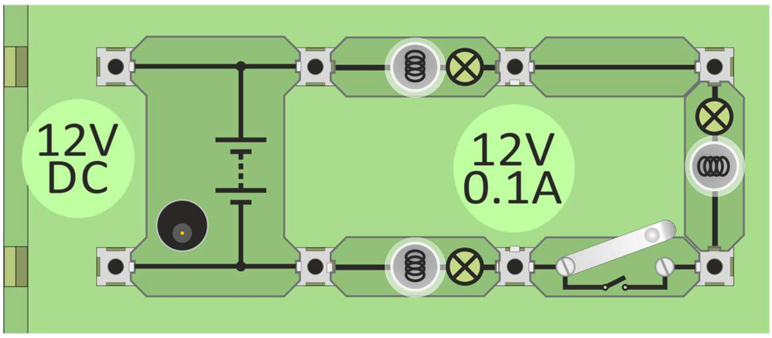
Sat-nav (satellite navigation) systems plan our route when travelling by car. These powerful electronic processors look at the possible routes and choose the best.

In some electrical circuits, there is only one possible route and all the electricity must flow around it. These are called **series** circuits.

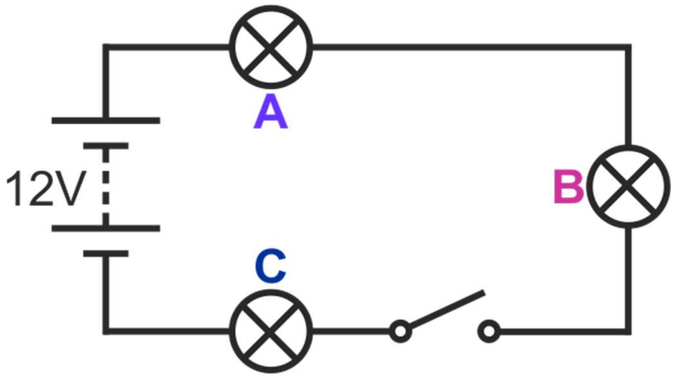
Photograph shows a sat nav system.

Over to you:

- Set up the arrangement shown in the layout opposite.
- This is a series circuit - everything connected in a line, one after the other. There is only one way for current to get from one end of the battery to the other. There are no junctions, no alternative routes!



- Here is the same circuit, drawn using symbols:



- Compare the two versions of the same circuit!
- Close the switch and notice how bright the bulbs look.
- Don't forget – for identical bulbs, the brighter the bulb, the greater the current flowing.
- Unscrew one of the bulbs and notice the effect. Does it matter which bulb you unscrew?
- Some people think that electric current is getting 'used up' as it goes round the circuit. If that were so, the bulbs would get dimmer as you move further from the battery. Does this seem to be the case?
- If the bulbs have the same brightness, then the current flowing through them must be the same. (Remember - the bulbs are mass-produced, and so are never completely identical.)
- Record all your findings in the Student Handout.

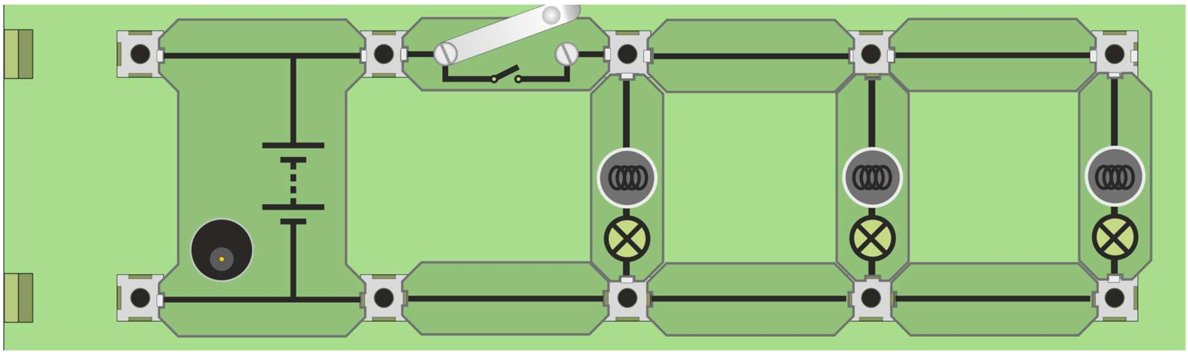
Challenge!

- Does it matter where you connect the switch? Try it in different places around the circuit.

Worksheet 6

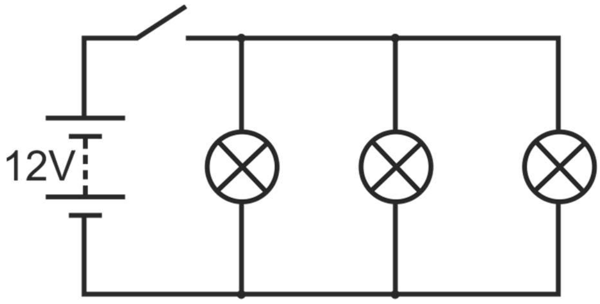
Series and parallel

Automotive electricity



Over to you:

- Set up the arrangement shown.
- This is a parallel circuit - there are a number of different current paths around the circuit.
- Trace these routes out.
- Here is the same circuit, drawn using symbols. Once again, compare the two diagrams!

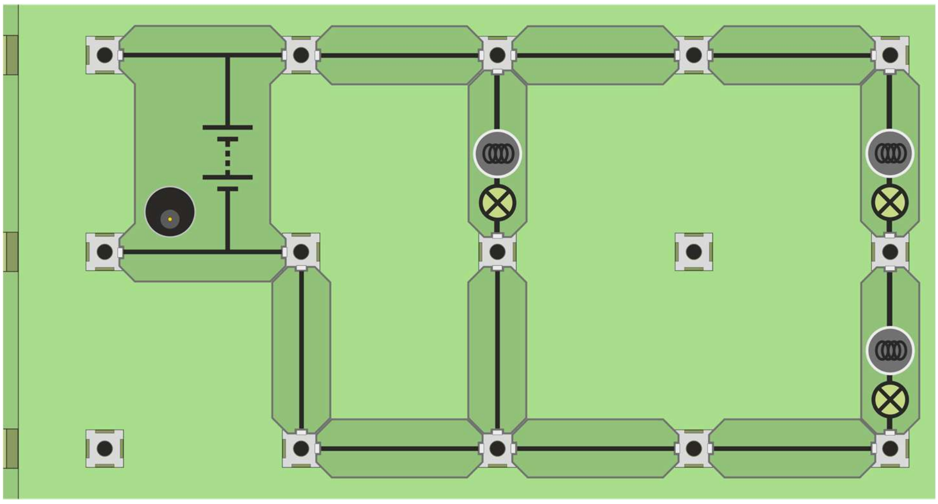


- Close the switch and compare the brightness of the bulbs.
- Don't forget – the brighter the bulb, the greater the current flowing!
- Unscrew one of the bulbs and notice the effect.
- Explain why the result is different here, compared with the series circuit.
- Why is this better than a series connection for the lamps in a vehicle?
- Record all your findings in the Student Handout.

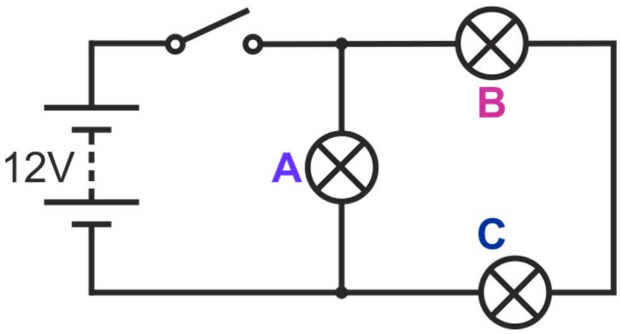
Worksheet 6

Series and parallel

Automotive electricity



Over to you:



- Now modify the circuit to that shown, still using 12V bulbs. One way to do this is shown in the layout diagram.
- This is **not** a series circuit - there are **two** ways to get from one end of the power supply to the other!
- Trace these routes out for yourself. (The blobs above and below bulb **A** indicate junctions in the circuit.)
- It is a mixture of series and parallel connections.
- Look at the brightness of the three bulbs. What does this tell us?
- Unscrew bulb **A**. What happens? Unscrew bulb **B**. What happens?
- Record your observations in the Student Handout.

So what?

- One route goes through only one bulb. The other route goes through two bulbs. That route is twice as difficult for electrons. Most will take the easy route through just the one bulb. More electrons per second = bigger current.
- In the Student Handout, explain how your observations support this idea.
- This circuit is a mixture of series and parallel connections. Bulb **B** is in ***series*** with bulb **C** - they are on the same route. Bulb **A** is connected in ***parallel*** with that series combination.

Challenge!

- Change the circuit so that the switch controls only bulbs **B** and **C**, **BUT** you can only move bulb **A** to achieve this.

Worksheet 7

Measuring electricity

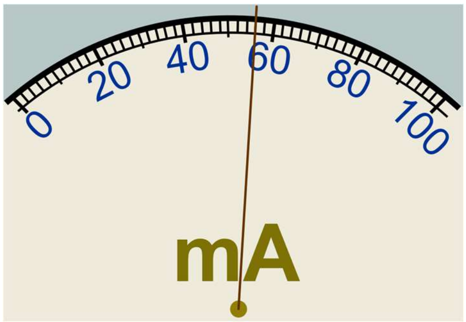
There are two basic types of electrical meter:

- digital meters - electronics within the meter convert the reading into a digital (numerical) readout.
- analogue meters - the bigger the reading, the further the pointer moves across the scale.

Photographs show a digital LCD meter and a analogue moving coil meter

Both types have advantages:

- digital meters are easy to read and can feed the reading into digital electronic processing systems like a micro-controller.
- analogue meters show trends in the behaviour of a circuit e.g. show that the current is increasing over time.



Here we focus on reading analogue meters - the more difficult of the two.

The diagram shows a typical analogue scale.

- To read the display, first work out the value of each graduation.
- There are ten steps between ‘0’ and ‘20’.
- Each step must be an increase of two units, milliamps (mA) in this case.

Meter symbols	
Ammeter	(A)
Voltmeter	(V)
Ohmmeter	(Ω)

Next, use that to work out the meter reading:

- The slightly longer graduation, mid-way between ‘40’ and ‘60’ has a value of ‘50’.
- The pointer sits over the third graduation past this mark.
- The reading is ‘50’ + (3 x ‘2’) = 56mA.

An ammeter measures electrical current, (in amps (A), milliamps (mA) or microamps (μA).

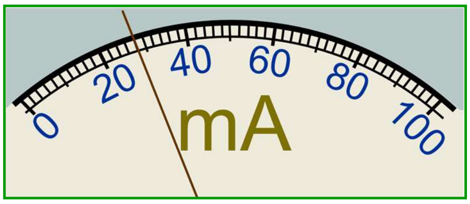
A voltmeter measures voltage, representing the force that drives electrons around the circuit.

An ohmmeter measures the resistance of a component or part of a circuit.

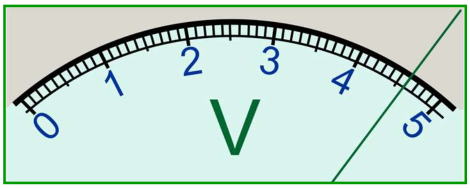
Over to you:

- Analyse each of the following diagrams of analogue meters and work out the value displayed on each.

A.

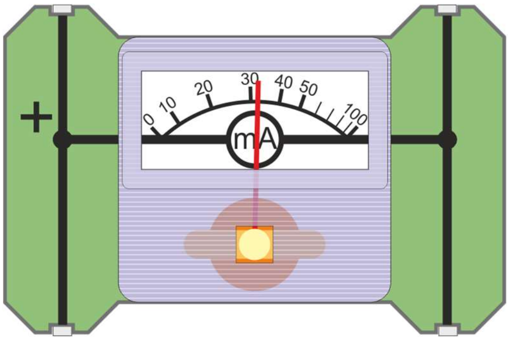


B.

