



ELECTRICITY MATTERS 2

CP7326

Inspiring The Next
Generation Of Engineers

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WORKSHEETS



WORKSHEETS

Worksheet 1 - Circuit Symbols

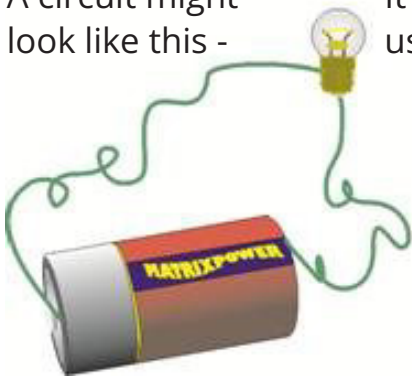


Everyday you come across **symbols**, used at home or when you are out and about.

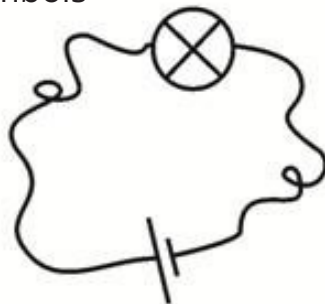
They are quicker to read than long messages using words!

Circuit symbols describe which components are used in a circuit, and show how they are connected.

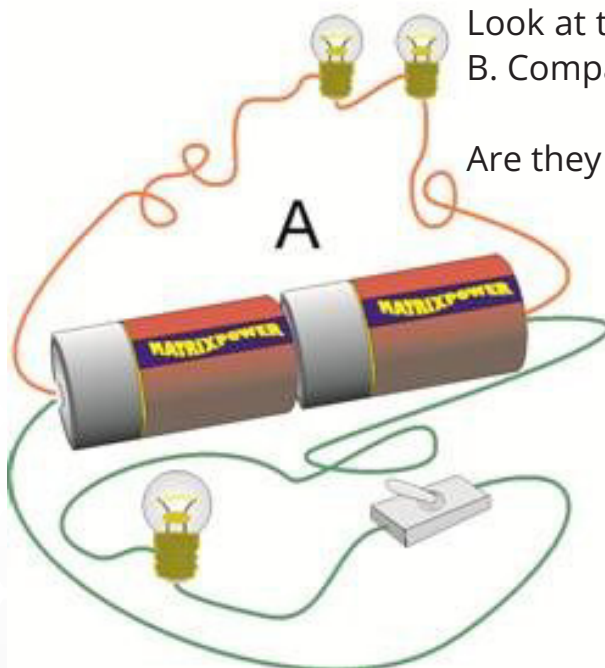
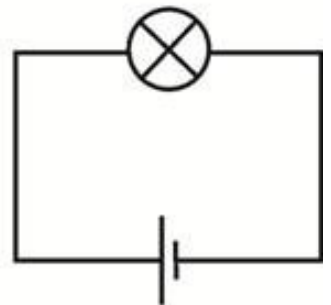
A circuit might look like this -



It is simpler to use symbols

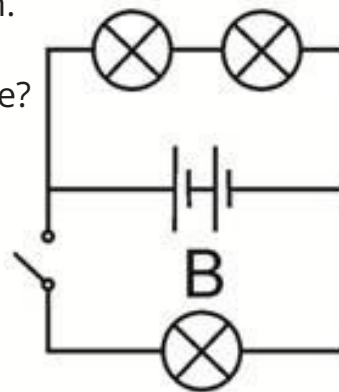


Or better still -



Look at the two circuits, A and B. Compare them.

Are they the same?



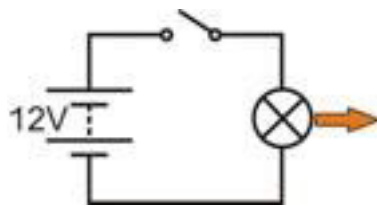
WORKSHEETS

Worksheet 1 - Circuit Symbols

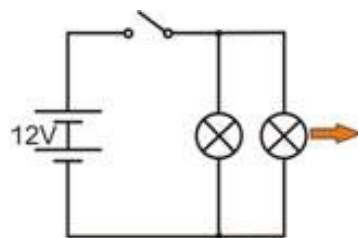
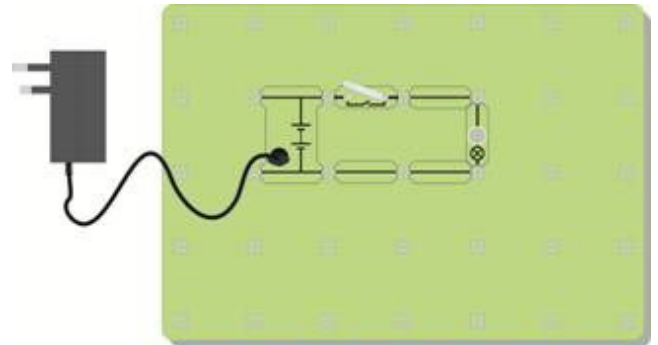
Over to you:

Here are four circuits, shown using symbols and also as 'real' layouts.

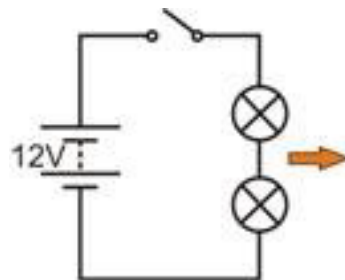
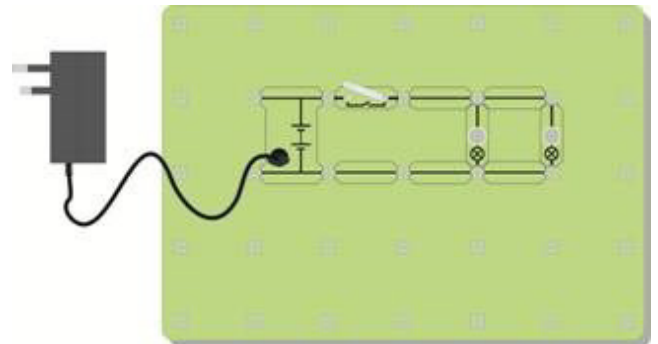
Build each one using 12V 0.1A bulbs, and work out the answers to the questions.



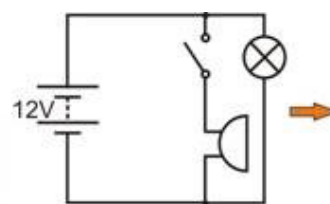
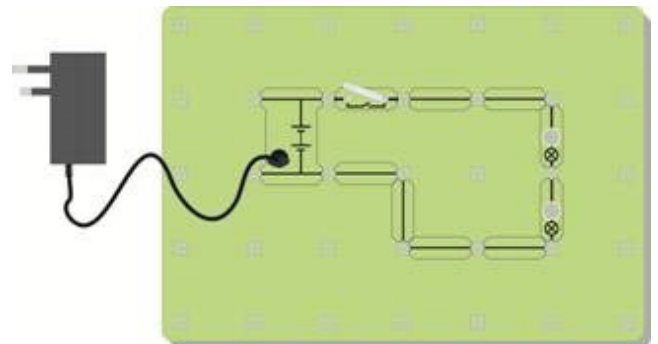
Bulb: Bright/Dim?



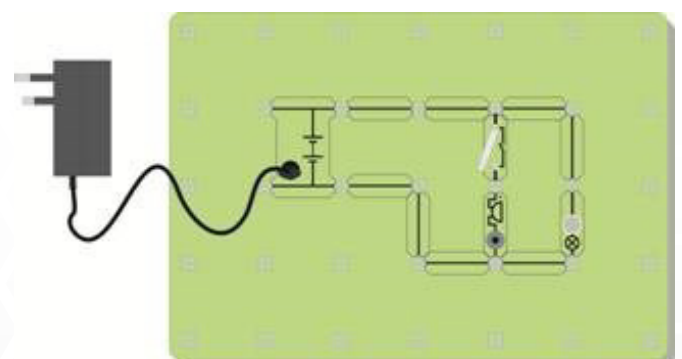
Bulbs: Bright/Dim?



Bulbs: Bright/Dim?



Switch Controls.....?



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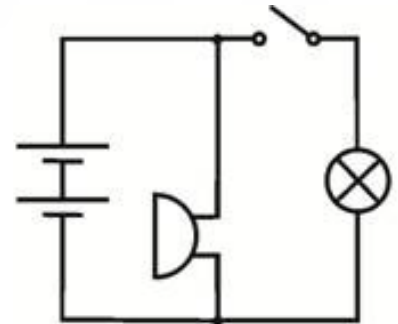
Worksheet 1 - Circuit Symbols

So What?

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

Here is another circuit.

Build it just using the circuit diagram, and then answer the question!



Now the switch controls.....?

For your records:

Copy the following table:

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

WORKSHEETS

Worksheet 2 - Conductors



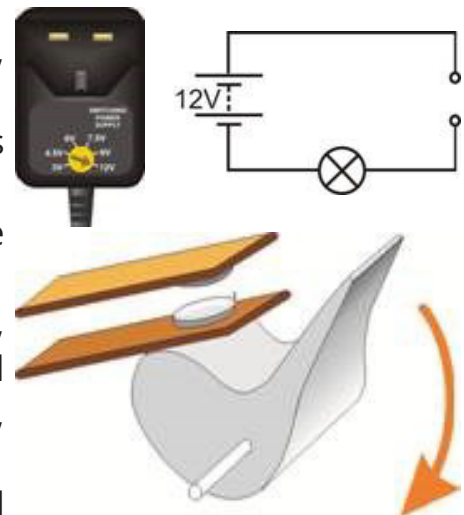
We are surrounded by many kinds of materials. They all behave in different ways.

