Electronics & Control

Analogue Electronics

Introduction

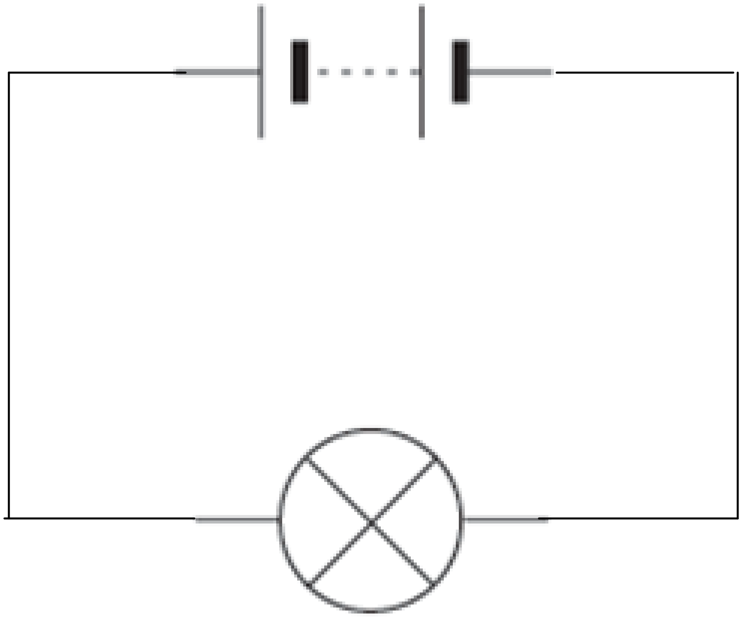
By the end of this unit you should be able to:

- Know the difference between a series and parallel circuit
- Measure voltage in a series circuit
- Measure voltage in a parallel circuit
- Measure current in a series circuit
- Measure current in a parallel circuit
- Work out the value of resistors
- Simulate electronic circuits
- Use Ohm’s Law
- Calculate total resistances in circuits
- Calculate voltages in different parts of a circuit
- Calculate current in different parts of a circuit
- Recognise a variety of electronic components and their symbols
- Connect circuits on a breadboard
- Calculate power consumed by components/appliances
- Understand how voltage dividers work
- Build circuits using analogue and digital components

Basic Circuits

To make something work in electronics, electric current must flow in a complete circuit. Conventional electric current flows from the positive (+) connection to the negative (-) connection.

Drawings are alright for simple circuits but it would be too complicated to draw a circuit for a TV like this. To make life easier we use simplified circuit diagrams as shown below.



Practical Task 1

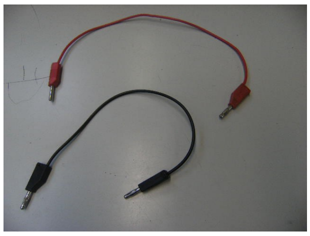
You will build a simple series circuit.

You will need the following components:-

Switch

3 Lamps

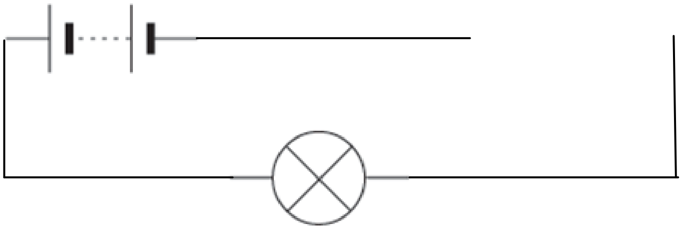
Power supply



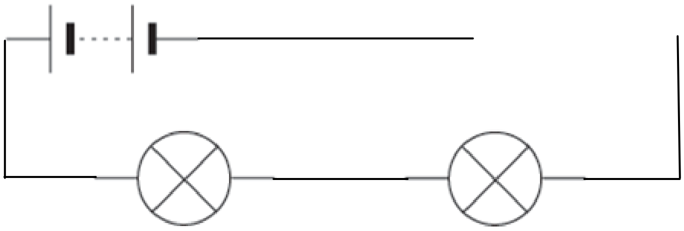
2 wires

Connect the components as shown in the diagram below.

Check with your teacher before you switch it on.



Draw this circuit and write one sentence explaining how the circuit works.



Add a third lamp to your circuit.

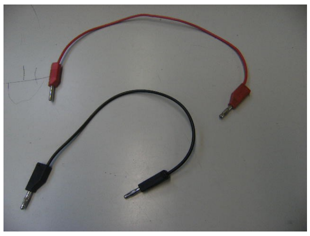
Notice what happens.

Write down what you think would happen if you added a forth lamp?

Practical Task 2

You will build a simple parallel circuit.

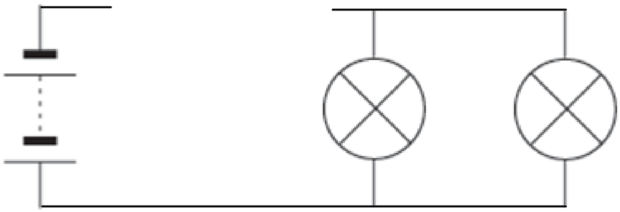
You will need the following components:-



Switch | 3 Lamps | Power supply | 2 wires

Connect the components as shown in the diagram below.

Check with your teacher before you switch it on.



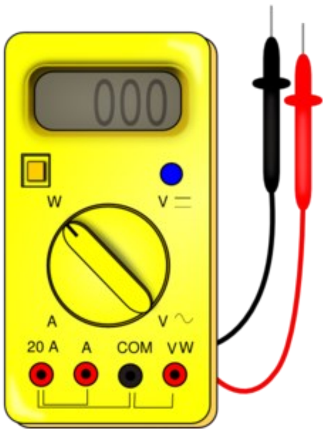
Draw this circuit and write one sentence explaining how the circuit works.

Add a third lamp in parallel and comment on the difference between both circuits.

What do you think would happen if you added a forth lamp?

Measuring Voltage

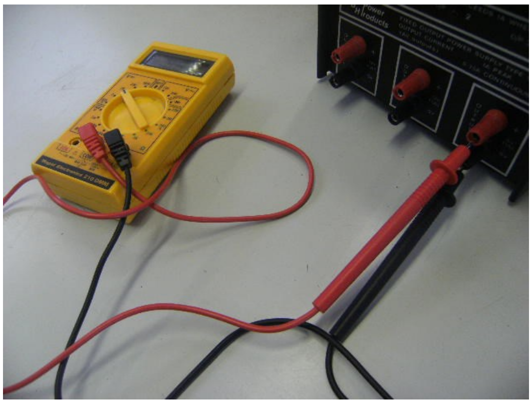
A typical digital multi-meter is shown below. It is a very useful piece of equipment and can be used to measure current, voltage and resistance.



To measure a DC voltage, firstly check the connections. The black probe should be connected to the 'COM' terminal. The red probe should be connected to the 'V' to measure Voltage. Secondly, the dial selector should be pointing to the 20V as shown below.