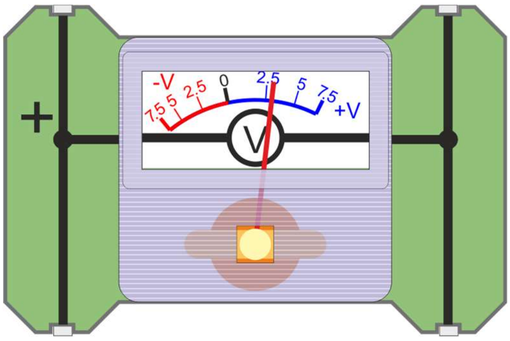


The next two diagrams represent two of the Locktronics meter carriers:

X.



D.



- Record your answers in the Student Handout. Don't forget to include the unit!

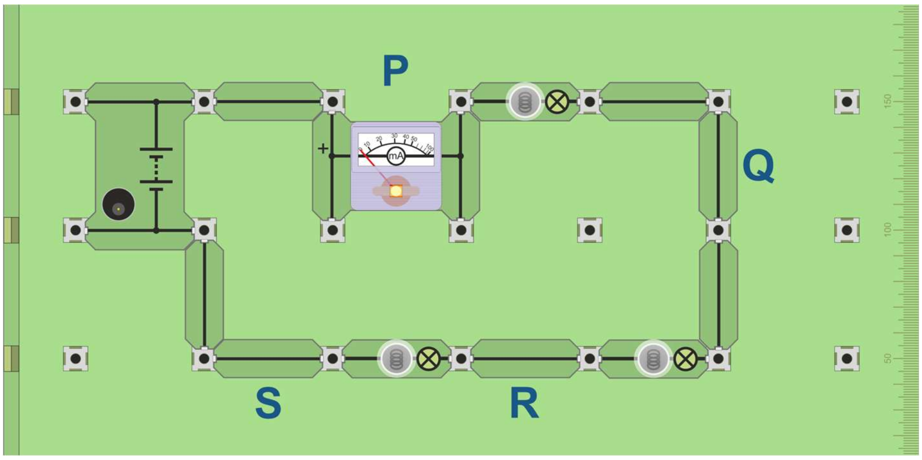
Worksheet 8

Measuring current

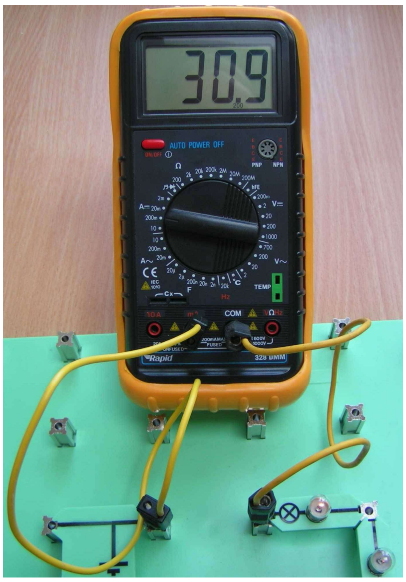
So far we have used the brightness of the bulbs to indicate the size of the current. This is not a very practical or accurate ay of measuring current: in practice we can make use of a Digital Multimeter to give us an accurate reading.

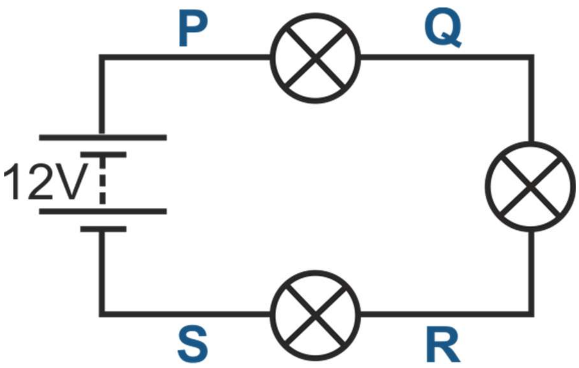
Photograph shows an ammeter from a vintage car,

Over to you:



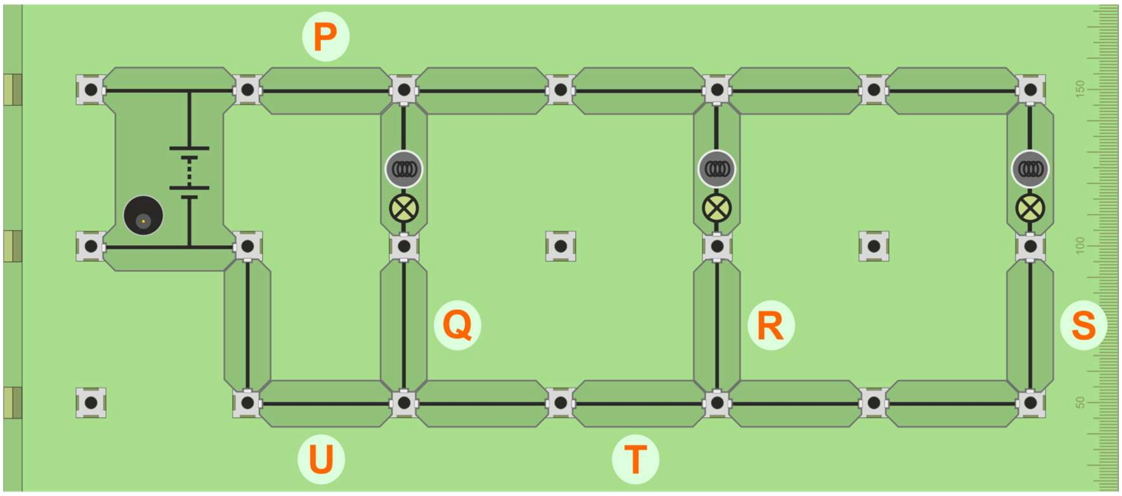
- Set up the arrangement shown.
- This is a series circuit - there is only one route around it.
- Measure the current flowing at point **P**.
- To do this, remove the link at **P** and connect the ammeter in its place.
- The pictures show how to do this for both the ammeter carrier and for the multimeter.
- Now replace the link at **P**.
- Measure the current at point **Q** in the same way.
- Measure the current at points **R** and **S** in the same way.
- Record all your measurements in the Student Handout and answer the question.



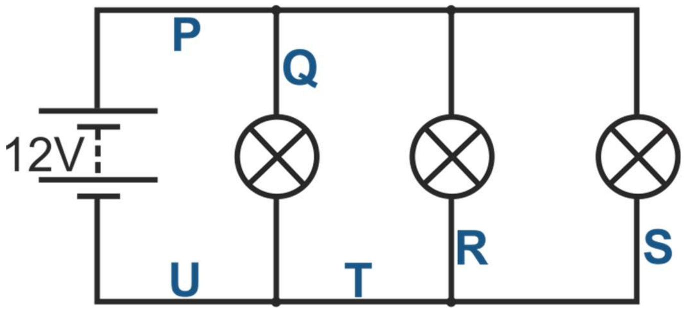


Worksheet 8

Measuring current

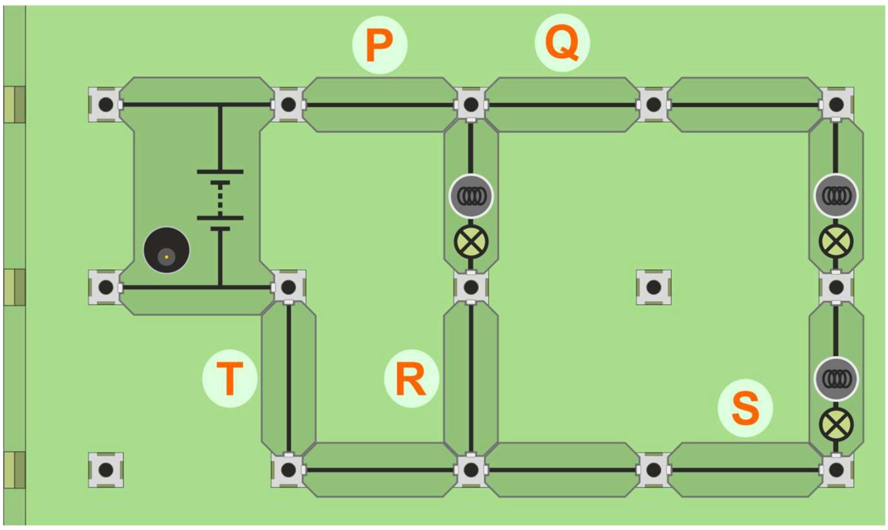


- Set up the parallel circuit shown.
- The layout uses extra carriers to make it easier to measure the currents.
- Measure the current flowing at point **P** in the same way as before.
- Then measure the currents at points **Q**, **R**, **S** and **T**.
- Can you spot a pattern?
- Record all your measurements in the Student Handout and answer the question.



Mixed circuit:

- Now do the same for the mixed series / parallel circuit .
- Once again, a possible layout is given below, including extra carriers to make current measurement easier .
- Again, record measurements in the Student Handout.



Worksheet 9

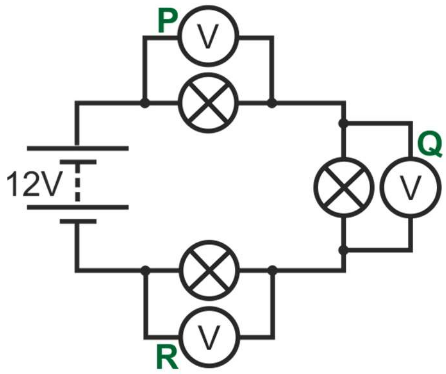
Measuring voltage

locktronics
Automotive electricity

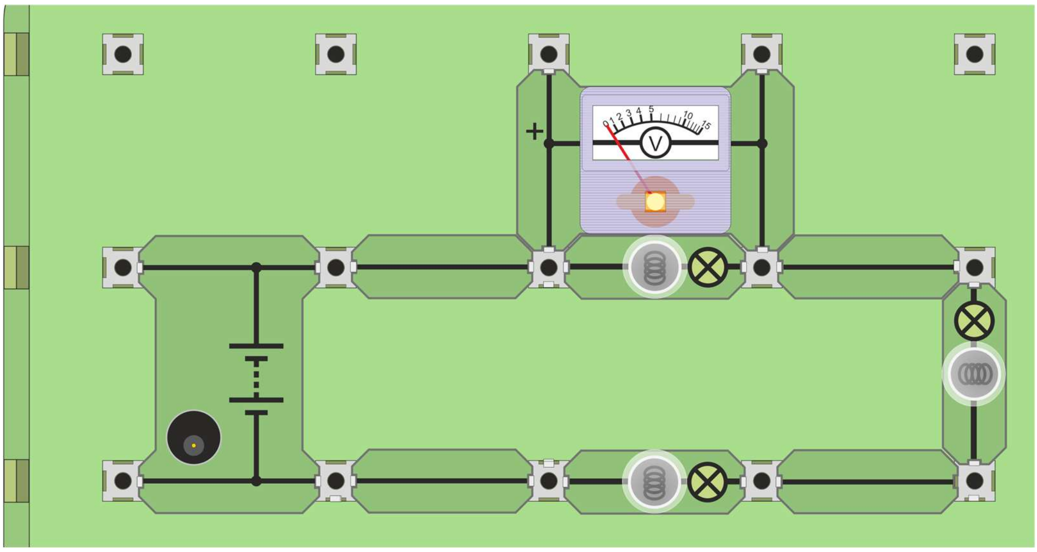
We can picture electric current as tiny electrons flowing around the circuit. Current represents the number of electrons passing a particular point in the circuit every second. Voltage is more difficult. Its a *measure* of the force that makes electrons squeeze along the wires. However, it is easier to measure voltage than current. Just connect the voltmeter in parallel with the component you are interested in!

Photograph: using a multimeter to measure voltage.