One way in which they are different is that some pass electricity, and others do not.

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

Over to you

- First of all, build a circuit that makes a 12V bulb light, to test that the components work.
- Swap one link for the carrier with the test gap. This arrangement is shown in the circuit diagram.
- Put different materials across the gap and see if the bulb lights.
- Try the following: kitchen foil (aluminium), a rubber, paper, wood, polythene, copper, air, lead, glass, pencil lead (graphite), a coin, a piece of cloth, a plastic pen, and any other handy items.
- Sort the materials into two groups – **conductors and insulators**.
- Fill in a table, like the one opposite, with the findings from your experiment.



Materials that conduct	Materials that insulate

So What?

- Look at the materials that let electricity pass.
- Which class of substance do they all belong to?
- Think of a way to test whether water is a conductor or an insulator. Check your idea with the teacher, and if you get the go-ahead, try your idea out.
- Test pure water, tap water (which is not the same thing!) and salty water. Is there a difference?

WORKSHEETS

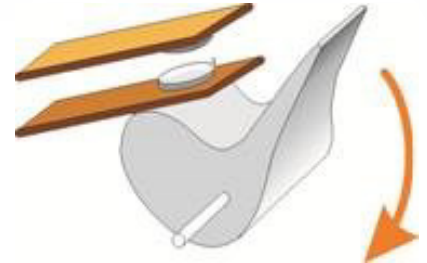
Worksheet 2 - Conductors

Switches:

We usually need something to activate our electrical circuits.
A switch does just that!

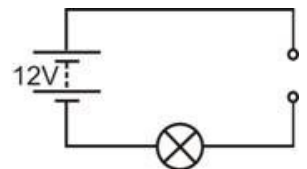
It relies on the fact that air is an insulator.

The diagram shows what happens inside a switch when you press the lever down to switch it on.



Over to you

- Set up the arrangement shown in the circuit diagram, using a 12V 0.1A bulb.
- Change the circuit so that there are two 6V 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.



Here are the names and symbols for two types of switch: A **push switch** is 'on' only as long as you are pressing it.

Toggle Switch Push Switch

When you turn on a **toggle switch**, it stays on, until you turn it off.

For your records:

- Most of the conductors belong to the class of substances called
- I think that the hard shiny object that felt cold would electricity, because it is probably made of a
- Pure water is an However, if there are any impurities in it, such as salt, or chlorine, then the water is a
- Air is an which explains why we do not get an electric shock when we stand near a mains electricity socket. A switch starts and stops the flow of
- When the switch is open, the gap stops the flow of electricity.
- When the switch is, the air gap disappears, and electricity flows around the circuit.
- A toggle switch stays on or stays off all the time. A push switch is on only as long as you press it.
- A doorbell is one type of switch. A light switch is one type of switch.

WORKSHEETS

Worksheet 3 - Resistors



Using a tap, we can change the flow of water from fast to slow.

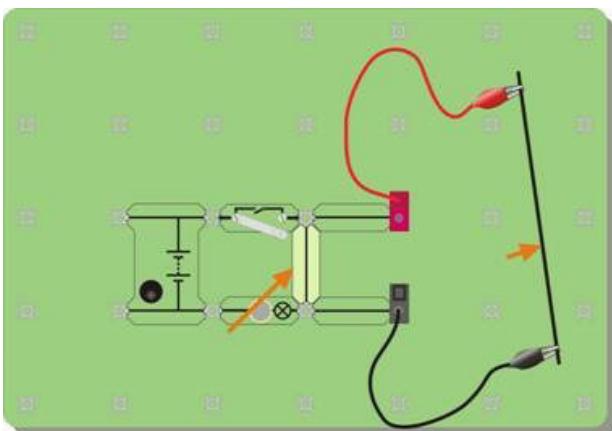
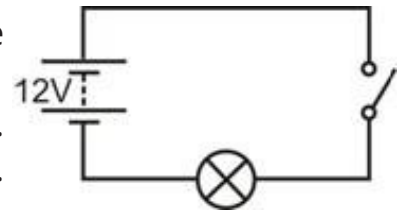
With electricity, we change the flow using a resistor.

Electric currents can cause a variety of effects – heating, lighting, magnetism and chemical. Although we cannot see them, tiny particles called electrons make up electric currents. The flow of these electrons can be reduced by adding more resistance to the circuit.

The effect of resistance is like you trying to run in mud!

Over to you

- Set up the following circuit, using a 12V 0.1A bulb. Make sure that the power supply is set to 12V!
- Close the switch and notice how bright the bulb looks. Remember - the brighter the bulb, the greater the current.
- Make your own resistor by clamping a rod of graphite (a mixture of carbon and clay, used in pencil lead,) using crocodile clips onto the ends of two connecting leads. The rod should be as long as possible, and at least 15cm long.
- Next, swap your pencil lead resistor for one of the connecting links. Close the switch again. What do you notice about the bulb? What does this tell you about the electric current?



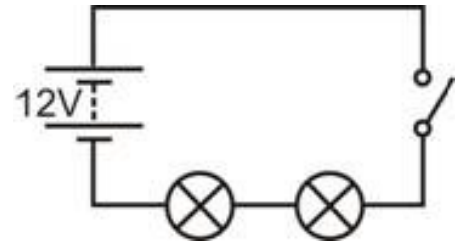
You could make it easier to compare by 'short-circuiting' your resistor. To do this, add a connecting link as shown in the diagram.

WORKSHEETS

Worksheet 3 - Resistors

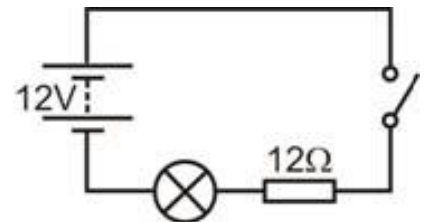
Over to you

- Now set up the circuit shown in the diagram.
- Close the switch.
- What do you notice about the brightness of the two bulbs compared to the brightness of the one bulb in the first circuit (before you added your resistor.)



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.
- Swap one of the bulbs for a 12 ohm resistor. Here is the symbol for a resistor. 



The circuit diagram for the new arrangement is shown opposite:

Notice the brightness of the remaining bulb.

What does this tell you about bulbs? (Once again, try 'short-circuiting' your resistor, by plugging in a wire into both ends, to check what is happening.)

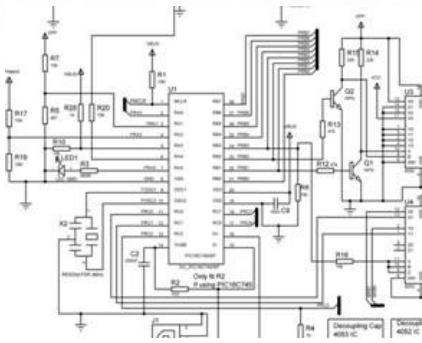
- **A good question** – where does the 'extra' electric current go when you add a resistor? Think about the flow of other things, like water, or traffic. When you turn a tap down a little to lower the flow of water, where has the 'missing' flow of water gone? When a car breaks down on a busy road, the flow of traffic is reduced. Where is the 'missing' flow of cars?
- A resistor can be simply a long piece of wire, made from a metal that does not conduct very well. This kind is usually wound as a coil around an insulating core. It can also be made by coating an insulating core with a thin layer of carbon, or by mixing carbon with a ceramic substance (like clay.)

For your records:

- A resistor limits the flow of electricity
- The bigger the resistance, the smaller the electric current.
- Resistance is measured in ohms. Usually, we use the Ω sign to mean 'ohms'.

WORKSHEETS

Worksheet 4 - Series and Parallel



In some circuits, there is only one route that the electric current can follow to get from one side of the power supply to the other.

In others, the current has a choice of route.

An electric current is a flow of negatively charged electrons. Overcrowded on the negative terminal of the battery, they flow around the circuit, attracted to the positive terminal.

A **series** circuit offers only one route around the circuit, from one end of the battery back to the other! There are no junctions in a series circuit.

A **parallel** circuit offers more than one route and so different currents can flow in different parts of the circuit.

Over to you

- Set up the arrangement shown, using 12V 0.1A bulbs.
- Make sure that the power supply is set to 12V!
- This is a series circuit—everything connected in a line, one after the other.
- There is only one way for electric current to get from one end of the power supply to the other. There are no junctions, no alternative routes!
- Does it matter where you connect the switch? Try it in different places in the circuit.
- Close the switch and notice how bright the bulbs look.
- Don't forget – 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?
- Does it look as if electric current is getting 'used up' as it goes round the circuit? (In other words, do the bulbs get dimmer as you move further round the circuit?)
- If the bulbs have the same brightness, then the current flowing through them must be the same.

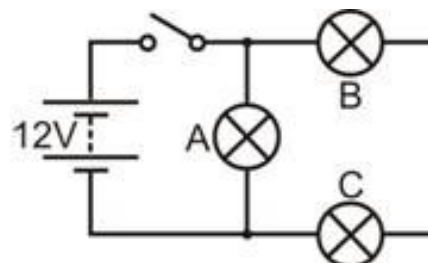


WORKSHEETS

Worksheet 4 - Series and Parallel

Over to you

- Now change the circuit for the one shown, still using 12V bulbs.
- Make sure that you set the power supply to 12V!



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 mark the junctions in the circuit.)

Look at the brightness of the three bulbs.

What does this tell us?

Unscrew bulb A. What happens?

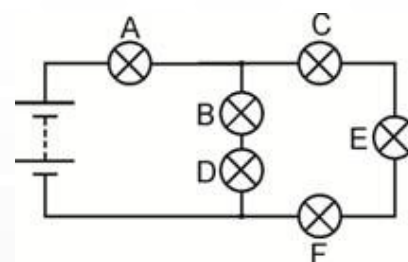
Unscrew bulb B. What happens?