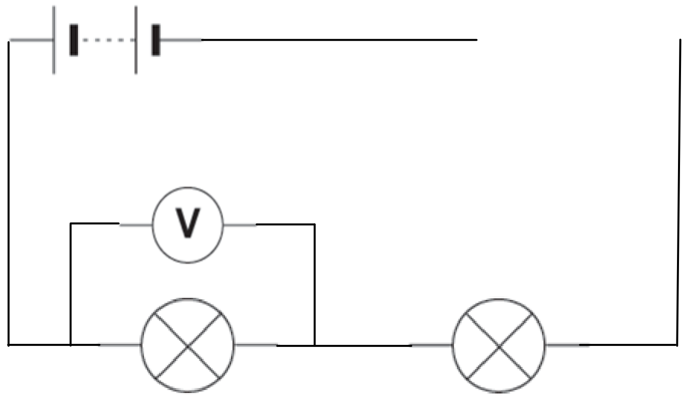
Practical Task 3

Rebuild the first series circuit with one lamp and measure the voltage from the power supply as shown below.



Now place the two probes on either side of the lamp and check the reading on the multi-meter. The two readings should be the same or very close to one another.

Switch off the power supply and add a second lamp in series with the first.



Now measure the voltage drop across each lamp.

These two voltages should be the same or very similar. They should also add up to give the amount of voltage that you measured from the power supply.

Copy the circuit and record your measurements.

$$\text{Voltage}_{\text{supply}} = \text{Voltage}_1 + \text{Voltage}_2$$

Add a third lamp in series with the first and second lamp.

Draw the circuit diagram and measure the voltage drop across each lamp.

Record your measurements.

Measuring Current

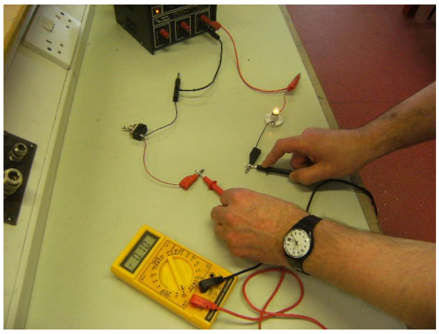
To measure current, firstly check connections.

The black probe should be connected to the 'COM' terminal.

The red probe should be connected to the '10A' to measure current.

Secondly, the dial selector should be pointing to the 10A as shown.

Practical Task 4



With one lamp in the series circuit 'break the circuit' as shown.

Then connect the probes from the multi-meter to complete the circuit.

You should now have a current reading on the multi-meter.

Add a second lamp in series then measure the current in the same way as before.

Try measuring the current in different parts of the circuit.

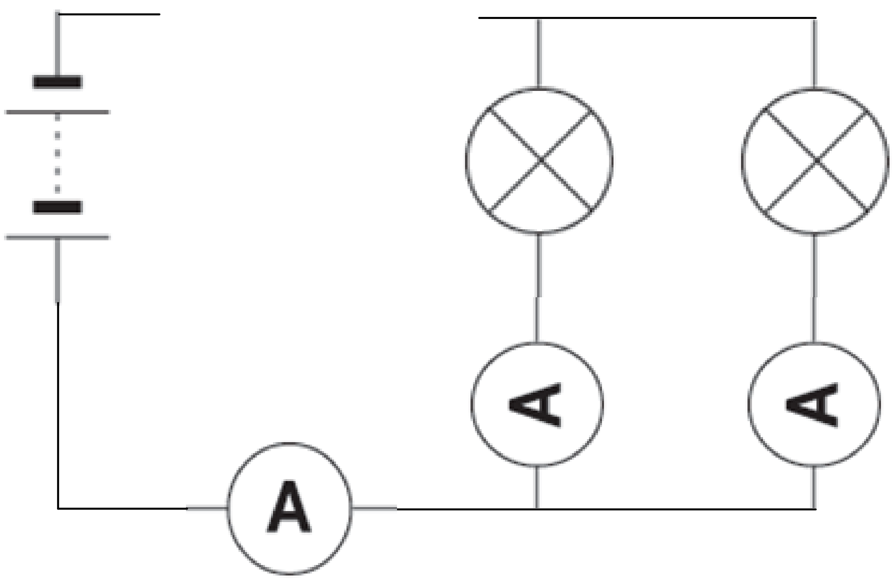
You should discover that the readings are all the same.

Draw the circuit and record your readings.

Practical Task 5

Build a circuit with two lamps in parallel.

Now measure the current in the positions indicated in the circuit diagram.



Draw the circuit and record your results. Write down a conclusion that you have proved.

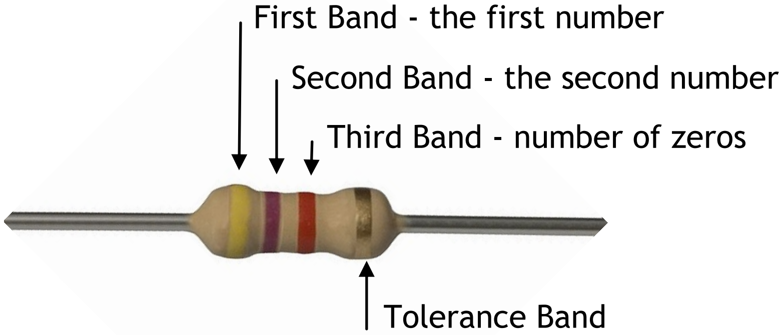
Resistors

Resistors are probably the most common and the cheapest of all electronic components costing less than 1p each. They are used to resist (reduce) or control the current through other devices and to create voltage "drops" in circuits. A typical fixed resistor is shown below with its colour coded bands. You will meet other special types of resistors later.

A fixed resistor

The circuit symbol

The coloured bands indicate the value of the resistor in Ohms (Ω). The three coloured bands together represent the actual value of the resistor.



The band on its own is called the tolerance band. This tells you how accurate the value of resistance will be. Here for example the gold band means that the tolerance is ±5% of its value. This means that a 100 Ω resistor could be anything between 95 Ω and 105 Ω.

The value of each colour is shown in the table.

Band Colour	Number
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

The resistor shown below is yellow-violet-red, so its value is 4700 Ω.

Common sizes of resistors go from 100 Ω to 1 MΩ (1 mega ohm is 1 000 000 Ω).

Other examples:

Green-blue-brown = 560 Ω

Yellow-violet-yellow = 470 000 Ω - this should be written as 470 KΩ

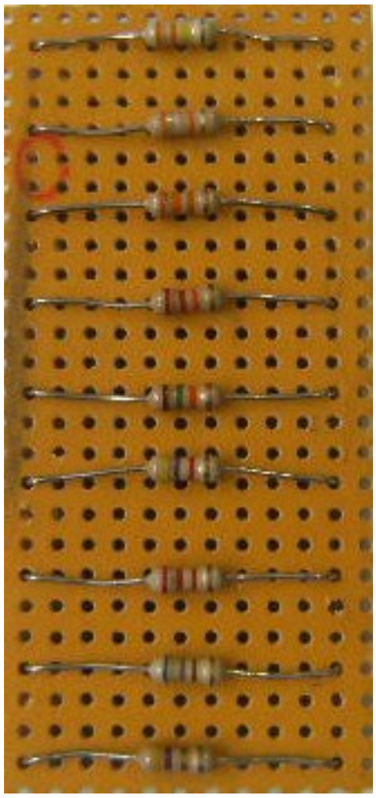
Red-red-red = 2200 Ω - this should be written as 2K2 Ω

Brown-black-green = 1 000 000 Ω - this should be written as 1 MΩ

Practical Task 6

Copy the table below into your jotter and complete it by calculating the values of these resistors. Then using a multi meter, measure their actual values.