Over to you:



- Set up the circuit shown, using 12V 0.1A bulbs, but without the voltmeters. This is a series circuit with only one route around it.
- Make sure that the power supply is set to 12V.
- Measure the voltage across the first bulb, by connecting the voltmeter at **P**. To do this, connect the voltmeter to the ends of the first bulb. The layout diagram shows how to do this.
- Next, measure the voltage across the second bulb, shown by connecting the voltmeter at **Q**.
- Then measure the voltage across the third bulb, at **R**, in the same way.
- Record your measurements in the Student Handout.

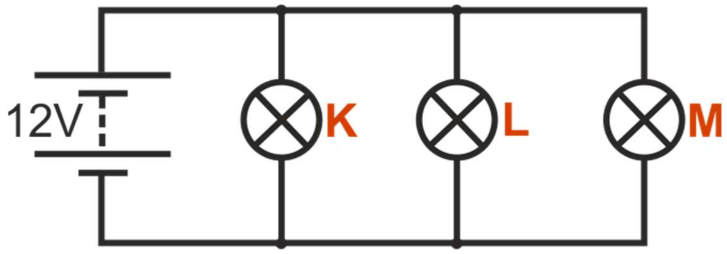


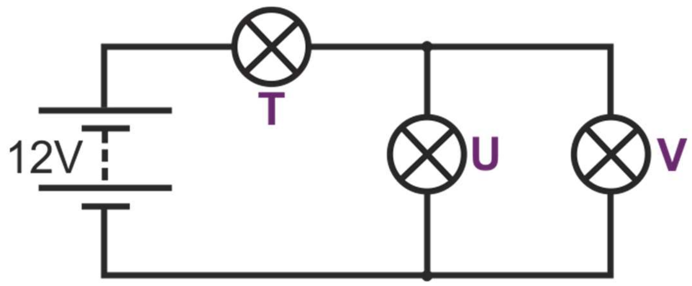
So what?

- Add together the readings of the voltmeters at points **P**, **Q** and **R**.
- Remembering that the power supply voltage for this circuit is 12V, what do you notice about this total?
- Answer this question in the Student Handout.

Challenge!

- Next investigate the voltages across the bulbs, all 12V 0.1A, in the following circuits.





- Record your measurements in the Student Handout.
- Again, see if you can spot a pattern?

Worksheet 10

Electrical power

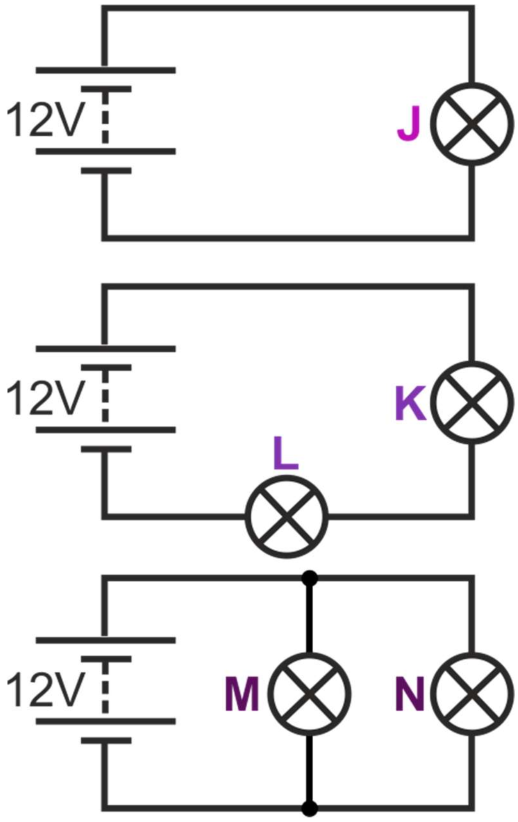
Automotive electricity

'Save energy!'

A familiar cry, but what is energy? The same as power? Is it voltage? Or wattage? Electricity stems from the behaviour of electrons, but unfortunately they are too small to see or measure. Whatever energy is, electrons (whatever they are,) gain it when they pass through a battery or a power supply, and lose it when they flow through resistors, or coils of wire.

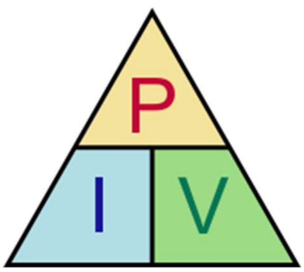
Over to you:

- Set up each the circuit in turn .
- For each bulb, measure:
    - the current through it,
    - the voltage across it.
- Record all measurements in the Student Handout.
- In the Student Handout, use your measurements to calculate:
    - the power dissipated in each bulb, (using P = I x V)
    - how much energy (in joules) the power supply is losing each second. (using E = Px t;)
- Then decide which battery will 'go flat' first and explain your choice.



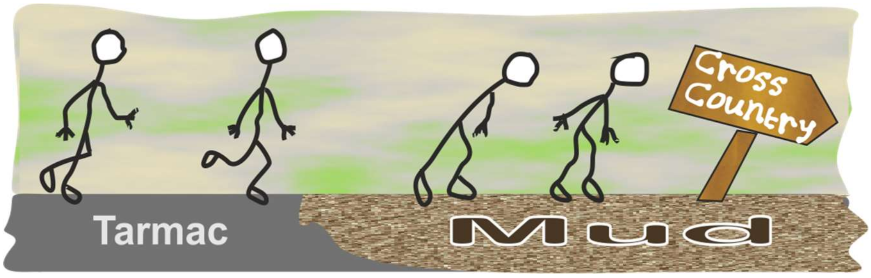
So what?

- With the bulbs in series, every electron passes through each bulb and shares its energy between them.
- With the bulbs in parallel, an electron passes through only one, and gives it all its energy.



Worksheet 11

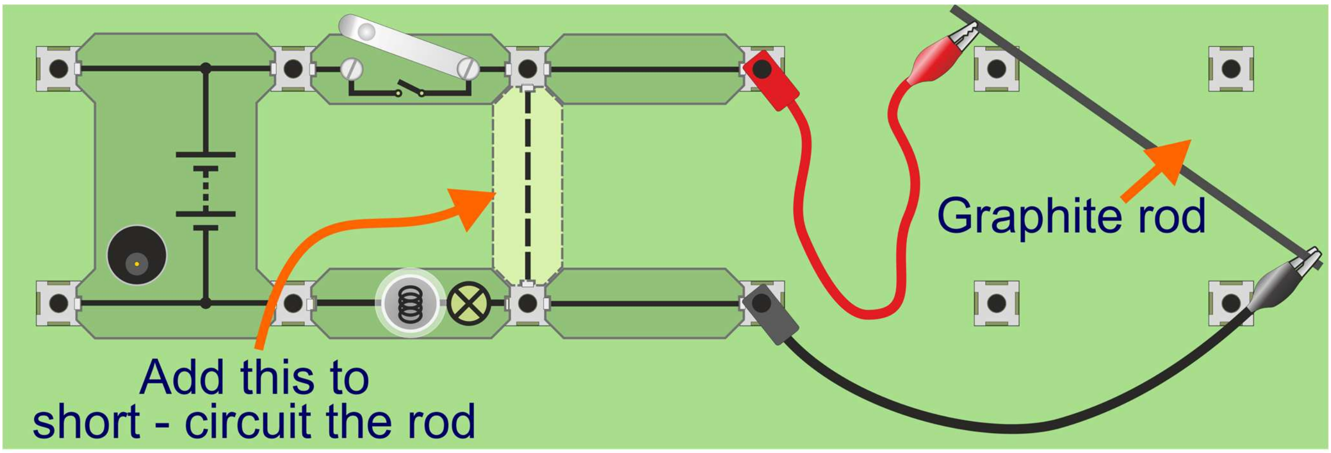
Resistors



In worksheet 1, we categorised materials as either 'conductor' or 'insulator'.

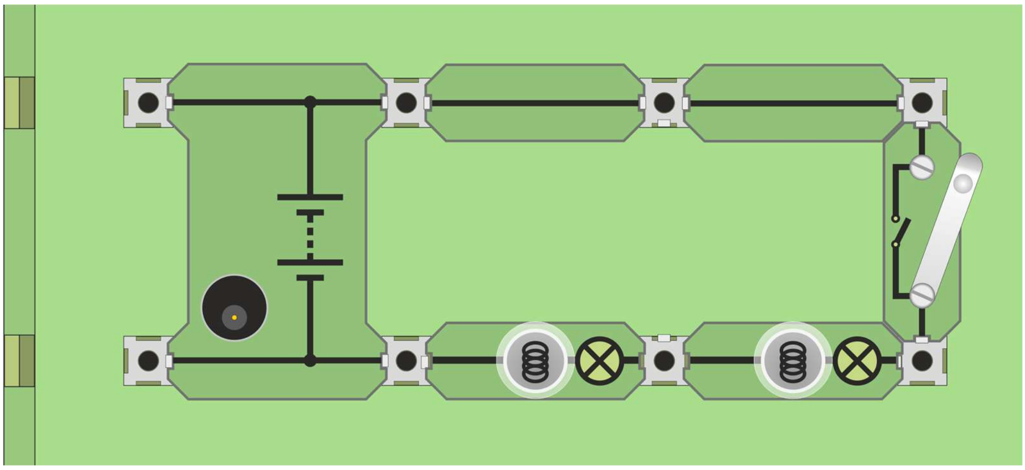
In reality, that is too crude. Some materials conduct electricity better than others. All offer some **resistance** to the flow of electricity through them. For electrons, the effect of resistance is like us trying to run in mud.

Using a tap, we can change the flow of water from fast to slow. With electricity, we change the current, i.e. the flow of electrons, using resistors, like those shown on the printed circuit board.



Over to you:

- Make your own resistor by clamping a rod of graphite (pencil lead,) using crocodile clips onto the ends of two connecting leads . The rod should be at least 15cm long.
- Set up the circuit using a 12V 0.1A bulb.
- Close the switch and notice how bright the bulb looks.
- Remember – the brighter the bulb, the greater the current flowing.
- To see the effect of the resistor, 'short-circuit' the rod by inserting the 'extra' connecting link between the switch and the bulb, as shown in the diagram.



Over to you ...

- Now set up the circuit shown in the second diagram, using two 12V 0.1A bulbs.
- Close the switch.
- What do you notice about the brightness of the two bulbs compared to the brightness of the single bulb (when the resistor was short-circuited)?
- Swap one of the bulbs for a 12 ohm resistor.
- Notice the brightness of the remaining bulb. What does this tell you about bulbs?
- Record all your observations and results in the Student Handout.

So what?

- Adding more resistance to a circuit makes the electric current smaller.
- It is not only ‘resistors’ that have resistance – pencil lead, bulbs, even the wires themselves and the power supply have some resistance.

Worksheet 12

Sensors

locktronics

Automotive electricity

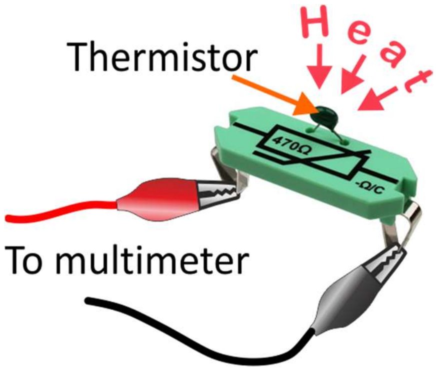
The focus here is on two common sensors, the thermistor, a temperature-dependent resistor, and the phototransistor, used to sense light levels.

They form the basis for light-sensing and temperature-sensing units.

Photograph shows a car dashboard displaying outside temperature and time.