So What?

- One route goes through only one bulb. The other route goes through two bulbs. That route is twice as difficult for the electrons. Most will take the easy route through just the one bulb. More electrons per second = bigger current. Explain to your partner or your teacher how your observations support this idea.
- The second circuit is not a series circuit as there are two ways to get from one side of the battery to the other. Bulb A is connected in parallel with the other two bulbs. Bulb B is in series with bulb C because they are on the same route.
- A challenge! Change the circuit so that the switch controls only bulbs B and C, **BUT** you can only move bulb A to achieve this.

For your records:

- A series circuit offers only one route for the electric current. If a break appears anywhere in the circuit, then the electric current stops everywhere. If one bulb fails in the circuit, then all the bulbs go out. The electric current is the same size throughout the circuit.
- A parallel circuit offers more than one route and so different currents can flow in different parts of the circuit.
- Copy the circuit diagram and answer these questions:
 1. Bulb B is in series with bulb
 2. Bulb C is in with bulb E and bulb F.
 3. Bulbs B and D are in with bulbs C, E and F.
 4. The biggest current will flow through bulb
 5. Bulb will be the brightest bulb.



WORKSHEETS

Worksheet 5 - Measuring Current



So far we have used the brightness of the bulbs as a measure of the size of the current.

This is too crude for a number of reasons:

- Bulbs are mass-produced and so not identical;
- It is difficult to judge small changes in brightness when the currents are similar;
- It doesn't work if the current is too small to light the bulb!

Meter Symbols

Ammeter — (A) —

Voltmeter — (V) —

Ohmmeter — (Ω) —

A much more reliable way of measuring current is to use an ammeter.

We also need ways of measuring voltage and resistance.

A multimeter offers a convenient and cheap way to measure important electrical quantities such as current, voltage and resistance. The photograph shows the controls on a typical multimeter.



Using a multimeter to measure current:

A multimeter can measure either AC or DC quantities.

The following symbols are used to distinguish between the two:

AC 
DC 

- Plug one wire into the black COM socket.
- Plug another into the red mA socket.
- Select the 200mA DC range by turning the dial to the '200m' mark next to the 'A ' symbol.
- Break the circuit where you want to measure the current, by removing a link, and then plug the two wires in its place.
- Press the red ON/OFF switch when you are ready to take a reading.

A possible problem!

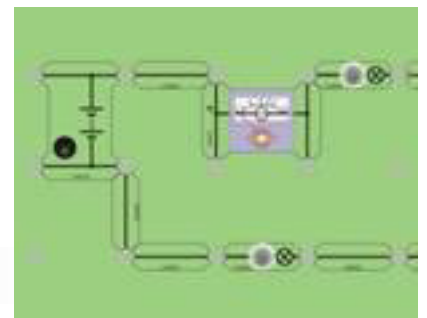
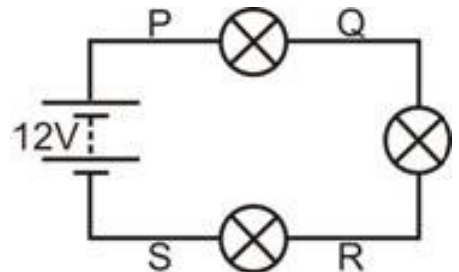
The ammeter range is protected by a fuse located inside the body of the multimeter. This fuse may have 'blown', in which case the ammeter range will not work. Report any problems to your teacher so that they can check the fuse.

WORKSHEETS

Worksheet 5 - Measuring Current

Over to you

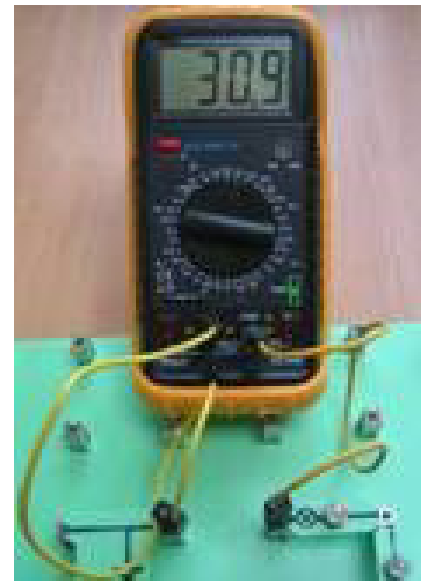
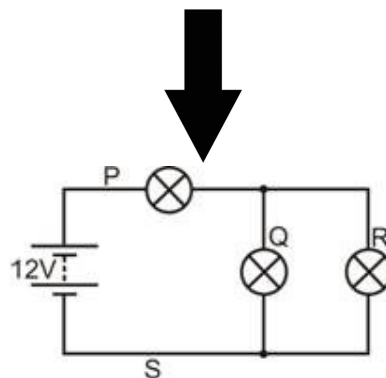
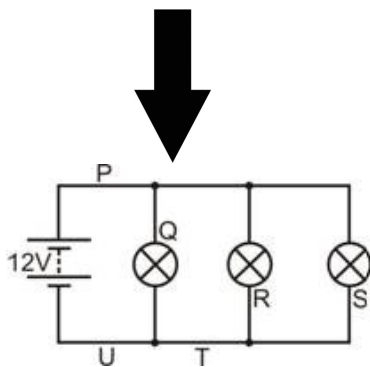
- Set up the arrangement shown, using 12V 0.1A bulbs.
- Make sure that the power supply is set to 12V.
- This is a series circuit. There is only one route around it.
- Measure the current flowing at point P. To do this, remove the link at P and connect the ammeter in its place. The pictures show how to do this for 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.



So What?

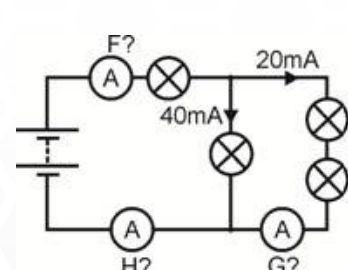
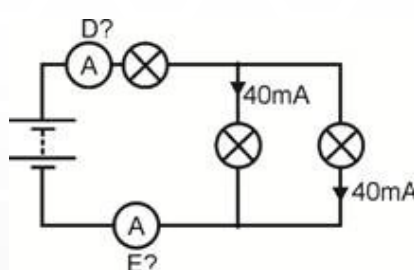
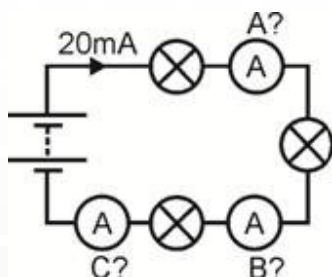
Next investigate the currents flowing at points P, Q, R etc. in the following circuits.

See if you can spot a pattern for the behaviour!



For your records:

- In a series circuit, the current flows in all parts.
- In a parallel circuit, the currents in all the parallel branches add up to the current leaving the
- Copy the following circuit diagrams, and calculate the readings on ammeters A to H.



WORKSHEETS

Worksheet 6 - Measuring Voltage



We can visualise electric current reasonably easily—it's the flow of tiny electrons around the circuit. More precisely, it measures the number of electrons per second passing a particular point in the circuit.

It is more difficult to picture voltage. It is a measure of the force that makes the electrons squeeze along the wires. The bigger the power supply voltage, the more energy the electrons are given, and then give up, as they travel around the circuit.

Meter Symbols

Ammeter — 

Voltmeter — 

Ohmmeter — 

However, it is easier to measure voltage than current. No need to break the circuit—just add the voltmeter in parallel with the component you are interested in!

Ammeters are connected in series whereas voltmeters are connected in parallel!

Using a multimeter to measure voltage:

A multimeter can measure either AC or DC quantities.



The following symbols are used to distinguish between the two:

AC 
DC 

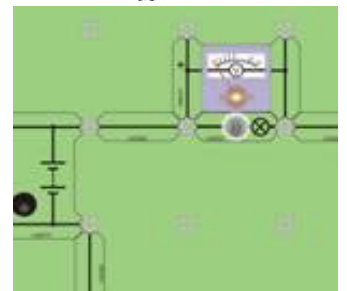
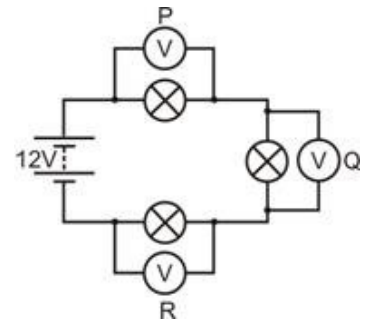
- Plug one wire into the black COM socket.
- Plug another into the red V socket.
- Select the 20V DC range by turning the dial to the '20' mark next to the 'V ' symbol. (It is good practice to set the meter on a range that is much higher than the reading you are expecting. Then you can refine the measurement by choosing a lower range that suits the voltage you find.)
- Plug the two wires into the sockets at the ends of the component under investigation.
- Press the red ON/OFF switch when you are ready to take a reading.
- If you see a '-' sign in front of the reading, it means that the wires from the voltmeter are connected the wrong way round. Swap them over to get rid of it!

WORKSHEETS

Worksheet 6 - Measuring Voltage

Over to you

- Set up the arrangement shown, using 12V 0.1A bulbs, but without the voltmeters.
- Make sure that the power supply is set to 12V.
- This is a series circuit with only one route around it.
- 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 pictures show how to do this for the 15V voltmeter carrier and for the multimeter.
- Next, measure the voltage across the second bulb, shown by connecting the voltmeter as shown at Q.
- Then measure the voltage across the third bulb, by connecting the voltmeter at point R.