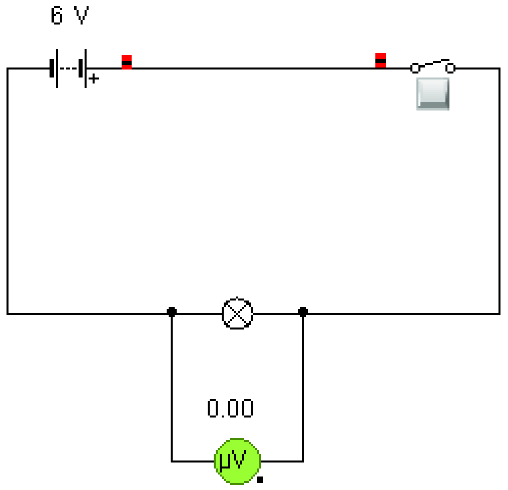
Colour			Calculated Value	Measured Value
1st	2nd	3rd		



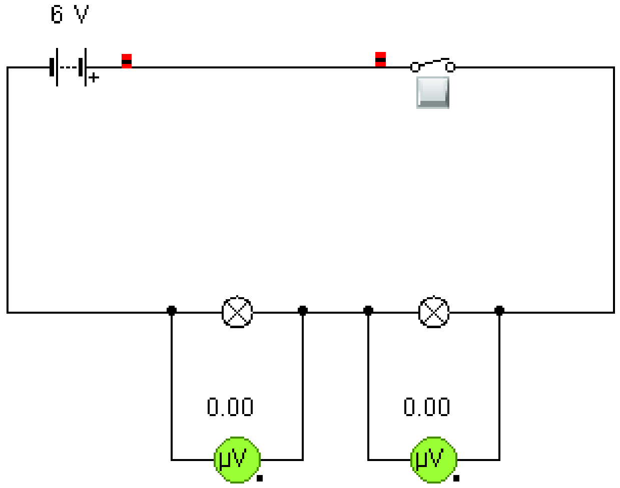
Computer Simulation Task 1

Using Yenka, build the circuits for measuring voltage which are shown below. You must show the circuit when it is switched off and when it is switched on. This will then be printed out and stuck into your jotter.

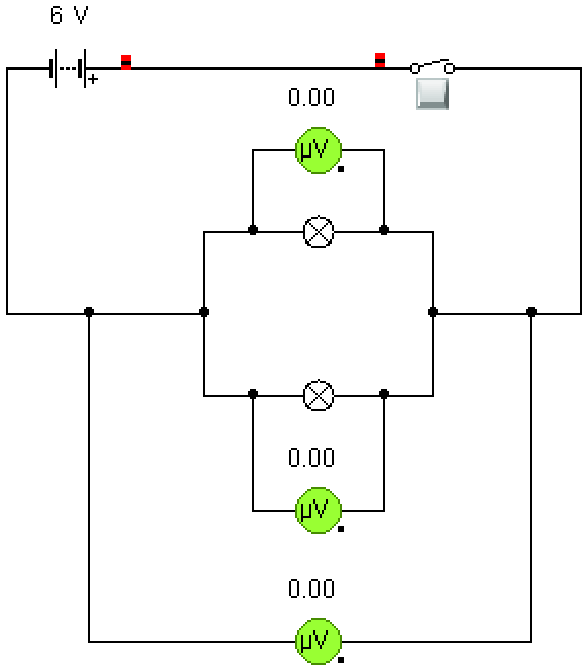
Circuit 1



Circuit 2



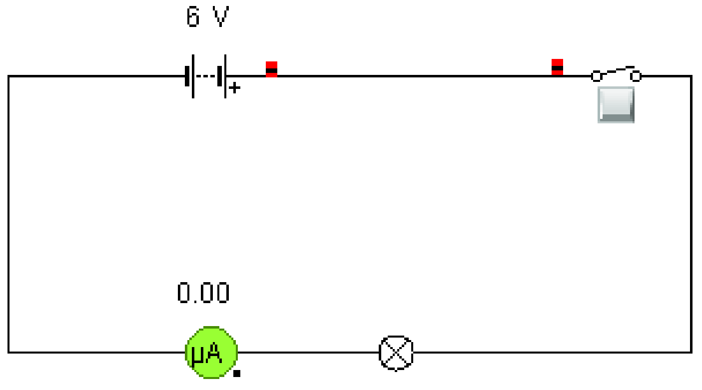
Circuit 3



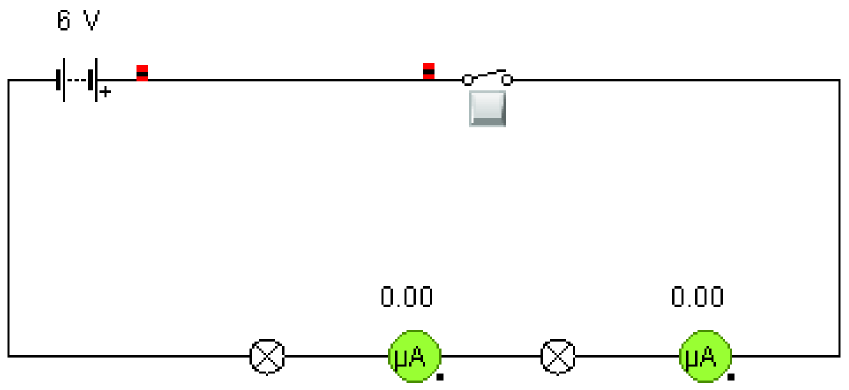
Computer Simulation Task 2

Using Yenka, build the circuits for measuring current which are shown below. You must show the circuit when it is switched off and when it is switched on. This will then be printed out and stuck into your jotter.

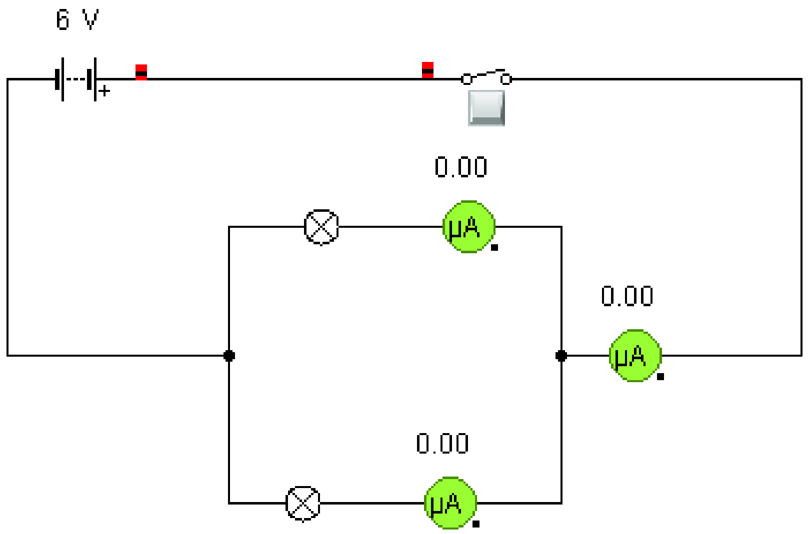
Circuit 1



Circuit 2



Circuit 3



Ohm’s Law

Ohm’s law is a formula which gives the relationship between voltage, current and resistance.