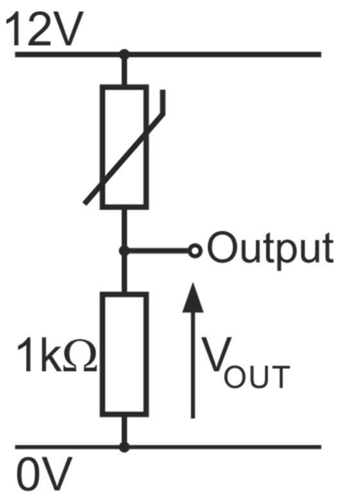
Over to you:

The thermistor



- Connect a thermistor to a multimeter, set up to measure resistance up to 1kΩ, as shown in the diagram.
- Measure its resistance at room temperature.
- Warm the thermistor between your thumb and finger.
- Notice the effect on the resistance of the thermistor.
- Measure its resistance again when the reading is steady.
- Record your results in the Student Handout and answer the questions.

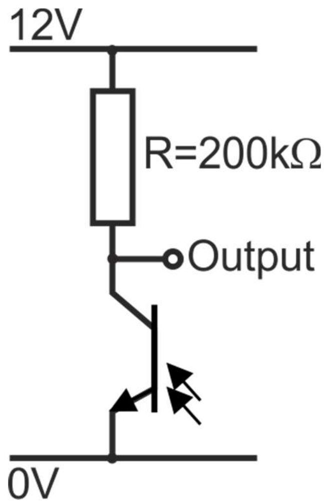
Temperature sensing unit



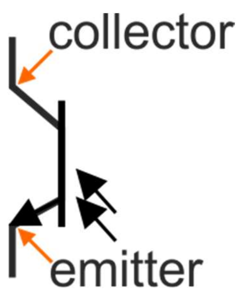
- Set up the arrangement shown in the circuit diagram.
- Measure the output voltage, V_{OUT}, at room temperature.
- Now warm the thermistor between your thumb and finger.
- Notice the effect on the output voltage.
- Measure the output voltage again when the reading is steady.
- Record your results in the Student Handout and answer the questions.
- Next, invert the temperature sensing unit, by swapping over the thermistor and resistor carriers.
- Investigate what happens to the output voltage when you warm the thermistor.
- Record your results in the Student Handout and answer the questions.

Over to you ...

Light sensing unit



- Set up the arrangement shown in the circuit diagram.
- Measure the output voltage, V_{OUT}, in full daylight.
- Now place your finger over the hole in the phototransistor carrier to reduce the light level on the phototransistor.
- Notice the effect on the output voltage.
- Measure it and record your results in the Student Handout.
- Now invert the light sensing unit, by swapping over the phototransistor and resistor carriers.
- Make sure that the phototransistor is connected the right way round, with its collector connected to the 12V rail - see the diagram opposite.
- Investigate what happens to the output voltage when you cover up the phototransistor.
- Record your results in the Student Handout.



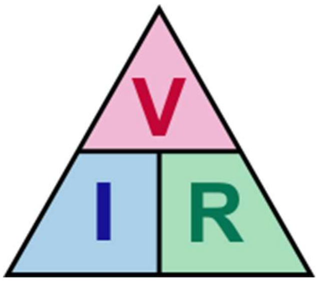
Challenge!

- Design an experiment to investigate how the output voltage of the light sensing unit changes when the intensity of the light falling on it changes.
- Think of a way to produce different intensities of light, and a way to measure it.
- The phototransistor must be shielded from other sources of light.

Current measures how many electrons pass per second.

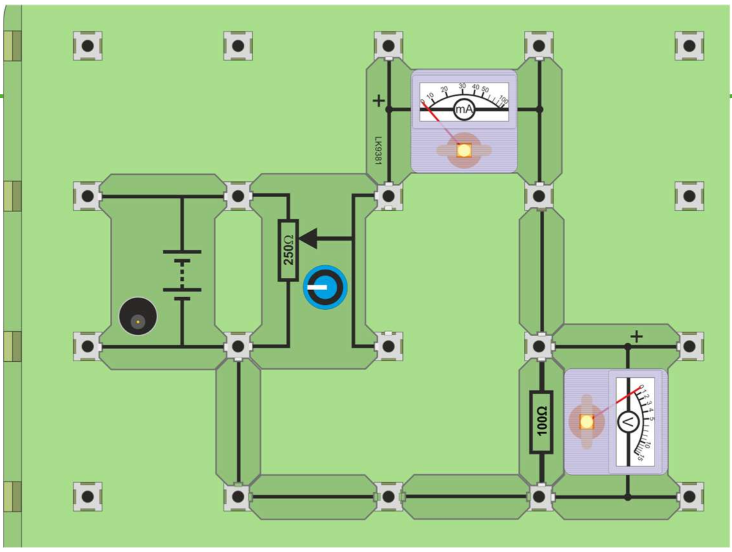
Voltage is a measure of how much energy the electrons gain or lose as they flow around a circuit.

Resistance shows how difficult it is for the electrons to pass through a material. In squeezing through, the electrons lose energy to the resistor, which warms up as a result.



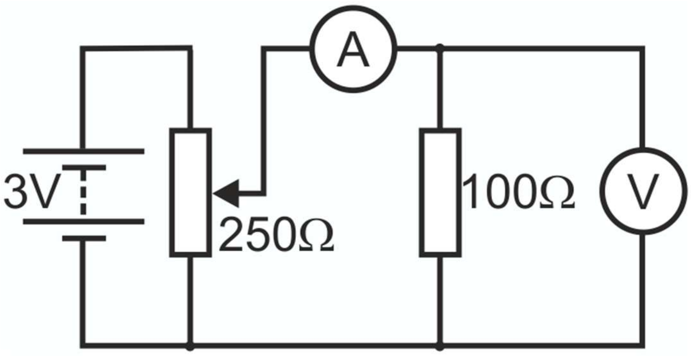
To use the triangle as a memory prompt, cover up the quantity you are trying to calculate.

For example, cover **V** and the formula is **I x R**, cover **I** to give **V / R** etc.



Over to you:

- Set up the circuit shown in the diagram.
- The 250Ω potentiometer allows us to change the voltage across the 100Ω resistor.
- The diagram shows one way to set this up. (You could use multimeters instead of meter carriers.)
- Make sure that the power supply is set to **3V!**
- Turn the knob on the 'pot' fully anticlockwise, to set the voltage supplied to a minimum.
- Then turn it slowly clockwise until the voltage across the resistor reaches 0.1V.
- Now read the current flowing through it.
- Turn the voltage up to 0.2V, and take the current reading again. Keep doing this until the voltage reaches 1.0V.



(Don't go past this or the resistor may overheat.)

- Record your results in the table in the Student Handout and then use them to plot a graph, following the guidelines given.

Worksheet 13

Ohm’s law

So what?

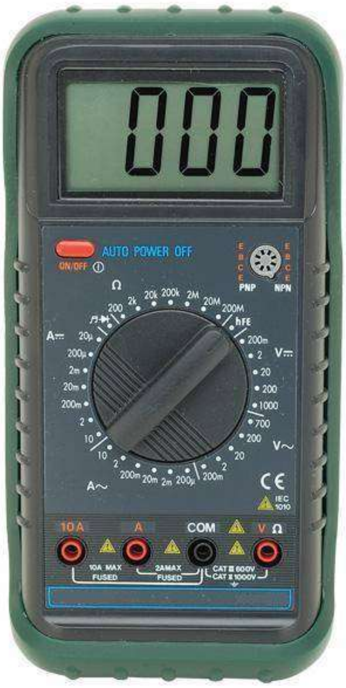
This experiment illustrates **Ohm’s law:**

“The voltage across a fixed resistor is directly proportional to the current flowing through it.”

This means that when you double the current through the resistor, you double the voltage across it. When you halve the current, you halve the voltage etc.

Using a multimeter to measure resistance:

You cannot measure the resistance of a component while it is in the circuit. It must be removed first.



- Plug one wire into the black ‘COM’ socket, and the other into the ‘V Ω' socket.
- Select the 200kΩ range, (or a range which is much higher than the reading you are expecting.)
- Plug the two wires into the sockets at the ends of the component under investigation.
- Press the red ON/OFF switch when you want to take a reading.
- Turn the dial to choose a lower range, until you find the reading.

Worksheet 14

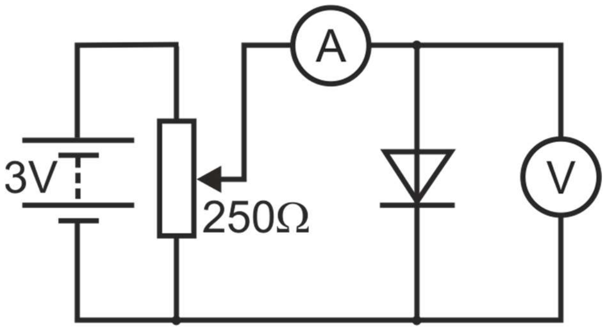
LEDs and diodes

Resistors behave in a very straightforward way - double the current and you double the voltage, quarter the current, quarter the voltage and so on.

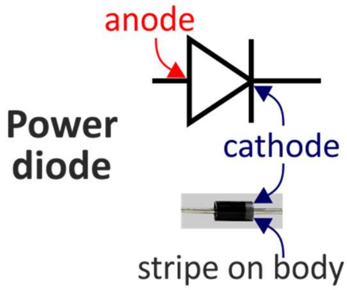
This result is known as Ohm's law. Very few components behave in this way. The diode does **not**!

Photograph shows a modern LED rear light cluster.

Over to you:



- Set up the circuit shown in the diagram.
- The layout is identical to that in the last worksheet except that the resistor is replaced by a power diode.
- Use the diagram to identify the anode and cathode terminals of the diode. With the anode is connected to the positive end of the power supply, as in this case, we say that the diode is ***forward-biased***.
- (Again, you could use multimeters instead of the meter carriers.)
- Make sure that the power supply is set to **3V!**
- The 250Ω potentiometer allows us to change the applied voltage.



- Turn the knob on the 'pot' fully anticlockwise, to set the supply voltage to zero.
- Now turn it slowly clockwise until the current through the diode reaches 2.0mA.
- Read the voltage across the diode.
- Turn the current up to 4.0mA, and take the voltage reading again.
- The current changes rapidly for a tiny change in voltage.

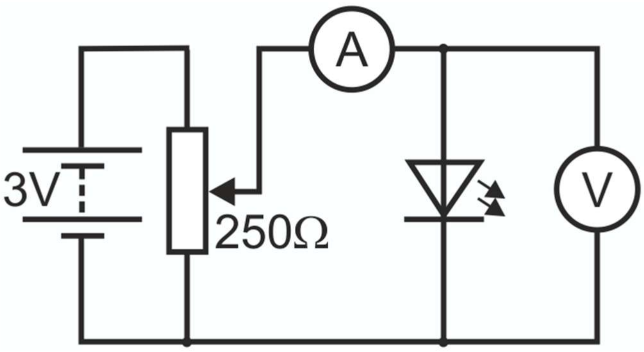
Be careful - adjust the voltage very gently!

- Keep increasing the current in 2mA steps, up to 20mA, measuring the voltage each time.
- Record your results in the table in the Student Handout and then use them to plot a graph, following the guidelines given.

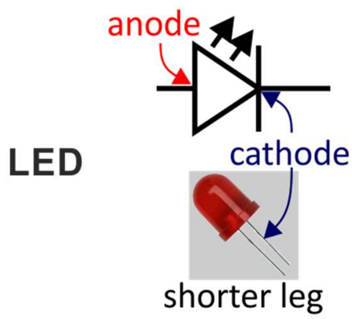
Over to you ...

- Now, turn the voltage down to zero, and switch off the power supply.
- Remove the diode from the circuit, and replace it the other way round.
- The diode is now ***reverse-biased***.
- Switch on the power supply.
- Turn the knob on the potentiometer slowly until the supply voltage is at its maximum.
- Notice the current reading on the ammeter as you do so. (No need for a graph here!)