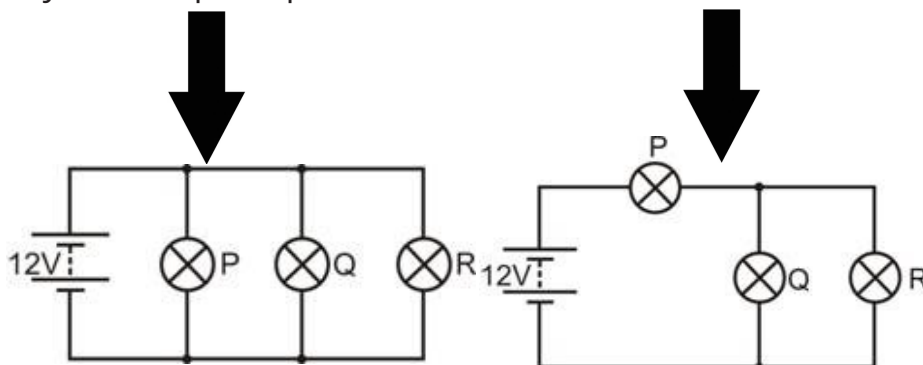


So What?

Add together the readings of the voltmeters at points P, Q and R. What do you notice about this total?

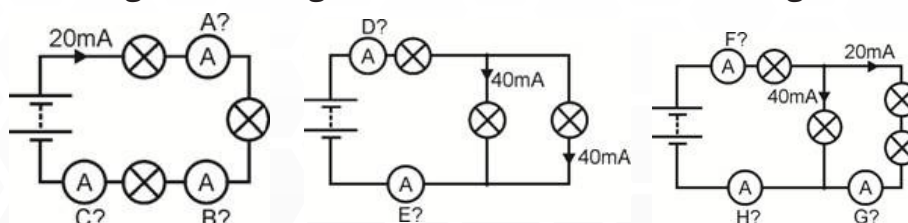
Next investigate the voltages across bulbs P, Q, and R, all 12V 0.1A, in the following circuits.

See if you can spot a pattern for the behaviour.



For your records:

- In a series circuit, the voltages across the components add up to the voltage across the
- In a parallel circuit, the components all have the voltage across them.
- Copy the following circuit diagrams, and calculate the voltages across bulbs A to E.



WORKSHEETS

Worksheet 7 - Ohm's law



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.

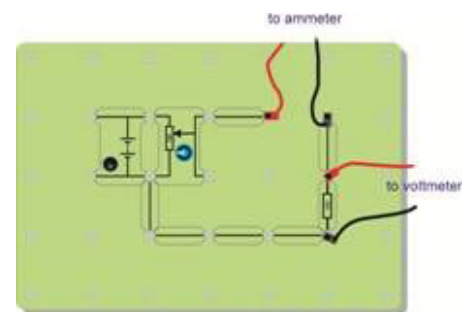
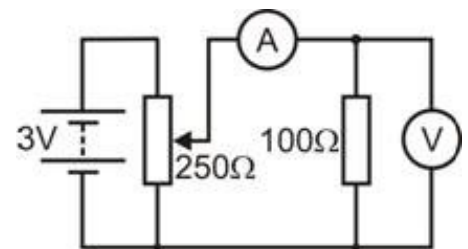
Resistance shows how difficult it is for the electrons to pass through a material. In squeezing through, the electrons lose energy to the resistor, which warms up as a result.

The photograph shows Georg Simon Ohm—a significant figure in this study!

Ohm's law leads to a very important relationship in electricity: $V = I \times R$

Over to you

- Set up the arrangement shown in the diagram.
- **Make sure that the power supply is set to 3V!**
- The variable resistor allows us to change the voltage across the 100Ω resistor.
- The picture shows one way to set this up.
- **Before you switch on**, select the **20mA DC** range on the ammeter, and the **20V DC** range on the voltmeter. Notice the positions of the red and black connecting wires. This ensures that the meters are connected the right way round to avoid '-' signs on the readings.
- Turn the knob on the variable resistor fully anticlockwise, to set the voltage supplied to a minimum.
- Turn the knob slowly clockwise until the voltage across the resistor reaches 0.1V. Then read the current flowing through the resistor.
- 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.**)
- Write your results in a table like the one opposite.



Voltage across Resistor	Current through Resistor
0.1V	
0.2V	

WORKSHEETS

Worksheet 7 - Ohm's law

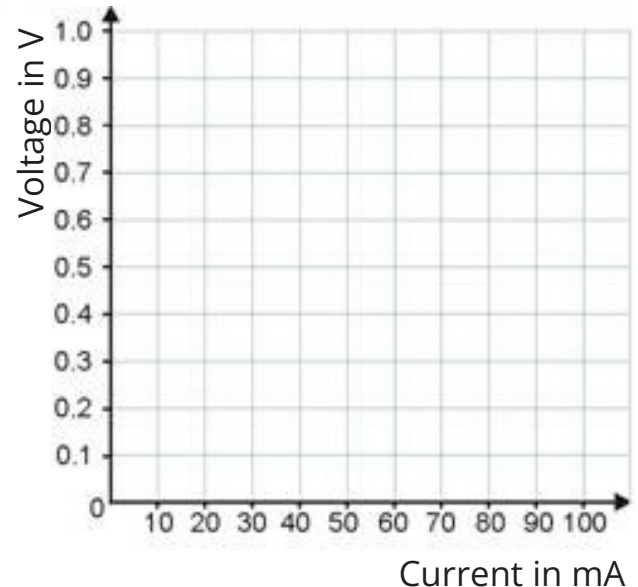
So What?

Plot a graph to show your results.

Ohm's law predicts a straight line, so draw the best straight line through your points.

If you know how, calculate the gradient of your graph.

Ohm's law calls this quantity the resistance of the resistor.



Black	Brown	Red	Orange	Yellow	Green	Blue	Purple	Grey	White
0	1	2	3	4	5	6	7	8	9

Resistor Colour Code:

Resistors often come with coloured bands across their body to show the value of the resistance. Each colour represents a number, as shown in the table.

To read the colour code, start from the opposite end to the gold or silver band:

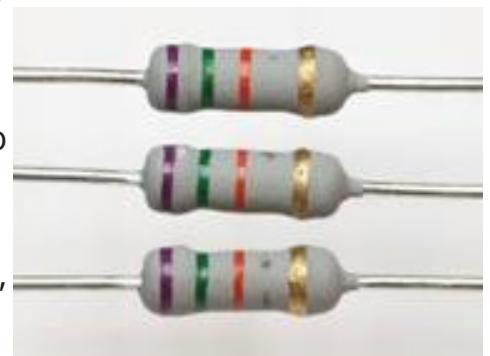
Write down the number shown by the first colour band, and then the second colour band.

Add the number of 0's shown in the next band (e.g. for red, add two 0's.)

The final band (usually gold, (5%) or silver (10%)) shows you the tolerance (how accurately made it is.)

For example, the resistors in the photograph have a resistance of:

$$\begin{aligned} &7 \text{ (purple)} 5 \text{ (green)} 000 \text{ (orange)} \\ &= 75000\Omega \\ &\text{and a tolerance of } 5\% \end{aligned}$$



WORKSHEETS

Worksheet 7 - Ohm's law

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 200k Ω 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 are ready to take a reading.
- Turn the dial to choose a lower range, until you find the reading.

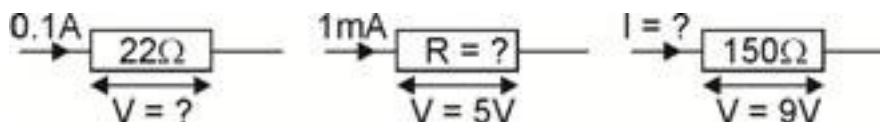


Note

$$1\text{k}\Omega = 1000\Omega$$

For your records:

- Ohm's law gives us the following equations: $V = I \times R$ $R = V / I$ $I = V / R$ where R = resistance in ohms, I = current in amps and V = voltage. (This also works when the resistance is in kilohms and the current in milliamps, because the kilo (thousands) and milli (thousandths) cancel out.)
- Copy the following diagrams, and calculate the missing quantities:



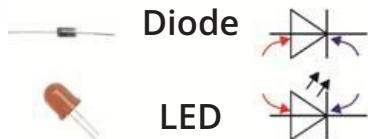
- The resistor colour code is used to show the resistance of a resistor.
- Copy the colour code table given on the previous page, and use it to complete the following table:

Band 1	Band 2	Band 3	Resistance
Brown	Black	Yellow	
Green	Blue	Red	
Grey	Red	Black	

WORKSHEETS

Worksheet 8 - LEDs and Diodes

Two kinds of diode



We have just seen that a resistor behaves in a very straight forward way—double the current through it, and you double the voltage across it; quarter the current through it and you quarter the voltage across it, and so on.

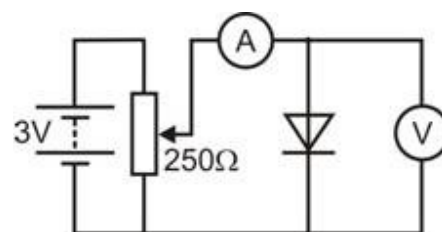
This result is known as Ohm's law.

Very few components behave in this way.
Here is one that does **not**—the diode.

There are two common forms of diode - the power diode, widely used in power supply circuits, and the light-emitting diode (LED), commonly used as an indicator.