Voltage = Current x Resistance

V = I x R

Voltage is measured in **Volts (V)**.

Current is measured in **Amps (A)**.

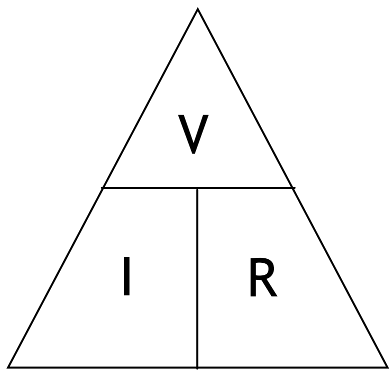
Resistance is measured in **Ohms (Ω)**.

In many electronic circuits 1A is a very big current so we often use milliamps instead (1mA = 0.001A).

$$V = I \times R$$

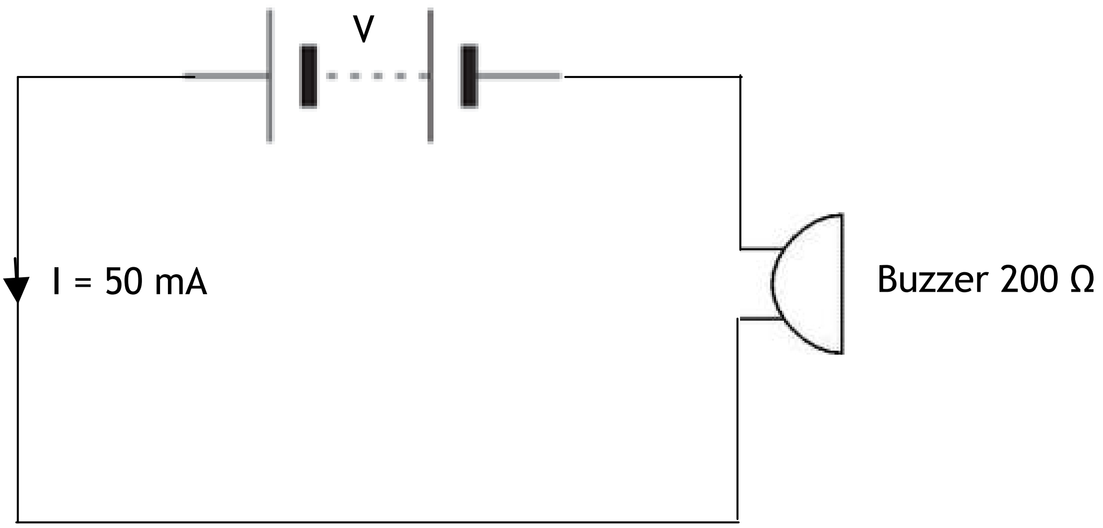
$$I = \frac{V}{R}$$

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



Worked example

Calculate the voltage supplied to the circuit shown below if a current of 50 mA flows through the buzzer which has a resistance of 200 Ω.



Note: a good habit is to draw your diagram as part of your solution.

$$V = I \times R$$
$$V = 0.05 \times 200$$
$$\underline{\underline{V = 10V}}$$

$$I = 50mA$$
$$I = 0.05A$$

Assignment 1

A battery and a single resistor of 150Ω are connected in series. If the current flowing in the circuit is 12mA, calculate the voltage supplied by the battery.

Assignment 2

A motor is connected in series with a battery. If the motor has a resistance of 800Ω and the current flowing through it is 15mA, calculate the voltage supplied by the battery.

Assignment 3

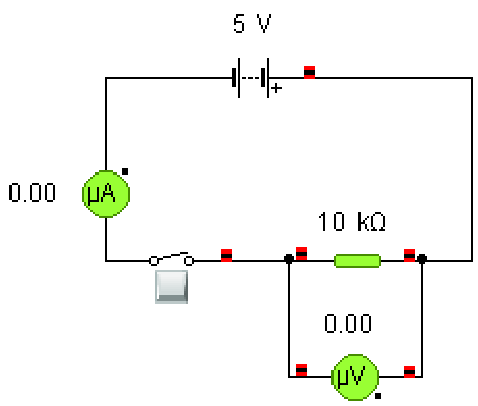
A voltage of 9V makes a current of 0.02A flow through an unknown resistor. Calculate the value of its resistance.

Assignment 4

What current will flow through a resistance of 10KΩ if an 8V supply voltage is applied across it?

Computer Simulation Task 3

Build and test the following circuit using Yenka. Measure the voltage and current in this circuit using various sizes of supply voltage. Copy and complete the table below using your findings. Then use calculations to confirm that your findings are accurate and to see if Ohm's Law is really true.

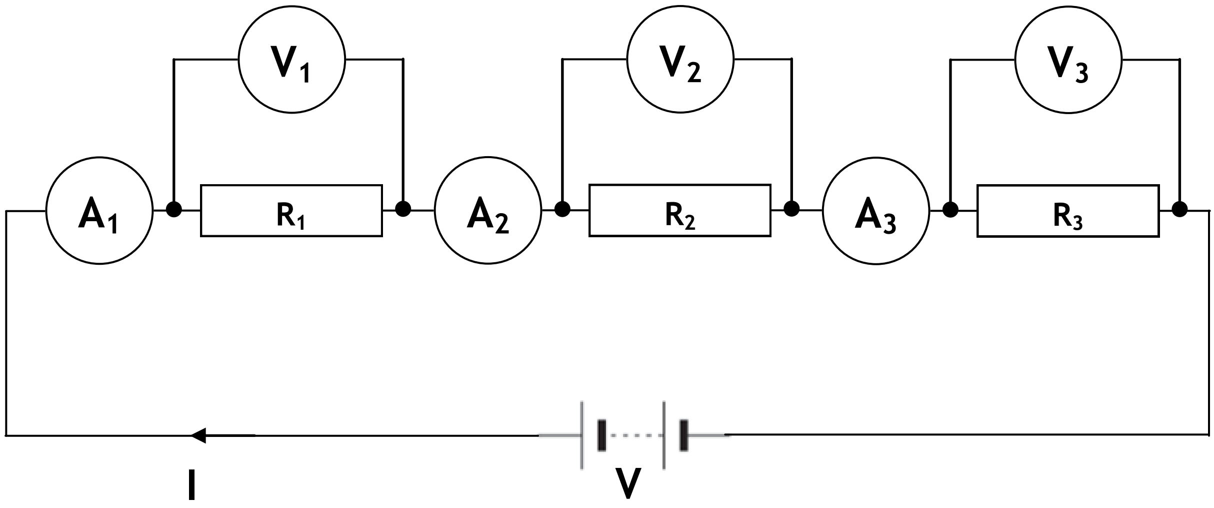


V (V)	R (kΩ)	I (mA)	I x R (V)
5	10	0.5	5
10	10		
15	10		
20	10		
25	10		

The first line has been done for you. You should have found that the current was 0.5mA (more or less), hence I x R = 5 Volts which was also the supply voltage.

Resistors in Series

Start by building the following circuit on Yenka using any resistors of the same value and a 6V supply voltage. Notice that we are calling the resistors R_1, R_2 and R_3 with the respective voltages across each of them V_1, V_2 and V_3 (that is V_1 is the voltage dropped across R_1, etc). The respective currents through each of the three resistors are I_1, I_2 and I_3.