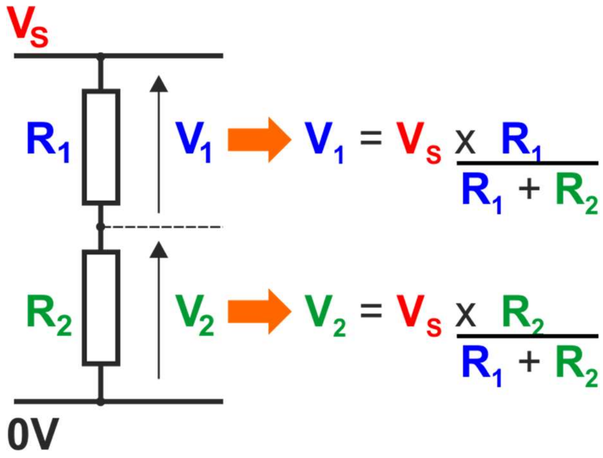
The LED



- Using the same circuit as before, connect the LED so that it is forward biased.
- Use the diagram to identify the anode and cathode terminals of the LED.
- Repeat the investigation, but this time increase the current in steps of 0.2mA, to a maximum of 2.0mA.
- Measure the voltage across the LED at each step and plot a graph to show your results.
- Draw a smooth curve, with the same shape as before, using your points as a guide.
- Finally, connect the LED the other way round, so that it is reverse -biased, and comment on its behaviour in the Student Handout.

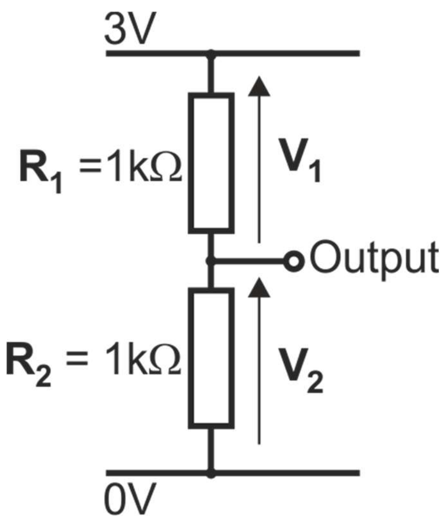


Combinations of resistors can carve up the voltage from a power supply into smaller portions. These combinations are called voltage dividers. The diagram shows how a power supply voltage V_S can be split into two smaller voltages, V_1 and V_2, by a voltage divider made up of two resistors. These are particularly useful when one of the resistors is a sensing component such as a phototransistor or a thermistor.



Over to you:

- Set up the circuit shown in the diagram.
- Make sure that the power supply voltage is set to **3V**!
- Measure voltages V_1 and V_2.
- Record the results in the table in the Student Handout.
- Now, change the power supply voltage to 6V.
- Measure voltages V_1 and V_2 and again record them in the table in the Student Handout.
- Do the same thing with a power supply voltage set to 9V.



- Next, swap R_2 for a 10kΩ resistor, leaving resistor R_1 unchanged.
- Change the power supply voltage back to 3V.
- Measure voltages V_1 and V_2 again.
- Repeat this process, first using a power supply voltage of 6V and then using 9V.
- Record all your results in the table in the Student Handout.

So what?

There is a straightforward way to view these results:

- The voltage from the power supply is shared between the resistors, so that $V_1 + V_2 = V_S$
- The bigger the resistor, the bigger its share of the voltage.
  - When $R_1 = R_2$ (=1kΩ), $V_1 = V_2 = ½V_S$.
  - When $R_2 = 10 \times R_1$, $V_2 = 10 \times V_1$.

Worksheet 16

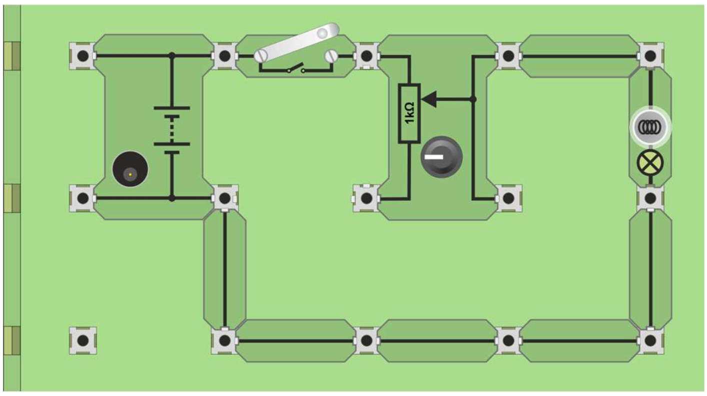
The ‘pot’

locktronics

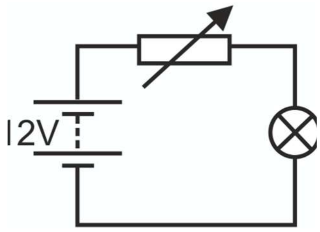
Automotive electricity

Earlier, we used resistors to limit electric current and in voltage dividers. Now, we look at variable resistors, also known as ‘potentiometers’ (often shortened to ’pot’). Common in a wide range of appliances, the ‘pot’ acts as a volume control in radios and hi-fi, as a mixer in karaoke and recording desks, and as a dimmer in lighting systems. They are widely used in sensors, such as light-sensing and temperature-sensing units.

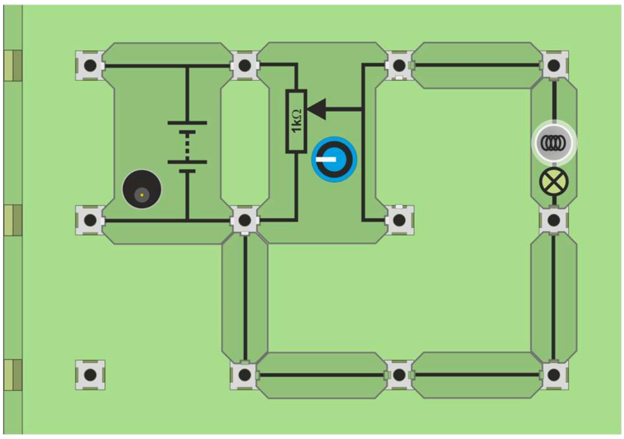
Over to you:



- Set up the circuit shown in the diagram, using a 12V 0.1A bulb.
- Here, the Locktronics component is set up as a variable resistor. You can tell this because the circuit uses only two legs of the pot (Resistors have only two legs!)
- Turn the knob on the variable resistor and notice the effect on the brightness of the bulb.



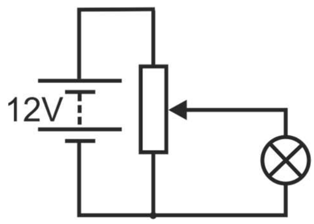
- Next connect the pot as a voltage divider.
- You used this arrangement earlier when studying diodes and LEDs. Notice that a new symbol is used for the component!
- A possible layout for the circuit is shown here.



- Test the circuit as before - turn the knob and see what happens to the brightness of the bulb.
- Compare the performance of the two circuits and write your observations in the Student Handout.

Challenge!

- Connect a voltmeter to read the voltage across the bulb and then unscrew the bulb.
- Turn the knob until the voltmeter reads 6V. Now screw in the bulb and watch what happens to the voltmeter reading.
- Explain why this happens!



Worksheet 16

The ‘pot’

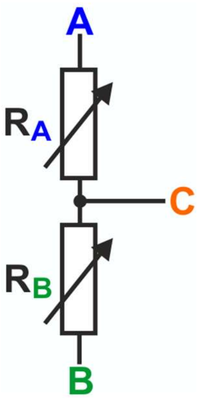
locktronics

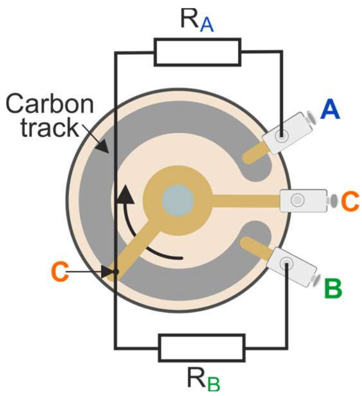
Automotive electricity

So what?

The pot can be used in two ways to control the brightness of a bulb:

- as a variable resistor - It controls the **current** flowing through the bulb. They are in series, so whatever current flows through the bulb also flows through the variable resistor. This current may be very small with the device at maximum resistance, but it is never zero.
- as a voltage divider - It controls the **voltage** applied to the bulb. The current through the bulb is zero when the knob is turned to one extreme. However, there is always a current flowing through the pot itself. It is important to make this current large, compared to the current flowing through the bulb.





The circuit diagram shows the structure of a typical ‘pot’ having three terminals, **A**, **B** and **C**.

Of these, **A** and **B** are connected to the ends of a carbon track, shaped like a horseshoe, which has a fixed resistance, such as 10kΩ. Terminal **C** is connected to a ‘wiper’, that slides around the track, when the knob on the pot is turned.

In effect, there are two resistors, $\mathbf{R_A}$ and $\mathbf{R_B}$, built into the device:

- $\mathbf{R_A}$ - the resistance of the track between **A** and **C**;
- $\mathbf{R_B}$ - the resistance of the track between **B** and **C**.

The symbols for these resistors are superimposed onto the diagram. The second diagram is more accurate as it shows that resistors $\mathbf{R_A}$ and $\mathbf{R_B}$ are in fact variable - hence the arrows on the symbols.

When the knob is turned in the direction shown by the arrow in the first diagram, the length of track between **B** and **C** increases, whereas the track between **A** and **C** shortens. As a result, $\mathbf{R_B}$ increases and $\mathbf{R_A}$ decreases.

Student handout

Worksheet 1 - Conductors and insulators

Materials that conduct	Materials that insulate

Looking at the materials that pass electricity, which class of substance do they belong to?

....

Would you expect a hard, shiny object that felt cold to touch to conduct electricity?

Explain your answer.

....

....

....

....

....

....

Worksheet 1 - Conductors and insulators ...

How did you test the water samples?

....

....

....

....

....

....

Did pure water, tap water and salty water behave in the same way?

....

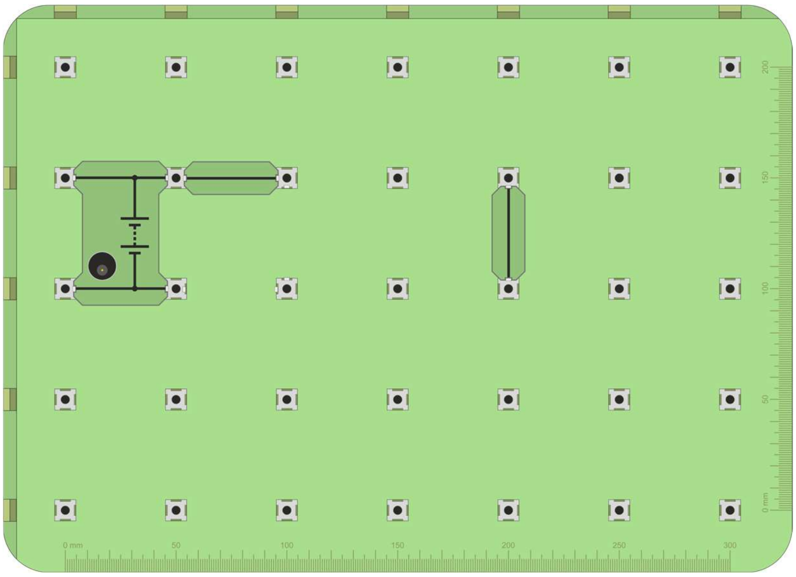
....

....

....