Over to you

- Set up the arrangement shown in the circuit diagram.
- **Make sure that the power supply is set to 3V!**
- The variable resistor allows us to change the applied voltage. Set up like this, with the anode connected to the positive end of the power supply, we say that the diode is **forward-biased**.
- **Before you switch on**, select the **20mA DC** range on the ammeter, and the **20V DC** range on the voltmeter.
- Turn the knob on the variable resistor fully anticlockwise, to set the supply voltage to zero.
- Turn the knob slowly clockwise until the current through the diode reaches 2.0mA. Then read the voltage across the diode.
- Turn the current up to 4.0mA, and take the voltage reading again. The current will change rapidly for a tiny change in voltage. **Be careful - turn the knob on the variable resistor very gently!**
- Keep increasing the current in 2mA steps, up to 20mA, taking the voltage reading each time. Write your results in a table like the one shown.



On a diode the cathode is marked by a line on the body of the diode



On an LED the cathode is the shorter lead.

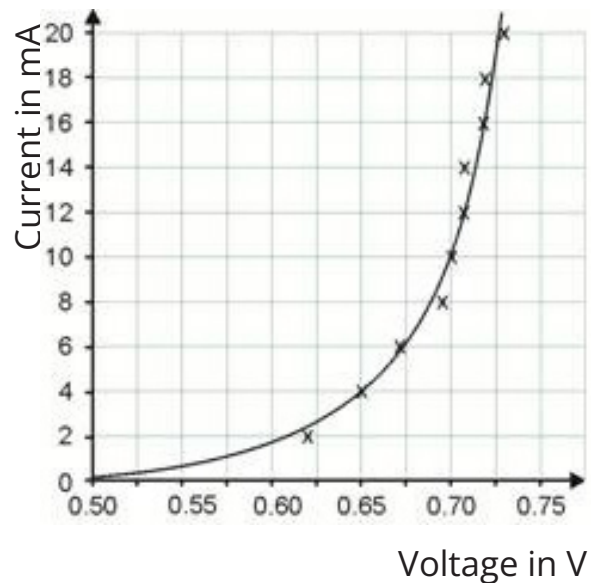
Current through diode	Voltage across diode
2.0mA	
4.0mA	

WORKSHEETS

Worksheet 8 - LEDs and Diodes

Over to you

- Plot a graph to show your results.
- Draw a smooth curve, like the one shown, using your plotted points as a guide.
- 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. We say that the diode is now **reverse-biased**.
- Switch on the power supply.
- Turn the knob on the variable resistor slowly, and increase the supply voltage to its maximum value.
- Notice the current reading on the ammeter as you do so! (No need to plot this on a graph!)

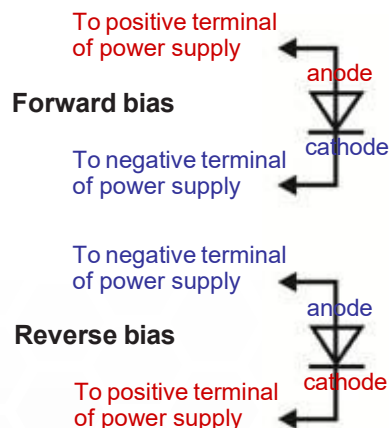


So What?

The diode is a 'one-way valve'. It allows a current to flow through it in only one direction. (A resistor does exactly the same thing whichever way you connect it. Try it !)

When it is forward-biased, it conducts, with a voltage drop of about 0.7V across it.

When it is reverse-biased, it does not conduct (for low voltages.)



Next you are going to carry out the same investigation but using a light-emitting diode (LED.) Look underneath the 12V LED component . It has a resistor connected in series with it, to protect it from high currents.

WORKSHEETS

Worksheet 8 - LEDs and Diodes

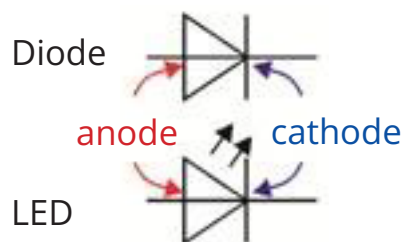
Over to you

- Using the same circuit as before, plug in the LED so that it is forward biased.
- Repeat the investigation, but this time increase the current in 0.2mA steps, 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.
- Connect the LED the other way round, so that it is reverse-biased, and check its behaviour.

For your records:

- Copy the following diagram showing the symbols for diodes and LEDs:

Two diode symbols



- The diode is a 'one-way valve'. It allows current to flow through it in only one direction. It conducts when it is forward-biased, and does not when reverse-biased. When it conducts, a silicon diode has a voltage drop of about 0.7V across it.
- Copy the diagram that shows the difference between forward and reverse bias.
- The light-emitting diode (LED) behaves in the same way. It lights up when forward biased, and the current reaches about 10mA. It then has a voltage drop of about 2V across it.
- It needs to be protected from high currents by connecting a resistor in series.

WORKSHEETS

Worksheet 9 - Sensors

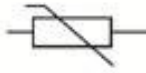
Two useful sensors



Phototransistor



Thermistor



This investigation focuses on two very useful types of sensor: The phototransistor, which is used to sense light levels, and the thermistor, which could be called a temperature-dependent resistor.

We will use them as the basis for light sensing and temperature sensing units, by combining them into voltage divider circuits.

Phototransistors and thermistors play an important role in sensing circuits that allow us to control a wide range of industrial and domestic systems.

Over to you

The aim of the first part is to measure the resistance of a thermistor at different temperatures.

This is done by lowering it into a beaker of hot water.

The resistance of the thermistor, and the temperature of the water, are measured.

You then add cold water to lower the temperature, and the measurements are taken again.

This process is repeated a number of times.

- Use an ohmmeter to measure the resistance of the thermistor. Before you switch it on, set the ohmmeter to the 20k range, and connect the thermistor to it using the COM and VΩ sockets.
- Water temperature is measured either with a mercury-in-glass thermometer, or with a temperature probe connected to a suitable meter or data logger.
- Set up the arrangement shown in the diagram.
- Stir the water gently to make sure that the thermistor and thermometer/probe are at the same temperature.



Take care when handling hot water!

Use heat-resistant gloves to hold the beaker while you pour in the hot water!

Do not put the clips in the water.

WORKSHEETS

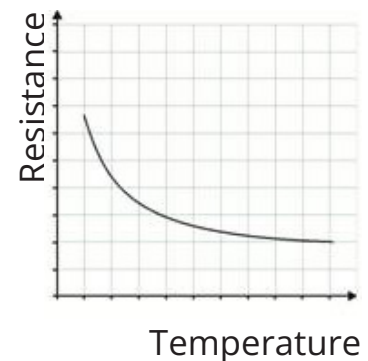
Worksheet 9 - Sensors

Over to you

- When the readings are steady, measure the resistance and temperature.
- Write your results in a table like the one shown opposite.

Temp in °C	Resistance in kΩ

- Plot a graph to show your results. Choose suitable scales to match the range of your readings.
- Draw a smooth curve, using your plotted points as a guide.



So What?

As the temperature drops, the resistance of the thermistor increases. This kind of thermistor is called NTC (negative temperature coefficient.)

You can buy PTC (positive temperature coefficient.) thermistors, in which the resistance drops when the temperature drops, and in which the resistance rises as the temperature rises.

Challenge

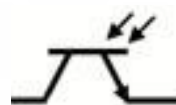
Design an experiment to investigate how the resistance of a phototransistor changes when the intensity of the light falling on it changes.

You will need a way to produce different intensities of light, and a way to measure that. The phototransistor must be shielded from other sources of light.

Discuss your ideas with your partner and then with your teacher.

For your records:

Copy the following diagram: Phototransistor



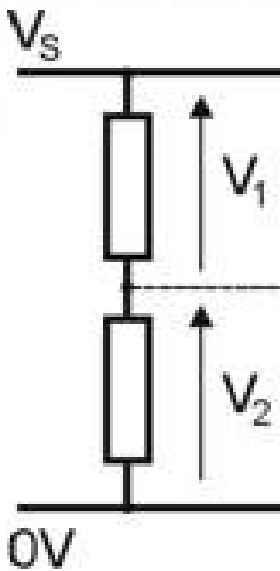
Thermistor



- A NTC thermistor has a resistance which falls as the temperature rises.
- A PTC thermistor has a resistance which increases as the temperature rises.
- A phototransistor lets more current flow through it as the light intensity increases.

WORKSHEETS

Worksheet 10 - Voltage Dividers



Earlier, we looked at how resistors restrict the flow of electric current. This is why a resistor, connected in series, can protect components, such as LEDs from damage by high current.

Combinations of resistors can be used with a different purpose - to carve up the voltage from a power supply into smaller portions. Not surprisingly, these combinations are called voltage dividers.

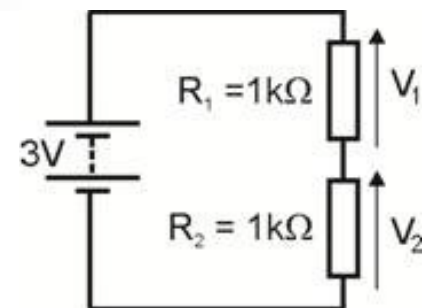
The diagram shows how a power supply voltage V_s can be split into two smaller voltages, V_1 and V_2 , by a voltage divider made up of two resistors.

These are particularly useful when one of the resistors is a sensing component such as a phototransistor or a thermistor.

Voltage dividers form the basis of many sensing sub-systems. The output voltage from them can represent temperature, light-level, pressure, strain or many other physical quantities.