V is the supply voltage (that is, the total voltage available), I is the total current in the circuit and R_T is the total resistance. You should find the following:

$$V = V_1 + V_2 + V_3$$

$$I = I_1 = I_2 = I_3$$

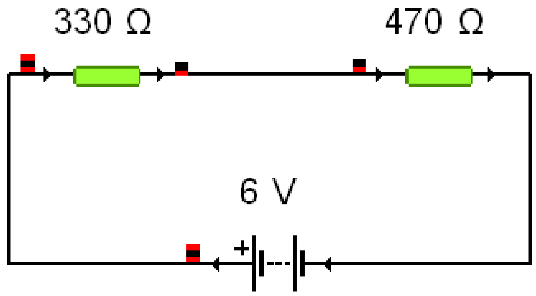
$$R_T = R_1 + R_2 + R_3$$

Assignment 5

For the circuit shown, calculate:

A) the total resistance of the circuit

B) The circuit current



Assignment 6

A 1KΩ resistor is connected in series with an electric motor which has a resistance of 600Ω. If the voltage supplied is 12V, calculate:

A) the total resistance of the circuit

B) The circuit current

C) The current through the motor

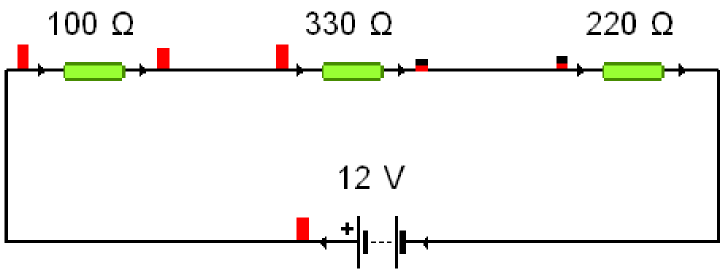
Assignment 7

For the circuit shown calculate:

A) the total resistance

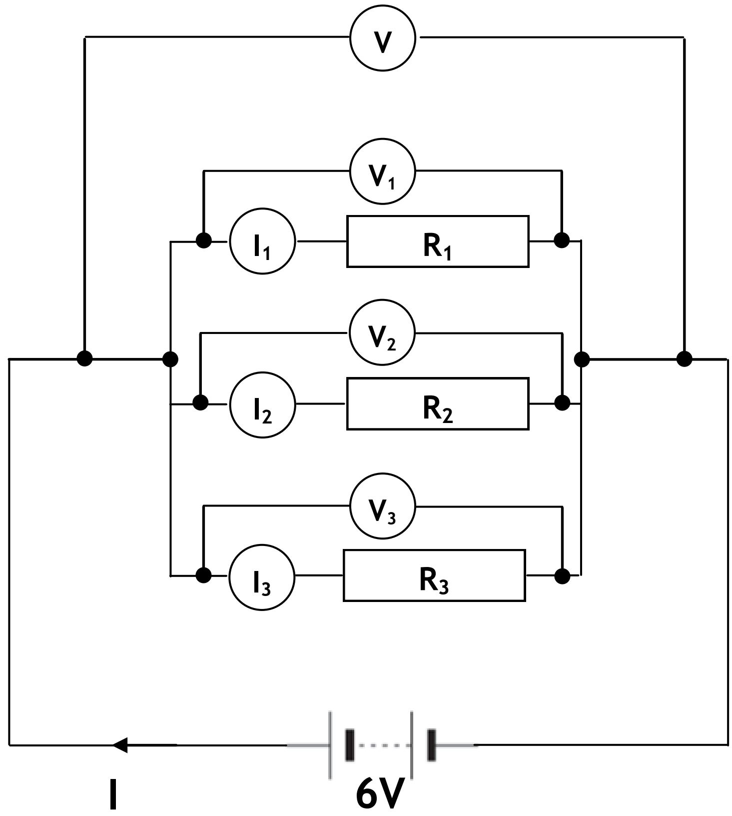
B) The circuit current

C) The voltage dropped across each resistor



Resistors in Parallel

Once again, use Yenka to build and test the circuit shown below. To keep the calculations simple, use a 6V battery and three 100Ω resistors. The voltage (V), current (I) and resistance (R) labels are just the same as last time but the formulae are very different.



You should find the following:

$$V = V_1 = V_2 = V_3$$

$$I = I_1 + I_2 + I_3$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Assignment 8

From your building and testing of the above circuit, explain what happens to the voltage, current and resistance in a parallel circuit.

You should have seen that in parallel circuits it is the voltage that stays the same in each branch of the circuit. It is the current this time which splits up according to the size of the resistor. The larger the resistor, the smaller the current flowing through it.

Worked Example 1

The complication with parallel circuits is the resistance formula. We will work it out using the actual values from the last circuit.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{100} + \frac{1}{100} + \frac{1}{100}$$

$$\frac{1}{R_T} = 0.01 + 0.01 + 0.01$$

$$\frac{1}{R_T} = 0.03$$

$$R_T = \frac{1}{0.03}$$

$$R_T = 33.3\Omega$$

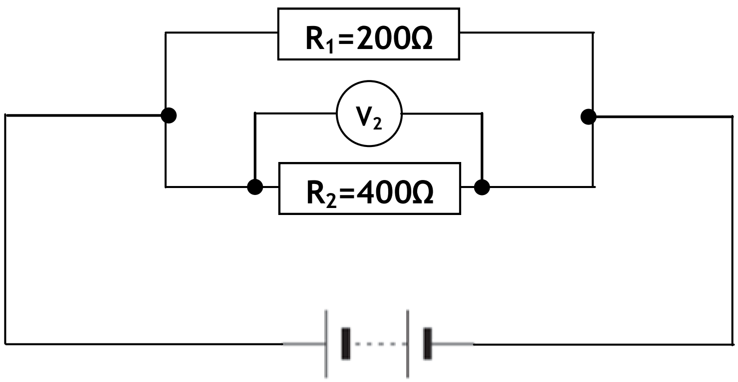
To find R_T you must invert both sides of the equation (flip it upside down).

Worked example 2

In the circuit shown below calculate:

A) the total resistance

B) the voltage across R_2



V_S=5V

A)
$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_T = \frac{200 \times 400}{200 + 400}$$

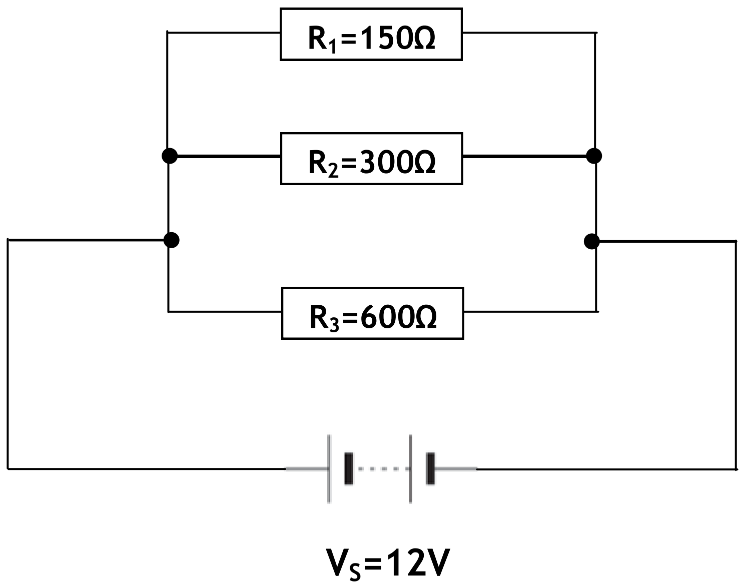
$$R_T = \frac{80000}{600}$$

$$R_T = 133\,\Omega$$

B) $V_2 = V_S = 5V$

Worked Example 3

Three resistors are wired up in parallel and then connected to a 12V supply. Their resistances are 150Ω, 300Ω and 600Ω respectively. Calculate the total circuit resistance and the current flowing through the 300Ω resistor.