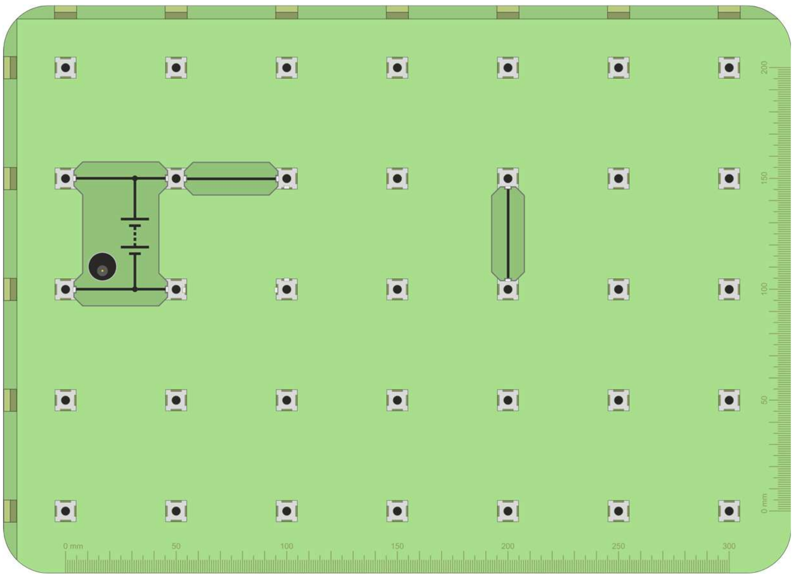
Worksheet 2 - Circuits and symbols

Complete the diagram to show how you made the bulb light.



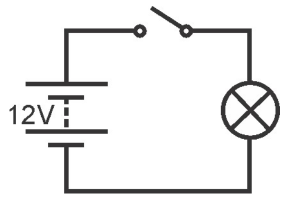
The actual shape of the circuit makes no difference.

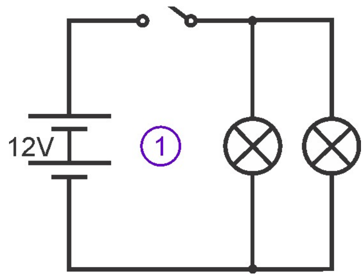
Draw a circuit that makes two bulbs light:



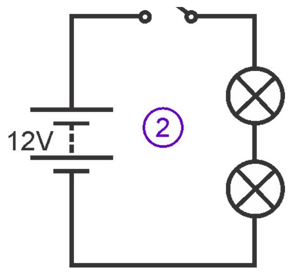
Worksheet 2 - Circuits and symbols ...

Compared to the brightness of the bulb in this circuit:

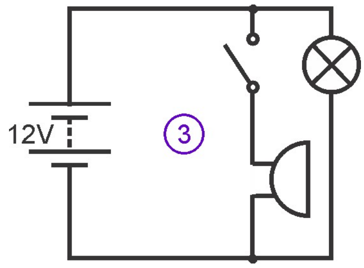




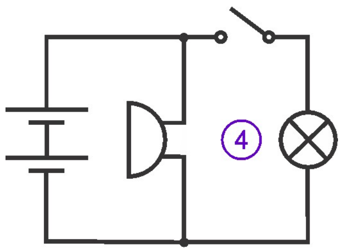
the bulbs in circuit **1** were ....,



while those in circuit **2** were ....



In circuit **3**, the switch controls the ....



Worksheet 2 - Circuits and symbols ...

Challenge!

The increasing use of plastic mouldings in vehicle bodies can cause complications. Explain why!

....

....

Worksheet 3 - Electric current

Observations

What is the effect of an electric current on:

- a filament bulb:

....

- strands of wire wool:

....

What happened when:

- you first closed the switch on the 'fuse' circuit;

....

- you short-circuited the bulb.

....

The advantage of low-energy light bulbs:

....

....

The fuse:

Describe another component that can act as a safety device:

....

....

Worksheet 4 - Electromagnetism

An electric current can make a coil of wire behave the same as a magnet.

When a current is passed through the coil:

………

………

When an iron nail is placed inside the coil:

………

The magnetic field could be made stronger by:

………

………

………

Worksheet 5 - Applications of electromagnetism

The solenoid:

In the circuit where the solenoid was controlled directly from a push-switch, what did you see when you:

closed the switch; ……………………………………………………………………………………………………

opened the switch. ……………………………………………………………………………………………………

The relay:

Measurements:

Current in control circuit = …………………….mA

Current in controlled circuit = …………………….mA

Comment on these values:

………

Worksheet 6 - Series and parallel

Series circuit

What do you notice about the brightness of these bulbs?

……………………………………………………………………………………………………

What happens when you unscrew one of the bulbs?

………………………………………………………………………………………………………
……………………………………………

Explain why this happens:

………………………………………………………………………………………………………
……………………………………………

If electric current were 'used up' in going round the circuit, what would happen to the brightness of the bulbs?

………………………………………………………………………………………………………
……………………………………………

Is this the case? ……………………………………………………………………...

Does it matter where you connect the switch?

…………………………………………………………………...……

Parallel circuit

When you close the switch. how do these bulbs compare in brightness?

……………………………………………………………………………………………

What happens when you unscrew one of the bulbs?

………………………………………………………………………………………………………
……………………………………………

Does it matter which bulb is unscrewed?

…………………………………………………………………...……

Explain why is different to the situation in the series circuit:

………………………………………………………………………………………………………
……………………………………………

Why is this better than a series connection for the lamps in a vehicle?

………………………………………………………………………………………………………
………………………………………………………………………………………………………

Worksheet 6 - Series and parallel

Mixed circuit

This circuit contains a mixture of series and parallel connections.

Bulbs ……… and ……… are connected in series.

Bulb ……. is in parallel with this series combination.

When you close the switch, what do you notice about the brightness of the bulbs?

……

Explain these observations.

……

……

What happens when you unscrew bulb **A**?

……

What happens when you unscrew bulb **B**?

……

Explain these observations.

……

……

Challenge

What change did you make so that the switch controls only bulbs **B** and **C**?

……

……

Draw the new circuit diagram.

Worksheet 7 - Measuring electricity

Reading on meter **A** = ………………..

Reading on meter **B** = ………………..

Reading on meter **C** = ………………..

Reading on meter **D** = ………………..

Worksheet 8 - Measuring current

Series circuit:

Point	Current flowing in mA
P	
Q	
R	
S	

What do you notice about the four currents?

………

………

Parallel circuit:

Point	Current flowing in mA
P	
Q	
R	
S	
T	
U	

Can you spot some relationships in these results?

………

………

Series parallel circuit:

Point	Current flowing in mA
P	
Q	
R	
S	

Worksheet 9 - Measuring voltage

Series circuit

Voltage across	P	Q	R

Voltage across P + voltage across Q + voltage across R

= ……………………..

What do you notice about this sum of the voltages around the circuit?

………

How do you explain this result?

………

………

Parallel circuit

Voltage across	K	L	M

Mixed circuit

Voltage across	T	U	V

How do you explain the results for the parallel circuit?

………

………

How do you explain the results for the mixed circuit?

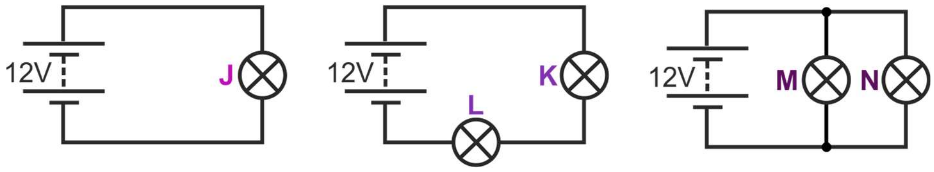
………

………

………

Worksheet 10 - Electrical power

For the circuits shown:



Measurements:

Bulb	Voltage V	Current I
J		
K		
L		
M		
N		

Bulb	Power P	Time to transfer 1J	Energy lost per s
J			
K			
L			
M			
N			

Which of the batteries shown in the three circuits will ‘go flat’ first? ……………………..

Explain why you chose this circuit.

………

………

………

Worksheet 11 - Resistors

Your observations:

When the graphite ‘resistor’ is connected, what happens to the brightness of the bulb?

……

When the graphite ‘resistor’ is short-circuited, what happens to the brightness of the bulb?

……

What do you notice about the brightness of the two bulbs in series compared to that of the single bulb (when the resistor was short-circuited)?

……

……

What was the effect of swapping one bulb for the 12Ω resistor?

……

What does this show about the resistance of a bulb?

……

Worksheet 12 - Sensors

Thermistor:

Resistance of the thermistor at room temperature = ……………………Ω

As the temperature increases, the resistance of the thermistor …………………… .

When the thermistor is at hand temperature, its resistance = ……………………Ω

Which type of thermistor is this, ptc or ntc? ……………………

Temperature-sensing circuit

Output voltage, V_{OUT}, at room temperature = ……………………V

As the temperature increases, the output voltage …………………… .

At hand temperature, the output voltage = ……………………V

When the temperature-sensing unit is **inverted**:

Output voltage, V_{OUT}, at room temperature = ……………………V

As the temperature increases, the output voltage …………………… .

At hand temperature, the output voltage = ……………………V

Challenge:

Describe how you would investigate how the resistance of a phototransistor changes when the intensity of the light falling on it changes.

……

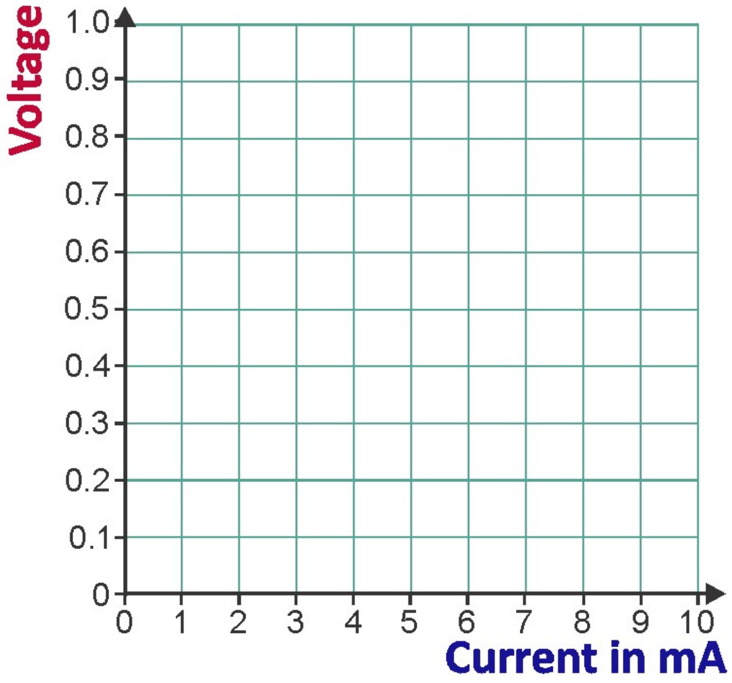
……

……

……

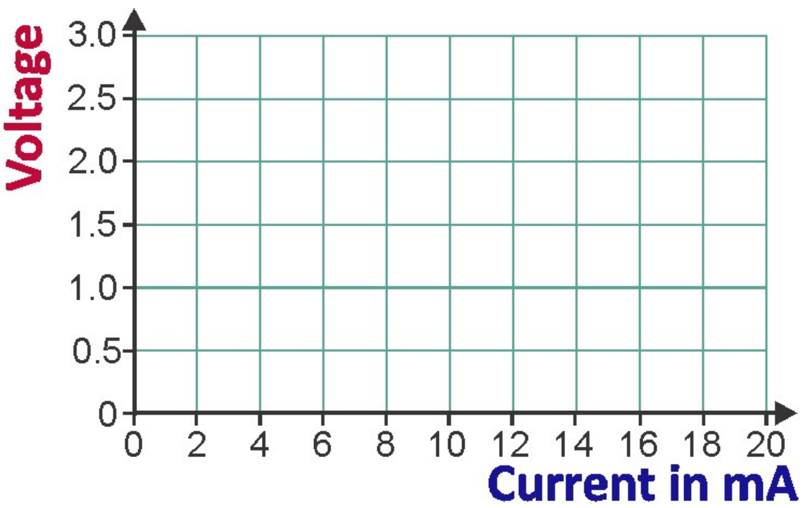
Worksheet 13 - Ohm's law

Voltage V	Current I
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1.0	



Worksheet 14 - LEDs and diodes

Current I in mA	Voltage V
2	
4	
6	
8	
10	
12	
14	
16	
18	
20	



What happens when the LED is reverse biased?