Over to you

- Set up the arrangement shown in the circuit diagram.
- Make sure that the power supply voltage is set to 3V!
- Use a voltmeter carrier or a multimeter to measure the voltages V_1 and V_2 in turn.
- Write your results in a table like the one opposite.
- Change the power supply voltage to 6V.
- Measure voltages V_1 and V_2 again and write the results in the second line of the table.
- Do the same thing with a power supply voltage set to 9V



Supply Voltage V_s	Voltage V_1 across $R_1 = 1k\Omega$	Voltage V_2 across $R_2 = 1k\Omega$
3V		
6V		
9V		



Supply Voltage V_s	Voltage V_1 across $R_1 = 1k\Omega$	Voltage V_2 across $R_2 = 1k\Omega$
3V		
6V		
9V		

- Next, swap R_2 for a $10k\Omega$ resistor.
- Leave resistor R_1 unchanged.
- Change the power supply voltage back to 3V.
- Measure voltages V_1 and V_2 again.
- Write the results in a new table.
- Repeat this process, first using a power supply voltage of 6V and then using 9V.

WORKSHEETS

Worksheet 10 - Voltage Dividers

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 $R_1 = R_2 (=1k\Omega)$, $V_1 = V_2 = \frac{1}{2}V_s$.
When $R_2 = 10 \times R_1$, $V_2 = 10 \times V_1$.

For example, look at the circuit opposite:

We know two things:

$$V_1 + V_2 = V_s = 12V$$

and: $R_1 = 2 \times R_2$, so $V_1 = 2 \times V_2$

In other words,

- One voltage is twice as big as the other,
- They add up to 12V.

A little thought should convince you that $V_1 = 8V$ and $V_2 = 4V$

For your records:

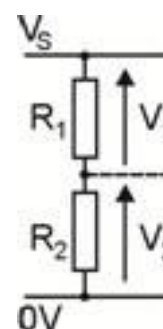
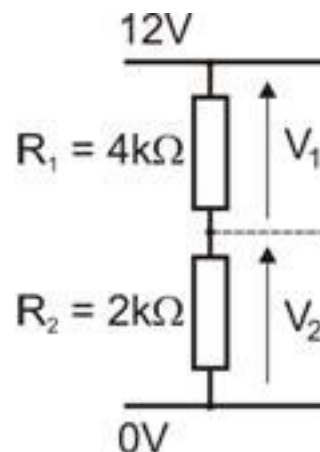
- Copy the diagram of a voltage divider:
- The voltage divider rules:

$$V_1 + V_2 = V_s$$

$$R_1 / R_2 = V_1 / V_2$$

- Copy the table.

Use the voltage divider rules to complete it.



Supply Voltage V_s	Resistor R_1 in $k\Omega$	Resistor R_2 in $k\Omega$	Voltage V_1 in V	Voltage V_2 in V
6V	12	12		
6V	1	2		
12V	3	1		
9V	2		3	

WORKSHEETS

Worksheet 10 - Voltage Dividers

Over to you

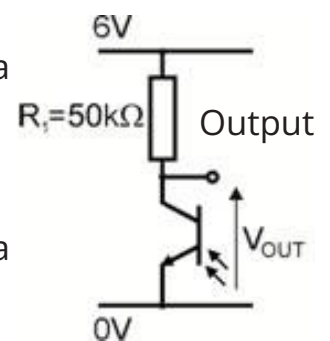
Voltage dividers form the basis of a number of sensing circuits.

One of the resistors is replaced by a sensor, whose resistance depends on an external factor such as temperature, pressure or humidity.

Here are two sensing circuits to investigate:

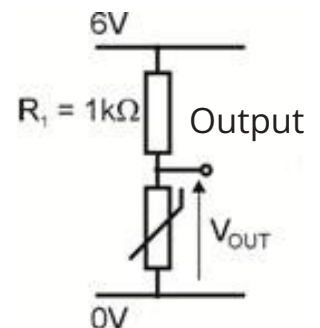
The Light-Sensing Unit:

- Set up the circuit shown opposite. It is a voltage divider with a phototransistor as one of the resistors.
- Make sure that the power supply voltage is 6V.
- Connect a voltmeter to read the output voltage V_{OUT} .
- Notice the effect of covering the phototransistor, or shining a torch at it.



The Temperature-Sensing Unit:

- Modify your circuit by swapping the phototransistor for a thermistor. (You may find it better to use a 5kΩ resistor for R_1 .)
- Connect a voltmeter to read the output voltage V_{OUT} .
- Notice the effect of warming up the thermistor between your fingers.
- What is the effect of turning the voltage divider upside-down so that R_1 is at the bottom and the thermistor at the top?



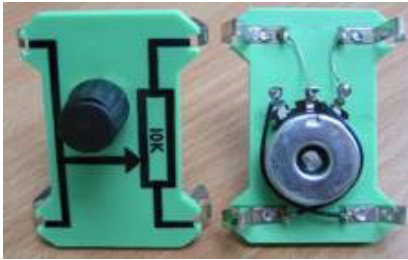
For your records:

- Copy the circuit diagram of the light-sensing unit.
- Copy and complete the following sentence: When light shines on the phototransistor, the output voltage
- Copy the circuit diagram of the temperature-sensing unit.
- Copy and complete the following sentences:
- When the thermistor warms up, the output voltage

To make the output voltage go the other way when the temperature rises, re-arrange the circuit by

WORKSHEETS

Worksheet 11 - Voltage Dividers



In earlier worksheets, we saw that resistors could be used to limit electric current, and looked at their use in voltage dividers. Now we turn to the use of variable resistors.

These are very common in a wide range of electronic appliances. They act as volume controls in radios and hi-fi, lighting dimmers, mixers in karaoke and recording desks, and adjustable thermostats in heating systems. They are widely used in sensors, such as light-sensing units.

The picture shows two views of the component in the 'Locktronics' system that can be used as a variable resistor.

Variable resistors are also called potentiometers (often shortened to 'pot'), or rheostats (when they are designed to carry high current.)

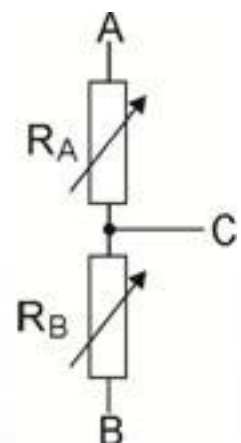
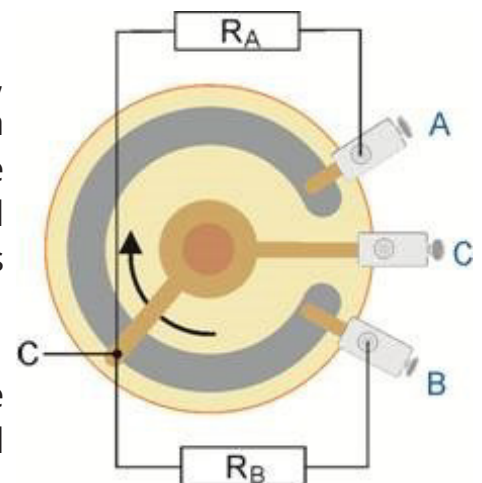
The diagram shows the inner workings of a typical 'pot'. There are three solder tag terminals, **A**, **B** and **C**.

A and **B** are connected to the ends of a carbon track, shaped, in the diagram as a letter 'C'. This track has a fixed resistance - 10 kilohm for the one shown in the picture. **C** is connected to a 'wiper', that slides around the carbon track, when the knob on the component is turned.

In effect, there are two resistors, R_A and R_B , built into the device. R_A is the resistance of the track between **A** and **C**, and R_B the resistance of the track between **B** and **C**. The symbols for these resistors is superimposed onto the first diagram.

The second diagram is more accurate as it shows that the two resistors R_A and R_B are in fact variable - hence the arrows through the symbols.

When the knob is turned in the direction shown by the arrow, the length of track between **B** and **C** increases, so that R_B increases, whereas the track between **A** and **C** shortens, so that R_A decreases.

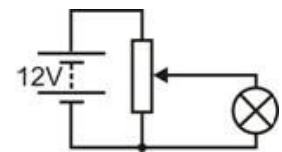
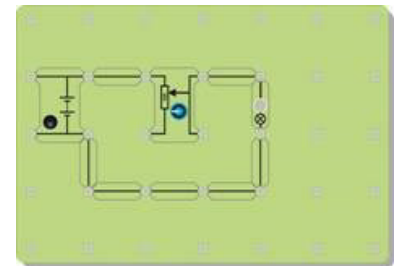
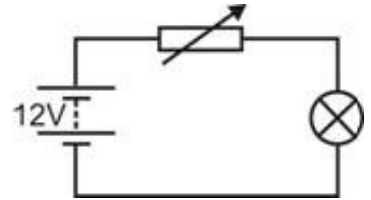


WORKSHEETS

Worksheet 11 - Voltage Dividers

Over to you:

- Set up the arrangement shown in the circuit diagram, using a 12V 0.1A bulb. Make sure that the power supply voltage is set to 12V!
- Here, the Locktronics component is set up as a variable resistor. You can tell this because the circuit uses only two legs of the component. (Resistors have only two legs!) It is quite difficult to build this circuit. The picture below shows how to set up the variable resistor
- Turn the knob on the variable resistor and notice the effect on the brightness of the bulb.
- Next connect the component as a voltage divider. You used this arrangement earlier when studying diodes and LEDs. The circuit diagram is shown below. Notice that a new symbol is used for the component!
- Test the circuit as before - turn the knob and see what happens to the brightness of the bulb.



So What?

There is an important difference in the way the component is used in the two exercises. 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 when the device is set to maximum resistance, but it is never zero.

As a voltage divider, it controls the voltage applied to the bulb. The current through the bulb will now be 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.

A challenge - Connect a voltmeter to read the voltage across the bulb. Unscrew the bulb. Turn the knob until the voltmeter reads 3V. Now screw the bulb in, and watch what happens to the voltmeter reading. Explain what is going on to your partner and then to your teacher.