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{150} + \frac{1}{300} + \frac{1}{600}$$

$$\frac{1}{R_T} = \frac{4}{600} + \frac{2}{600} + \frac{1}{600}$$

$$\frac{1}{R_T} = \frac{7}{600}$$

$$\frac{R_T}{1} = \frac{600}{7}$$

$$R_T = 85.7\Omega$$

Voltage across the 300Ω resistor = supply voltage = 12V

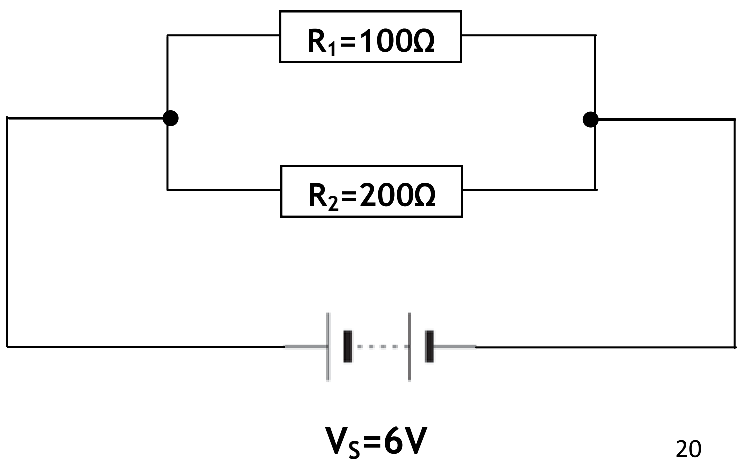
Current through the 300Ω resistor = circuit current $= \frac{V}{R} = \frac{12}{300} = 0.04A$

Assignment 9

For the circuit shown below, calculate:

A) the total resistance

B) The circuit current



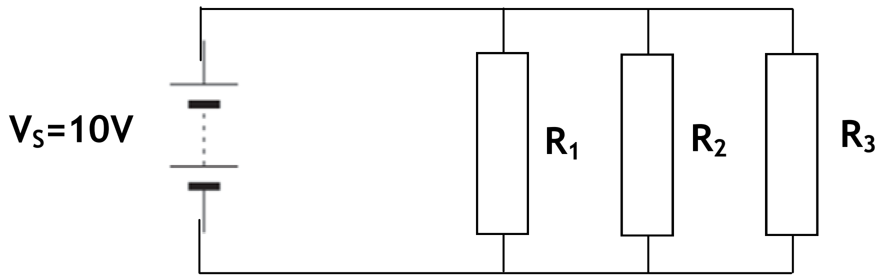
Assignment 10

Three resistors are connected in parallel and then connected to a 10V supply voltage as shown. R_1 = 2KΩ, R_2 = 5KΩ and R_3 = 10KΩ. Calculate:

A) the total resistance

B) the circuit current

C) the current through R_1



Assignment 11

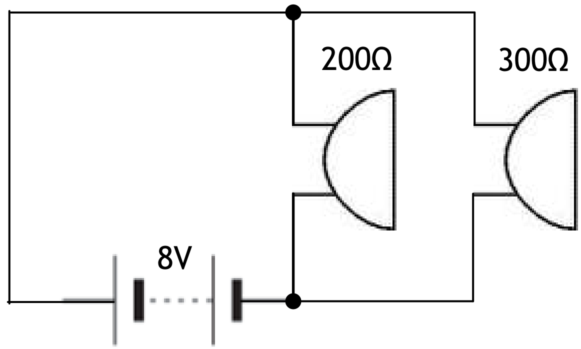
The circuit for a burglar alarm is shown.

Calculate:

A) the circuit resistance

B) the circuit current

C) the current through the 200Ω buzzer



Assignment 12

A student needs a 50Ω resistance to complete her electronics project. Unfortunately she only has two 100Ω resistors available. Draw a solution to her problem and explain your answer by providing proof that it is correct.

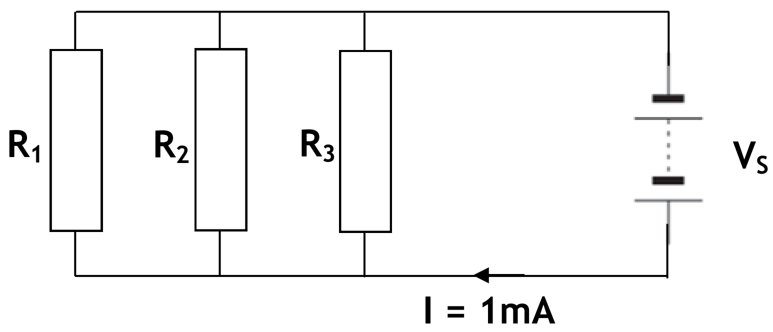
Assignment 13

The circuit shown below has three resistors in parellel connected to an unknown supply voltage. The size of the resistors R_1, R_2 and R_3 are respectively 3K3, 4K7 and 8K2. If the total current flowing through the circuit is 1mA, calculate:

A) the circuit resistance

B) the supply voltage (V_S)

C) the current flowing through R_1



Switches

It is a good idea to use a switch when designing circuits, this allows you to switch on and off the current as required. Most switches are simple on-off devices but they come in all sorts of different types and sizes.

Push Button

Slide Switch

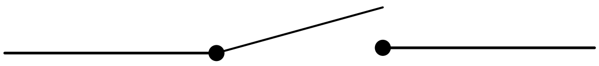
Toggle Switch

Rocker Switch

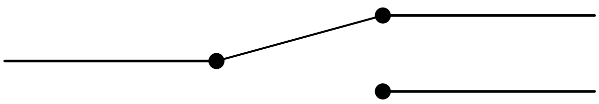
Reed Switch

Mercury Tilt Switch

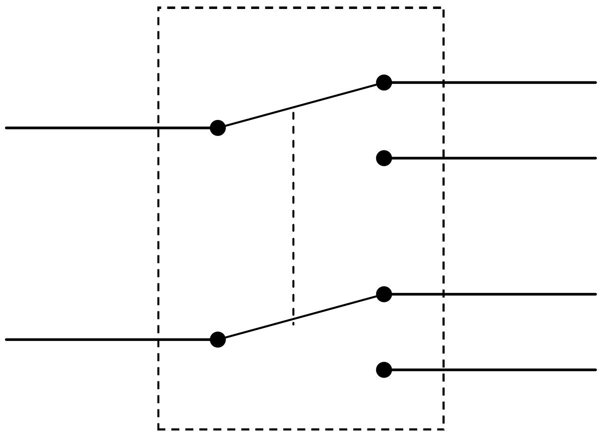
Some of the above switches can be single-pole single-throw (SPST), single-pole double-throw (SPDT) or even double-pole double-throw (DPDT). Their symbols are shown below.