....

....

Worksheet 15 - Voltage dividers

Resistor R_1	Resistor R_2	Power supply V_S	Voltage V_1	Voltage V_2
1kΩ	1kΩ	3V		
1kΩ	1kΩ	6V		
1kΩ	1kΩ	9V		
1kΩ	10kΩ	3V		
1kΩ	10kΩ	6V		
1kΩ	10kΩ	9V		

Worksheet 16 - The 'pot'

Compare the performance of these circuits:

....

....

....

With the voltage divider circuit, when you unscrew the bulb, what happened to the voltage across it? Give a reason as to why this happened.

....

....

....

Instructor guide

Introduction

The course is essentially a practical one. Locktronics equipment makes it simple and quick to construct and investigate electrical circuits. The end result looks like the conventional circuit diagram, thanks to the symbols printed on each component carrier.

Aim

The course aims to introduce students to basic concepts underlying automotive electricity.

Using this course:

Each worksheet has:

- an introduction to the topic under investigation;
- step-by-step instructions for the investigation that follows;
- a summary of the significance of the results, and, usually, extension work, flagged up as a 'Challenge'. These aim to encourage application of new concepts and embed new ideas.

The Student Handout is printed for each student taking the course and is for recording their results.

It is expected that Worksheets and the Student Handout are printed / photocopied, preferably in colour, for the students' use. Students do not need a permanent copy of the worksheets but do require their own copy of the Student Handout.

This format encourages self-study, with students working at a rate that suits their ability.

It is for the instructor to monitor that their understanding is keeping pace with their progress through the worksheets. One way to do this is to 'sign off' each worksheet, as the student completes it, and in the process have a brief chat to assess the student's grasp of the ideas involved in the exercises it contains.

"...but I'm really a gear box guy..."

Knowing that multidisciplinary teaching teams are increasing in popularity, the Instructor Guide is written with the intention of helping instructors for whom automotive electricity is not their principal qualification or area of experience. It includes anecdotes and analogies to help deliver the concepts, and advice about pitfalls and misconceptions that may be present.

Time:

It will take students between twelve and seventeen 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.

Learning Objectives

On successful completion of this course the student will have learned:

- the difference between the electrical properties of conductors and insulators;
- how to test whether a material conducts electricity readily or not;
- the need for a complete circuit for conduction to take place;
- the meaning of a range of electrical symbols;
- to construct a simple electrical circuit from a circuit diagram;
- that the shape of a circuit has no effect on its behaviour;
- to recognise and avoid a short-circuit situation;
- the function of a switch in an electrical circuit;
- how to place a switch to control only part of a circuit;
- that automobile manufacturers use a variety of different circuit diagrams and symbols;
- that an electric current can cause a significant heating effect;
- that a fuse uses this heating effect to switch off the current if it is too large;
- the function of a fuse in an electrical circuit;
- that an electric current can cause an appreciable magnetic effect, which is intensified by coiling the conductor, and using a core of magnetic material;
- that this magnetic effect is used in a solenoid to convert electrical energy into mechanical movement;
- that this magnetic effect is used in a relay to switch large currents on and off;
- to name three advantages of using a relay in a car electrical system;
- that a reverse biased diode is used to protect sensitive switching devices from damage caused by 'back e.m.f.' when a magnetised coil de-energises;
- to recognise a series connection and recall its properties;
- to recognise a parallel connection and recall its properties;
- to compare the behaviour of voltages and currents in series, parallel and mixed circuits;
- to distinguish between analogue and digital meters;
- to use an ammeter to measure electric current in series, parallel and mixed combinations of components;
- to recognise that measuring current measures the flow of electrons passing a point in the circuit;
- to predict the current flowing in part of a circuit, given information about the currents flowing in other parts;

Learning Objectives continued…

On successful completion of this course the student will have learned:

- to use a voltmeter to measure voltage in series, parallel and mixed combinations of components;
- to recognise that measuring voltage measures the energy delivered to or by electrons in passing through a component;
- to predict the voltage across a component, given information about voltages across other components;
- to use current and voltage to calculate the power rating and energy delivered to a bulb;
- the effect of resistance on the size of the current flowing;
- that resistance is measured in ohms;
- to recall and use the formulae derived from Ohm’s Law;
- to recall and use the resistor colour code;
- to connect a diode and a LED in forward biased mode;
- to compare and distinguish between the properties of diodes and LEDs in both forward and reverse bias;
- to describe the change in resistance that takes place when a thermistor is warmed;
- to describe the change in resistance that takes place when a phototransistor is exposed to light;
- to design a light-sensing unit to meet a given specification;
- to design a temperature-sensing unit to meet a given specification;
- to calculate the voltage across the components of a voltage divider;
- to set up a variable resistor to control the brightness of a bulb;
- to distinguish between using a variable resistor and using a voltage divider to control the brightness of a bulb;

Work-sheet	Notes for the Instructor	Tim-ing
1	Introductory brainstorming/discussion/trigger questions could cover: What is electricity? Where does electricity come from? What do we use it for? The aim is to introduce the two classes of substance - conductors and insulators. To begin with, students set up a simple circuit to light a bulb, to give them experience of and confidence in using the kit. They then test a range of materials to see which class they belong to, by clamping samples under the screw terminals of the sampler carrier. When the bulb lights, the material is deemed to be a conductor! The exercise points students towards the idea that metals conduct electricity well, and most other classes of substance do not. Most importantly, air is an insulator (though the instructor might raise the issue of lightning!) They devise a means for testing water. In reality, the result depends on the purity of the water used. This could lead to a discussion on appropriate testing methods. It becomes apparent that some substances conduct better than others. Semiconductors, neither conductors nor insulators under normal conditions, are at the heart of the present-day electronics industry. The exercise also shows that an electric current flows only when there is a complete circuit. This topic is covered in more detail in the next worksheet. The switch is introduced here as it can move from 'conductor' to 'insulator'. Under normal circumstances, it does not matter where the switch is located in the circuit. However, as the worksheet illustrates, under some circumstances, it does matter!	30 - 45 mins
2	Here, it is worth comparing and contrasting a number of 'transport phenomena' - flow of water, flow of traffic, flow of people, flow of gas, with the flow of electricity. • Electrical circuits do not leak and do not 'burn' electrons. • Electrons do not park, don't crash and can't be squashed up. Electrical appliances convert electrical energy into a different energy form. The electrical energy is transported around the circuit by electrons. They are rather like rail trucks, carrying coal or oil. Once they discharge the cargo, they return to pick up more energy from the power supply. The worksheet focuses on the need for a complete circuit and then looks at the benefits of using standard symbols to describe it. Should a student question the need for a complete circuit by saying that only one wire is needed to give an electric shock, contrast the case of birds that sit on high-voltage cables, painlessly, provided their other leg is not touching the pylon! The dangers of creating a short-circuit are introduced, and should be reinforced by the instructor. It should never be possible to move from one terminal of the power source to the other without passing through a component such as a bulb. On a practical level, batteries that are short-circuited go flat very quickly, and wastefully. The power supply alternative is current-limited, and will simply switch off if short-circuited. More importantly, electric currents warm up the wires they flow through, and a short-circuit can warm them up so much that it causes a fire. Students practice interpreting standard circuit symbols to create circuits. At this stage, they use the brightness of the bulbs as a measure of the current flowing. The worksheet ends with the practical point that many motor manufacturers use their own, non-transferable form of circuit diagram, unfortunately!	25 - 40 mins

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3	We cannot see the current of electrons flowing around a circuit. We know it is there by the effects it creates, such as its heating effect. As electrons 'brush' past the positive ions in a wire, they make them vibrate a bit more. We see an increase in temperature. Students could make a list of appliances that use the heating effect. The wire wool experiment should produce sufficient heat to make the strands glow, (and possibly snap,) allowing comparison with filament lamps. If this does not happen, the student has clamped too many strands between the posts of the sampler.(Damp paper or cardboard will protect the baseboard from molten metal.) The effect can give rise to a discussion on the use of fuses. As an aside, the student is asked to consider the advantages of 'low-energy' lighting, now common in both domestic and automotive applications. The student then creates a circuit fault that could lead to damage - to the power supply (e.g. car battery) or to the wiring itself. The presence of a fuse avoids this. The steel fibres have a greater resistance than the copper connecting wires, but more of that later, when the idea of resistance has been introduced. As before, where the wire wool does not melt, then the student has probably used too many strands. In practice, we want the fuse to carry 'normal' levels of current and to melt only when that is exceeded. The instructor should relate this behaviour to that of a switch and to the basic ideas of conductor vs insulator. The worksheet ends by asking the student to research alternatives (more modern) to the simple fuse, for example re-settable circuit breakers.	20 - 30 mins
4	A most important effect of electrons flowing is the magnetic effect they produce. A wide range of appliances use electromagnetism - electromagnets, motors, transformers, solenoids .... The magnetic effect around a single wire is very weak but it can be intensified by wrapping many strands of wire into a coil, especially when a core of a magnetic material such as iron, is inserted into that coil. Students are asked to think about ways to intensify the magnetic field. Answers will probably include increasing the number of turns on the coil of wire, adding a magnetic core and increasing the current through the coil. The instructor may wish to explore some of these suggestions with the class.	20 - 30 mins
5	This worksheet looks at two applications of electromagnetism - the solenoid and the relay. To begin with, it lists some common uses of solenoids in a vehicle. Some of these may not be familiar to the students and the instructor may wish to expand on what is given. The structure of a typical solenoid is described. In the same way that an electromagnet attracts magnetic materials, the energised coil of the solenoid attracts the plunger. The result is linear motion of the plunger (actuator). Students then test a solenoid in a simple circuit. The considerable force with which the plunger moves should be readily apparent. The worksheet then looks at the electromagnetic relay, an electronic switch which controls one circuit by means of actions in another. As far as the controlled circuit is concerned, the relay is a switch that is operated remotely. One benefit, seen here, is using a small current in the control circuit to switch a much larger current in the controlled circuit. Another is that a low (and relatively safe) voltage source can power the control circuit to switch much higher voltages in the controlled circuit. Relays are common in automotive circuits, though increasingly are replaced with fully electronic devices such as thyristors, which are not subject to frictional wear due to moving parts.	25 - 40 mins

Worksheet	Notes for the Instructor	Timing
6	Another important idea—series and parallel connections! For a series circuit, some students start with the erroneous belief that current gets smaller as it flows around the circuit. This is true for a gas installation, where a number of burners are fed from a common supply pipe. Each burns a certain volume of gas each minute, leaving a smaller flow down the pipe to the next burner. Using brightness as a measure of current, the similar brightness of all bulbs in a series circuit is used to dispel this idea. Series circuits offer only one route for electrons. None are 'siphoned off' and 'burned'. They pass through all parts of the circuit. Their energy gets smaller but the number flowing stays the same. When a break occurs in the circuit, such as a faulty bulb, or 'blown' fuse, no current can flow anywhere. The effect is like that of a road block. Very soon, the flow of traffic stops everywhere, not only at the site of the road block. Students are asked to try different positions for the switch around the circuit. Rather like moving the road block, the effect is the same no matter where it happens. A parallel circuit offers the electrons alternative routes around the circuit. Students should be encouraged to trace these out and to assess which of them is easiest from the electron's perspective. That route we expect to carry the highest current. In terms of traffic flow, parallel routes are often called bypasses, and are built to increase traffic flow either by avoiding features such as narrow bridges, or simply by having two roads to carry the traffic. Instructors should refer to local examples of these, where possible. Looking at the circuit diagram for the parallel circuit, there is a direct connection from the power supply to each bulb. In other words, each bulb functions independently. What the others are doing, e.g. removed or 'blown' has no effect. This is often an advantage as it means that most of a lighting installation continues unaffected when a fault occurs in one lamp. The third circuit has both series and parallel connections in it. However, the rules established in the previous two circuits still apply. The flow of electrons through bulb A is greater than that that through B (and C) as it is an easier route. Put another way, the full power supply voltage appears across bulb A, whereas bulbs B and C share it and see only half each. The challenge is to change the position of the switch so that it controls only bulbs B and C. The solution is to move bulb A to the left of the switch.	30 - 45 mins
7	Students will meet two forms of measuring instruments - analogue and digital meters. In an analogue meter, something copies the behaviour of (is an analogue of) the measured quantity. In a mercury-in-glass thermometer, the mercury column gets longer when the temperature gets higher. In an analogue speedometer, the faster the vehicle moves, the further the pointer rotates. Each type has its strengths and weaknesses. The analogue meter is useful for seeing a trend in a changing reading. It is easy to tell whether a vehicle is speeding up or slowing down by looking at its analogue speedometer. A digital speedometer samples the speed. Where the sampling rate is very small, it would take some time to decide what the vehicle was doing. The analogue meter is the more difficult to read, however. This worksheet looks at how to do that and gives examples for the student to try.	20- 30 mins