For your records:

- Copy the diagram that shows the inner workings of the 'pot'. Write instructions to connect this as a variable resistor to control the brightness of a bulb. Explain what is going on when you turn the knob.
- Copy the two circuit diagrams to show how to control the brightness of the bulb using the variable resistor method, and using the voltage divider method.

WORKSHEETS

Worksheet 12 - Electrical Power



'Save energy' - a familiar message today!

It would help to know what energy is!

Is it the same thing as power? Is it voltage? Or wattage?

Our aim is to spell out some connections between these quantities.

We said earlier that electricity stems from how electrons behave, but unfortunately, they are too small to see, or measure.

Electric current is a measure of how many electrons are passing per second.

Voltage is a measure of the energy the electrons gain or lose as they pass through an electrical component.

First - a confession:

Some of the greatest physicists of modern times don't know what energy is, so don't expect glib answers from us!

Instead, here's an equally difficult question - what is 'money'? To some, it is silver discs with writing stamped on it. To others it is pieces of paper with words printed on it, bars of gold, or diamonds, or barrels of oil, or how many goats your family has. What it is never worries us - we just spend it!

With energy, it is the same. We can't really say what it is, but we know how to use (and abuse) it!

Next - a convenient invention:

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 or the like.

However, we can't track individual electrons, so we invent a name for a large number of them. We call it a **coulomb**.

To estimate how many people turn up at a football match, you could count the number of buses bringing them, knowing that a bus carries a certain number of people.

It is rather like that with electricity.

We talk about coulombs of electrical charge, knowing that each coulomb is a huge number of electrons (6,250,000,000,000,000 in fact - quite a bus-full!)

WORKSHEETS

Worksheet 11 - Voltage Dividers

Now, the relationships:

First fact:

Number of coulombs $Q = \text{Current } I \times \text{time } t$

Common sense - current measures how many electrons pass per second, so to find out how many have passed in 10 seconds, for example, you multiply the current by 10!

Second fact:

One volt means one joule of energy given to or lost by a coulomb of charge.

A 12V battery gives each coulomb of charge that passes through it 12J of energy.

If the voltage dropped across a resistor is 2V, every coulomb that passes through it loses 2J of energy (i.e. converts 2J to heat energy.)

It's the electrons struggling to squeeze past the bits of atoms in the resistor - it makes them hot!

Third fact:

Power is the rate at which energy is converted.

A power rating of one watt means that one joule of energy is converted from one form to another every second.

The old style of domestic light bulbs had power ratings of about 60W.

Newer types have a rating of 15W for the same brightness, because they convert less electrical energy to heat - that's energy-saving!

Formula juggling - ignore all but the result if you wish:

P = E / t from fact 3 and E = Q x V from fact 2
so P = Q x V / t

but Q = I x t from fact 1
so P = I x t x V / t

or, cancelling out the 't' **Result P = I x V**

The cast:

P = power in watts

Q = charge in coulombs

V = voltage dropped (in volts!)

E = energy converted in joules

I = current in amps

t = time energy conversion took (seconds)

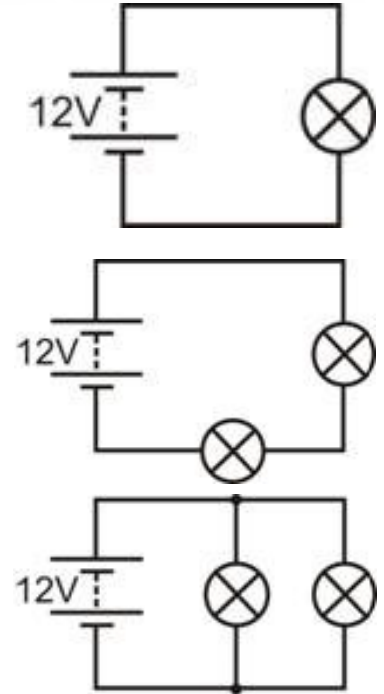
WORKSHEETS

Worksheet 12 - Electrical Power

Over to you

- Set up each the circuit in turn.
- For each bulb, measure:
 - The current through it,
 - The voltage across it.

(First, decide where to connect the ammeter and voltmeter!)



So What?

Calculate:

- The power dissipated in each bulb (using the formula $P = I \times V$);
- How long it takes each bulb to take 1J of energy from the electrons;
- How much energy (in joules) the power supply is losing each second.

Which battery will 'go flat' first? Explain your answer to your teacher.

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.

For your records:

- Copy the three facts given on the previous page (but not the comments that accompany them.)
- When a component has a voltage V across it, and a current I flowing through it, it is converting energy from one form to another at a rate given by the power formula:

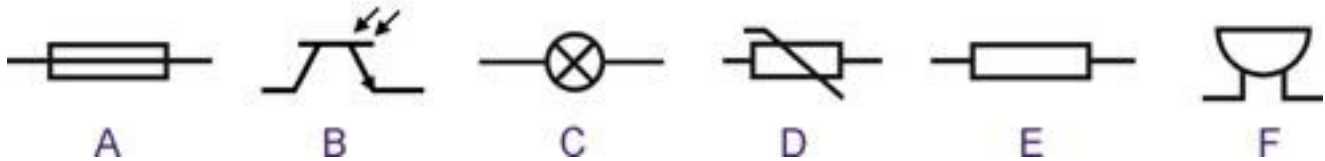
$$P = I \times V.$$

Quiz

Round 1

- (a) Write down the names of **five** materials which conduct electricity.
 (b) What is the name of the substance in a switch that stops the electric current flowing when the switch is turned off?

Here are six circuit symbols. Which one:



- (c) Is the buzzer (sounder) ?
 (d) Is used as an indicator?
 (e) Has a resistance that gets less when it gets hot?
 (f) Is the phototransistor?

Round 2

Use either the word 'series' or the word 'parallel' to fill in the gaps:

- (a) Voltmeters are connected in with the component they are measuring.
 (b) Ammeters are connected in to measure the current through a component.
 (c) In a circuit, the same current flows everywhere.
 (d) Components connected in have the same voltage across them.
 (e) Resistors connected in reduce the current flowing more than the same resistors connected in

Round 3

Black	Brown	Red	Orange	Yellow	Green	Blue	Purple	Grey	White
0	1	2	3	4	5	6	7	8	9

Resistor	Band 1	Band 2	Band 3	Band 4
A	yellow	purple	orange	silver
B	yellow	purple	black	gold
C	brown	red	brown	silver
D	red	red	brown	silver
E	green	blue	red	silver

The first table shows the resistor colour code.

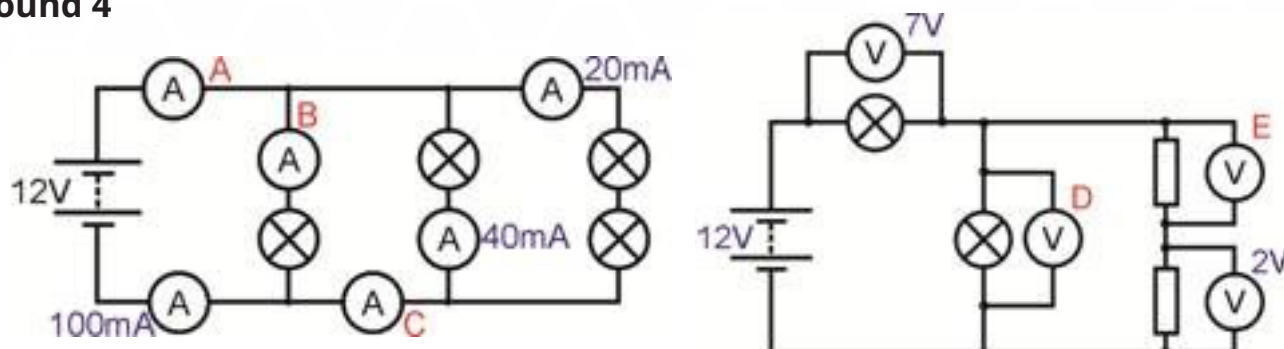
The second one gives the colours of the bands of five resistors **A to E**.

Which one of these resistors :

- (a) has the biggest resistance?
 (b) has a resistance of 47Ω ?
 (c) when connected in series with a 100Ω resistor, has a combined resistance of 220Ω ?
 (d) is made to the greatest accuracy?

Quiz

Round 4

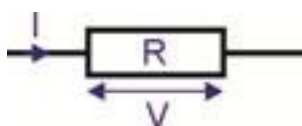


Write down the readings on ammeters **A**, **B** and **C**, and voltmeters **D** and **E**.

Round 5

A resistor R has a current I flowing through it and a voltage V across it.

Use Ohm's law formulae to calculate the missing values in the table below.



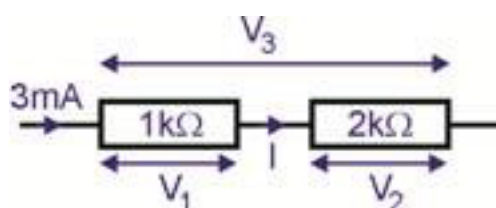
	Current I	Voltage V	Resistance R
(a)	0.1A	2V	?
(b)	0.3A	?	20 Ω
(c)	?	12V	100 Ω
(d)	5mA	?	2.2k Ω

Round 6

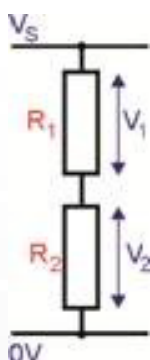
Look at the circuit opposite.

Calculate the following quantities:

- (a) current I ;
- (b) voltage V_1 ;
- (c) voltage V_2 ;
- (d) voltage V_3 .



The next table gives you information about some voltage dividers like the one shown. Complete the table by calculating the missing information.