Single-Pole Single-Throw Switch (SPST)



Single-Pole Double-Throw Switch (SPDT)

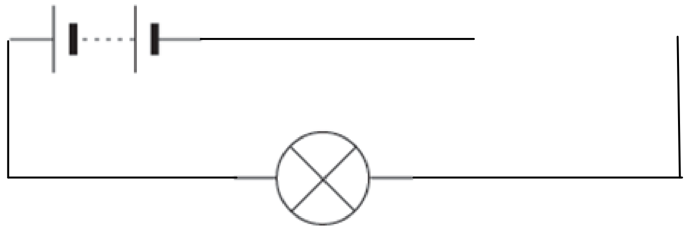


Double-Pole Double-Throw Switch (DPDT)

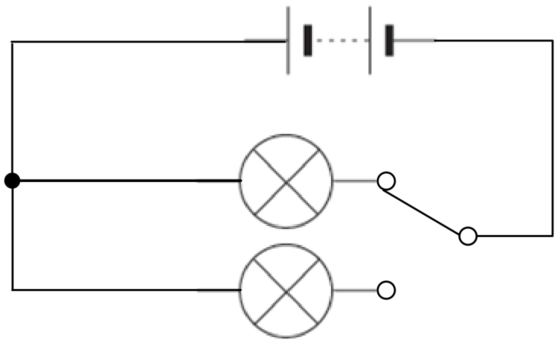
Practical Task 7

Build the following circuits to see how the different types of switches work. Then draw them in your jotter and write a sentence to explain what happens in each.

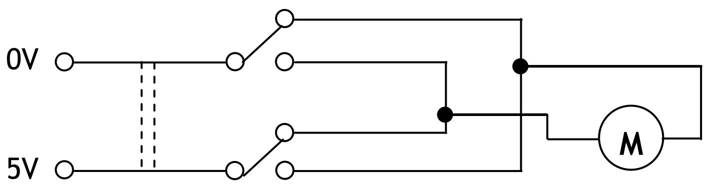
SPST Circuit



SPDT Circuit



DPDT Circuit



Once you have completed these circuits, build them using Yenka.

Introduction to Breadboards

The main things to know about how a breadboard works are:

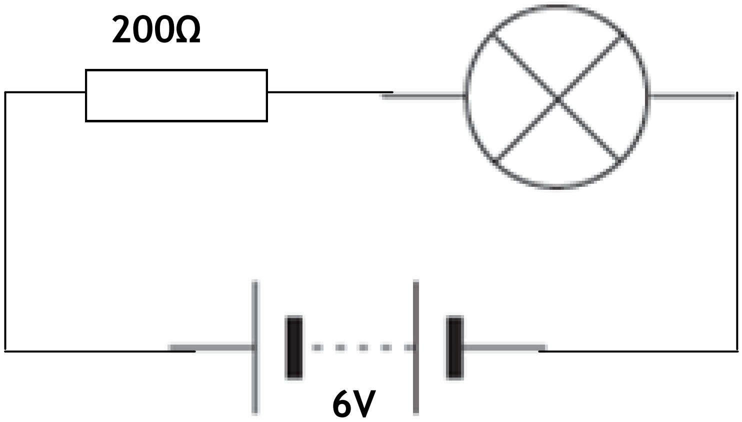
The top and bottom rails run horizontally, so if you were to connect 5V into the top left hole, the entire top rail running across the board would be 5V.

The middle rails run vertically, so if you were to connect 5 V into this one here every hole below that one would also be 5V.

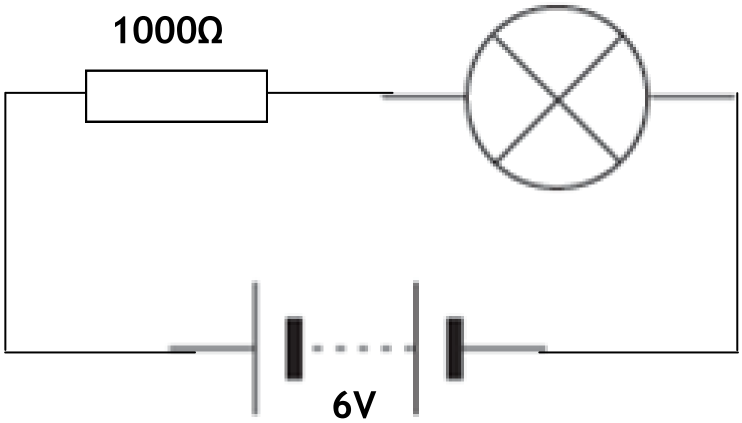
Controlling Voltage

The speed of motors and the brightness of bulbs etc. can be changed or controlled by the amount of voltage supplied to it. Batteries have a fixed voltage so the easiest way to control the voltage is with a resistor. Using the breadboards build the following circuits to prove the point.

Circuit 1

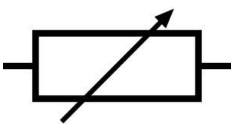


Circuit 2



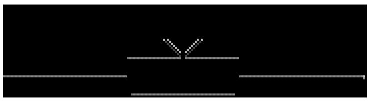
By applying the rules for series circuits ($V=V_1+V_2+V_3$) we can see that the lamp in circuit 2 will be less brightly lit. Most of the voltage will be dropped over the 1000Ω resistor leaving only a small voltage to light the lamp. The smaller the voltage across the lamp, the less light it will produce.

Full control of the voltage can be achieved by using a pre-set variable resistor where the resistance may be changed by rotating the centre screw with a small screwdriver. In a circuit one of the wires should be connected to the centre pin and the other one to one of the other pins.



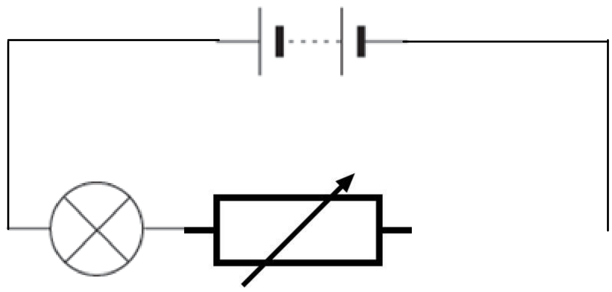
Circuit Symbol

Another different looking variable resistor is a potentiometer which is usually much bigger than the pre-set. The resistance of this one can usually be altered by turning the centre shaft by hand. Note that the circuit symbol is slightly different.



Circuit Symbol

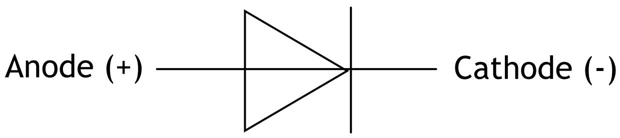
Try building the circuit as shown.



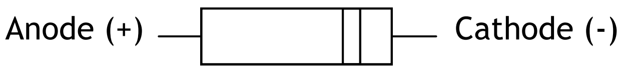
Once you have completed the circuit, build it using Yenka.