Work-sheet	Notes for the Instructor	Tim-ing
8	Using bulb brightness as a measure of electric current is too crude, for the reasons given in this worksheet. The investigation shows how to measure current using an ammeter instead. That can be either analogue or digital, as the instructor wishes. It might be desirable to use both types, in different parts of the investigation, to allow the student to compare the two. The worksheet revisits the three circuits studied in worksheet 5, using this more refined approach and encourages students to look for patterns in their results. The instructor could go on to give further examples of circuits, providing currents in some sections and inviting students to deduce the currents in other parts.	30 - 45 mins
9	The concept of voltage can be a difficult one to convey. To be precise, it is the energy delivered to / transformed by one coulomb of charge. That reduces to "a measure of the energy gained or lost by an electron," - "gained" when it passes through a voltage source, "lost" when it passes through a device with some kind of resistance. The good news is that voltage is easy to measure. The voltmeter is connected in parallel with the device under investigation. The first investigation looks at a series circuit. It aims to show that the sum of the voltages across the components in the series circuit is equal to the power supply voltage As pointed out when discussing current in a series circuit, the number of electrons passing per second is the same at all points in a series circuit. As the electrons pass around the circuit, the energy that they gained in passing through the voltage source is lost to the devices (and wires) that they pass through. Eventually, they arrive back at the voltage source, having lost all the energy they initially gained. They then repeat the whole process again. This should be the finding from the first investigation. This is the picture that the students need to have to dispel all the erroneous ones. They then investigate voltages in a parallel circuit. As pointed out earlier, the same voltage, the full power supply voltage, appears across each bulb, so that they operate independently of all the others. Students should not think that they can add up the voltages in this circuit! A law known as Kirchhoff's Second Law says that the voltages in any loop of the circuit add up to the power supply voltage. There are three such loops in this circuit, as the students should have identified earlier. Finally, students set up and investigate the mixed circuit. In this, they should be able to recognise elements of both the series and parallel circuits.	20- 30 mins

Work-sheet	Notes for the Instructor	Tim-ing
10	Electrical science is plagued by concepts which have a precise and unique meaning but which are used sloppily in everyday speech. The result is a general confusion about them. Students should be encouraged to use the correct term. It is up to the instructor whether they accept 'ampage' for current, and 'wattage' for power. The fact that we cannot see, or monitor, individual electrons causes all the problems. If electrons were the size of marbles and behaved like them, life would be so much easier (but they are not and do not)! Electrical power spells out the rate at which a device converts energy. For a resistor, it is how much heat energy is generated each second. For an LED, it is (roughly) how much light energy is generated each second. The worksheet starts by spelling out some relationships. The instructor must judge how far to develop these, knowing the mathematical abilities of the students. The important result is the relationship 'P = I x V'. The investigation measures current through and voltage across the bulbs in a number of circuits, and hence allows the student to calculate the power dissipated in each. 'Power dissipated' means energy delivered to and converted by these bulbs.If that energy came from a battery, it would eventually go flat. The more enrgy it delivers per second, the more quickly it would go flat. The students make an assessment of which circuit would flatten its battery first.	25 - 40 mins
11	This worksheet introduces resistors as a means of controlling current. That is certainly one of their roles, but they also play a part in delivering voltage signals, as the later worksheet on voltage dividers shows. Virtually everything that conducts electricity offers some resistance to its flow. First of all, a rod of graphite is used to demonstrate this. It reduces the current flowing through the bulb, demonstrated by later short-circuiting the rod. Then a second bulb is added in series. It too has resistance, roughly comparable to that of the graphite rod (depending on the proportions of the rod.) Its resistance varies depending on the temperature of the filament, so it is rarely used as a resistor. The second bulb is then replaced by an 'official' resistor.	20- 30 mins
12	This worksheet looks at a couple of exotic resistors. The thermistor is a temperature-dependent resistor. (Actually, as pointed out when discussing bulbs in the previous section, most resistors are temperature-dependent. Thermistors are manufactured to a precise specification.) The one used in the investigation is a ntc (negative temperature coefficient) thermistor. In other words, its resistance drops as its temperature rises. The opposite, ptc (positive temperature coefficient) thermistors are available. These are useful in preventing a component from overheating. In thermal contact with the component and in series with it, its resistance rises should the component get hot. This reduces the current through the component, lowering its temperature. Either type cam be used in a temperature-sensing unit, but they have opposite behaviour. The change in resistance of the thermistor and the change in voltage when it is used in a temperature-sensing circuit are both examined in this worksheet. The phototransistor behaves in a similar way when the light level on it changes. As a result, it can be used to make a light-sensing unit. Students are challenged to design an experiment to show exactly how the behaviour of a phototransistor depends on light level.	20- 30 mins

Work-sheet	Notes for the Instructor	Tim-ing
13	Ohm’s law is a bit over-rated really. It works only when the temperature of the resistor stays the same and so hardly ever applies! Nevertheless, it looms large in most electricity courses. It shows the relationship between the current through a resistor and the voltage across it. The relationship is straight-forward. Current is directly proportional to voltage. That means that if you double the current, you double the voltage. When you quarter the current, you quarter the voltage etc. This investigation seeks to illustrate that and students are guided into showing their results in the form of a graph. Depending on their mathematical ability, they may need further intervention from the instructor to achieve this. This leads to a section showing how many resistors have their resistance marked on them using the ‘Resistor Colour Code’. Students are given an example to demonstrate how to use it. The Student Handout gives further examples. It is important that the students know the meaning of the prefixes ‘micro’, ‘milli’, ‘kilo’ and ‘mega’. The worksheet ends with the important practical point that you cannot measure the resistance of a component while it is connected in a circuit. The multimeter will show a resistance value but you cannot be sure what it s measuring. A number of components are connected together. Always isolate the component you are interested in!	25 - 40 mins
14	The word ‘diode’ simply means ‘two-legged’. In electronics, that hides their special behaviour. They are one-way valves for electrons. More precisely, they offer a low resistance to electron flow in one direction through them and a very high resistance to electron flow in the other direction. There are a number of different types of diode. The first studied here is the power diode, so called because it is used in power supplies, to turn AC into DC. The investigation looks at how the current through the diode depends on the voltage across it. The circuit is the same as that used in the previous worksheet but the behaviour of the diode is completely different. For one thing, the work on the resistor resulted in a straight-line graph. This one does not. With the resistor experiment, it did not matter which way round the resistor was connected. With this it does. The instructor may wish to reinforce the ideas of forward and reverse bias and should emphasis the need to change the voltage very slowly since the current can change extremely quickly. The student looks at both aspects of the diode’s behaviour, forward and reverse bias. The second part looks at a LED (light-emitting diode). Similar in many ways to the power diode, this is designed to emit light when forward biased at the right level. The instructor should ensure that students can identify the anode and cathode legs of the LED. Using a 3V power supply is important. A higher voltage could damage the components.	25- 40 mins

Work-sheet	Notes for the Instructor	Tim-ing
15	This topic, voltage dividers, strikes fear into the heart of many a brave student. As a result, the instructor needs to tread cautiously and monitor progress carefully. In reality, the behaviour is not complicated. It is spelled out at the bottom of the first page of the worksheet and in the Student Handout. In many ways, it offers a good test of how well students have assimilated the ideas earlier in the course. The investigation aims to provide confirmation that these relationships work! The instructor may decide to test the students with further examples to assess their level of understanding.	25 - 40 mins
16	Here is another topic that many would prefer to avoid - the potentiometer, or 'pot'. As a component, it has three terminals and has a spindle that you can turn. It may be best to start this section by going into detail over the structure of the pot. The instructor may be able to pass around an opened example to illustrate it. In reality, it can create two resistors - one between the slider and one end, the other between the slider and the other end. It has two uses - as a variable resistor and as a voltage divider. It is important that students can recognise which is in use in a given situation. Resistors have two legs and so do variable resistors. Voltage dividers contain two resistors, connected together, and have three legs. The first part of the investigation uses the pot as a variable resistor. That means exactly that - its resistance is variable - from roughly zero to the maximum resistance of the track, 250 ohms in this case. It can control the brightness of the bulb from a low value to full brightness. It cannot reduce the current through it to zero. That would require infinite resistance. The second part looks at its use as a voltage divider. Here it acts as a variable voltage source. The voltage it delivers to the bulb can be varied from zero to the full value of the supply voltage. As a result, it can control the current through the bulb from zero to the maximum value. That makes it sound to be the ideal control device. However, this control comes at a cost in terms of efficiency. Regardless of what the bulb is doing, thre is a current flowing down the track in the pot. This is wasted current in reality. It does nothing to light the bulb. The students are asked to explain why the voltage across the bulb changes when it is unscrewed. The answer lies in the currents flowing through the pot. When the bulb is lit, the current through one section of the track is greater than that through the other section of the track, since one is carrying the bulb current as well. When the bulb is unscrewed, the current is the same throughout the track. As a result, the voltage across the bulb depends on whether it is passing a current, i.e. plugged in.	25- 40 mins

Bill of materials

What the student will need:

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

1	**HP2666**	**Adjustable DC power supply**
1	HP4039	Tray Lid
1	HP5540	Deep tray
1	HP7750	Daughter tray foam cutout
1	HP9564	62mm daughter tray
1	HP8600	Crash foam
1	LK3246	Buzzer, 12V, 15mA
1	LK3982	Voltmeter, 0V to 15V
1	LK4002	Resistor, 100 ohm, 1W, 5% (DIN)
1	LK4100	Resistor, 12 ohm, 1W, 5% (DIN)
2	LK5202	Resistor, 1k, 1/4W, 5% (DIN)
1	LK5203	Resistor, 10k, 1/4W, 5% (DIN)
1	LK5208	Potentiometer, 250 ohm (DIN)
2	LK5243	Diode, power, 1A, 50V
15	LK5250	Connecting Link
1	LK5280	Relay, 12V, normally open
3	LK5291	Lampholder, MES
1	LK5401	Thermistor, 470 ohm, NTC (DIN)
1	LK5570	Pair of leads, red and black, 600mm, 4mm to croc clip
1	LK5603	Red 4mm to 4mm lead, 1m
1	LK5604	Black 4mm to 4mm lead, 1m
1	LK6207	Switch, push to make, metal strip
1	LK6209	Switch, on/off, metal strip
1	LK6238	Resistor, 200K, 1/4W, 5%
1	LK6635	LED, red, 12V
1	LK6706	Motor, 12V
1	LK6838	Solenoid
1	LK7290	Phototransistor
1	LK7936	Universal component carrier
1	LK8275	Power supply carrier with battery symbol
1	LK8397	Ammeter, 0A to 1A
1	LK8900	7 x 5 metric baseboard with 4mm pillars
1	LK9071AP	Accessories kit
1	LK9381	Ammeter, 0A to 100mA
1	LK9998	400 Turn coil carrier

Version control

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Automotive electricity

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