	R_1	R_2	V_1	V_2	V_s
(e)	5k Ω	5k Ω			12V
(f)	2k Ω		2V	4V	
(g)		10k Ω	3V		9V
(h)	20k Ω	5k Ω		1V	

Quiz

Round 7

- (a) A current of 0.2A flows through a resistor for 10 seconds.
How many coulombs of charge have passed through the resistor?
- (b) A resistor has a current of 20mA flowing through it. A voltmeter connected across it has a reading of 5V. What power is dissipated in the resistor?
- (c) An electric kettle has a power rating of 3000W when connected to a 250V supply.
(i) What current flows through the kettle element when it is switched on?
(ii) Which of the following fuses should be used to protect the kettle?

3A 5A 13A 50A



STUDENT HANDOUT



Student Handout

Worksheet 1

Add the correct symbols:

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

Worksheet 2

- Most of the conductors belong to the class of substances called
- I think that the hard shiny object that felt cold would electricity, because it is probably made of a
- Pure water is an However, if there are any impurities in it, such as salt, or chlorine, then the water is a
- Air is an which explains why we do not get an electric shock when we stand near a mains electricity socket.
- A switch starts and stops the flow of
- When the switch is open, the gap stops the flow of electricity.
- When the switch is, the air gap disappears, and electricity flows around the circuit.
- A toggle switch stays on or stays off all the time. A push switch is on only as long as you press it.
- A doorbell is one type of switch.
- A light switch is one type of switch.

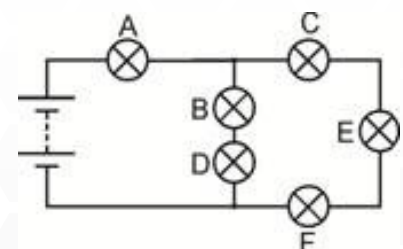
Worksheet 3

- A resistor limits the flow of electricity.
- The bigger the resistance, the smaller the electric current.
- Resistance is measured in ohms. Usually, we use the Ω sign to mean 'ohms'.

Worksheet 4

- A series circuit offers only one route for the electric current.
- If a break appears anywhere in the circuit, then the electric current stops everywhere.
- If one bulb fails in the circuit, then all the bulbs go out.
- The electric current is the same size throughout the circuit.
- A parallel circuit offers several routes so that different currents can flow in different parts of the circuit.

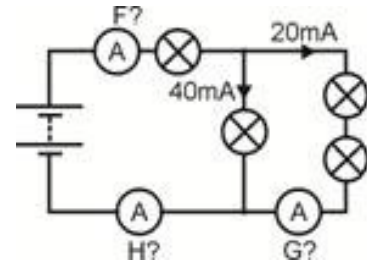
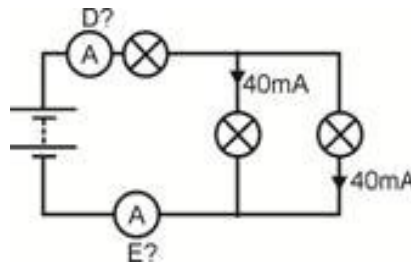
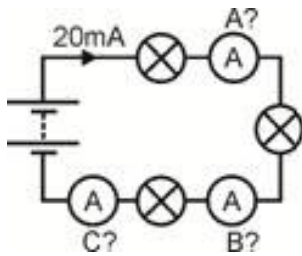
1. Bulb B is in series with bulb
2. Bulb C is in with bulb E and bulb F.
3. Bulbs B and D are in with bulbs C, E and F.
4. The biggest current will flow through bulb
5. Bulb will be the brightest bulb.



Student Handout

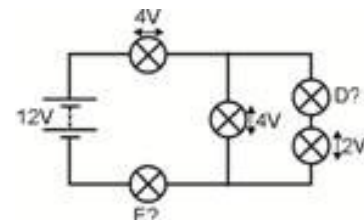
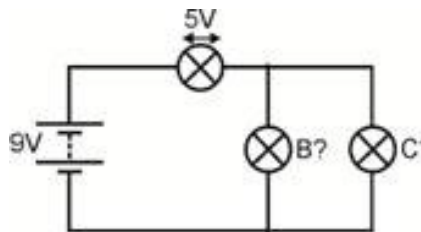
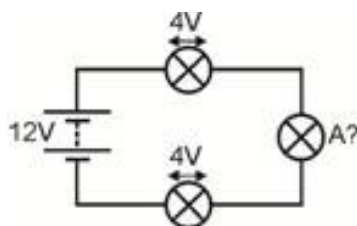
Worksheet 5

- In a series circuit, the current flows in all parts.
- In a parallel circuit, the currents in all the parallel branches add up to the current leaving the
- Write the readings on ammeters A to H alongside each ammeter.



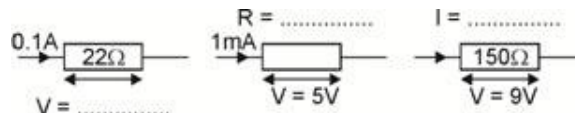
Worksheet 6

- In a series circuit, the voltages across the components add up to the voltage across the
- In a parallel circuit, the components all have the voltage across them.
- Write the voltages across bulbs A to E alongside each voltmeter.



Worksheet 7

- Ohm's law gives us the following equations: $V = I \times R$ $R = V / I$ $I = V / R$ where R = resistance in ohms, I = current in amps and V = voltage. (This also works for resistance in kilohms and current in milliamps, because kilo and milli cancel out.)
- Calculate the missing quantities:



- The resistor colour code is used to show the resistance of a resistor.

Black	Brown	Red	Orange	Yellow	Green	Blue	Purple	Grey	White
0	1	2	3	4	5	6	7	8	9

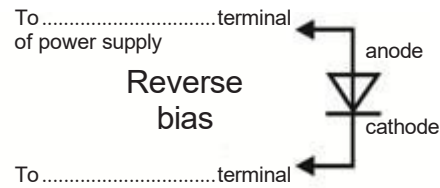
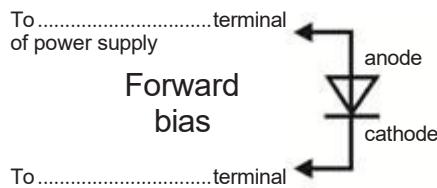
- Use it to complete the table:

Band 1	Band 2	Band 3	Resistance
Brown	Black	Yellow	
Green	Blue	Red	
Grey	Red	Black	

Student Handout

Worksheet 8

- The diode is a 'one-way valve'. It allows current to flow through it in only one direction.
- When it conducts, there is a voltage drop of about 0.7V across it.
- It conducts when it is forward-biased, and does not when reverse-biased.
- Add the correct labels to the diagram:



- Draw the symbol for a LED in the box that follows. LED
- The light-emitting diode (LED) behaves in the same way.
- It lights up when forward biased, and the current reaches about 10mA.
- It then has a voltage drop of about 2V across it.
- It needs to be protected from high currents by connecting a resistor in series.

Worksheet 9

- Draw the symbols for a thermistor and a phototransistor.



Thermistor

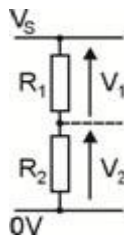


Phototransistor

- A NTC thermistor has a resistance which falls as the temperature rises.
- A PTC thermistor has a resistance which increases as the temperature rises.
- A phototransistor lets more current flow through it as the light intensity increases.

Worksheet 10

- The voltage divider rules:
- $V_1 + V_2 = V_s$
- $R_1 / R_2 = V_1 / V_2$



- Complete the following table by calculating the missing values:

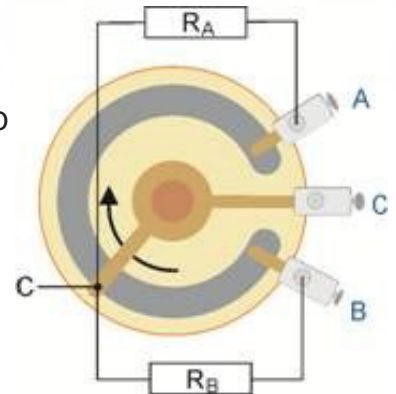
Supply Voltage V_s	Resistor R_1 in $k\Omega$	Resistor R_2 in $k\Omega$	Voltage V_1 in V	Voltage V_2 in V
6V	12	12		
6V	1	2		
12V	3	1		
9V	2		3	

Student Handout

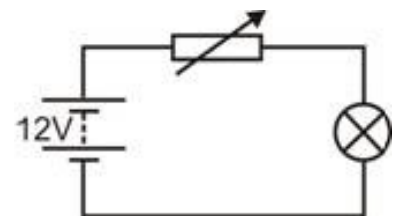
Worksheet 11

The diagram shows the inner workings of a 'pot'.

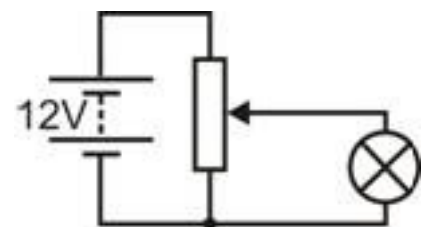
- Write instructions to connect this as a variable resistor to control the brightness of a bulb.
- Explain what is going on when you turn the knob.



Circuit 1 - using a variable resistor to control the brightness of a bulb:



Circuit 2 - using a voltage divider to control the brightness of a bulb:



Worksheet 12

- First fact: Number of coulombs $Q = \text{Current } I \times \text{time } t$
- Second fact: One volt means one joule of energy given to or lost by a coulomb of charge.
- Third fact: Power is the rate at which energy is converted.
- When a component has a voltage V across it, and a current I flowing through it, it is converting energy from one form to another at a rate given by the power formula

$$P = I \times V.$$

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[illegible]

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ELECTRICITY MATTERS 2

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