Diodes & Light Emitting Diodes

Another commonly used electronic component is a diode. It is a one-way device in that it allows current to flow in one direction only. A diode is a polarity conscious device in that it has a positive and negative end and it must be connected the right way round. Diodes are about the size of a resistor and you can recognise the positive and negative ends by looking for the single band around it. They are often used to stop current going through a part of a circuit you don't want it to go through. Try building the two circuits shown below to help you understand which way round it goes.



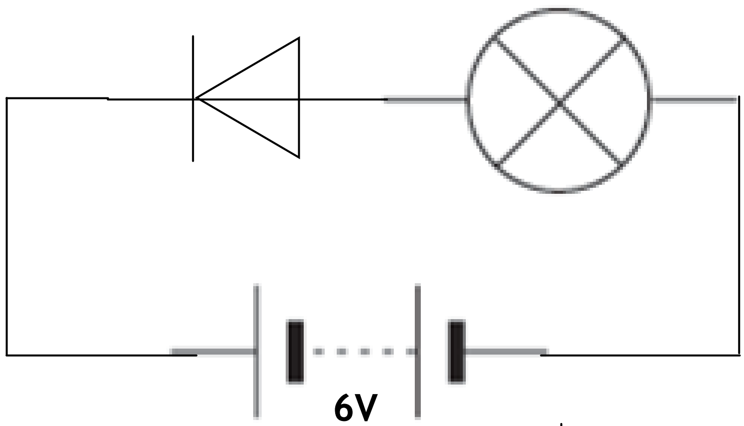
Circuit Symbol



Diode

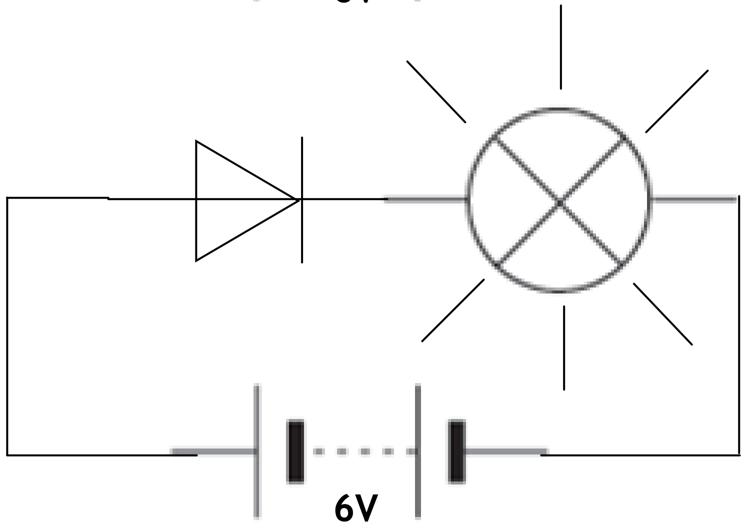
Circuit 1

No current flows



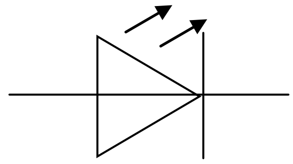
Circuit 2

Current flows



A special type of diode is the Light Emitting Diode (or LED as it is commonly called). First of all, it does the same job as any other diode - it stops current flowing in one direction but it also illuminates or lights up when a current flows through it.

Light Emitting Diode



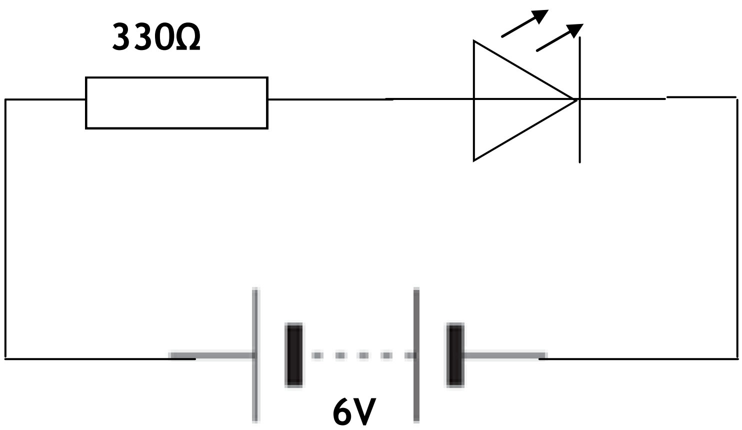
Circuit Symbol

LEDs come in different sizes and different colours but the 5mm red ones are probably the most popular. They are often used as little indicators to tell you if an appliance is on or off. You must have seen them on radios, televisions, music systems, etc.

NOTE - you cannot connect the LED directly to a 6 volt supply or it will “blow”. For this voltage you must put a 330Ω resistor (which is often called a “current limiting resistor”) in series with it to reduce the current to a level that can safely pass through the LED.

Practical Task 8

You are now going to build and test the following circuit using the breadboards.

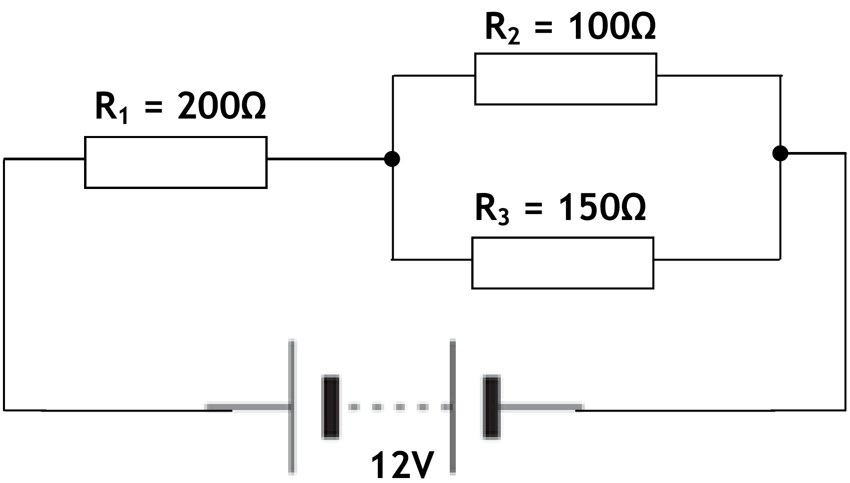


Combined Series & Parallel Circuits

In real life, electronic circuits may have components wired up in a combination of series and parallel.

Worked example

Study the circuit shown below. The supply voltage V_{CC} is 12V. A 100Ω and a 150Ω resistor are connected in parallel with a 200Ω resistor in series. Calculate the total resistance of the circuit.



For the parallel branch

$$\frac{1}{R_T} = \frac{1}{R_2} + \frac{1}{R_3}$$

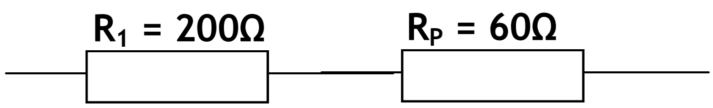
$$\frac{1}{R_T} = \frac{1}{100} + \frac{1}{150}$$

$$\frac{1}{R_T} = \frac{3}{300} + \frac{2}{300}$$

$$\frac{1}{R_T} = \frac{1}{60}$$

$$R_T = 60\Omega$$

The equivalent resistors now become



Total circuit resistance

$$R_T = R_1 + R_P$$

$$R_T = 200 + 60$$

$$R_T = 260\Omega$$

Assignment 14

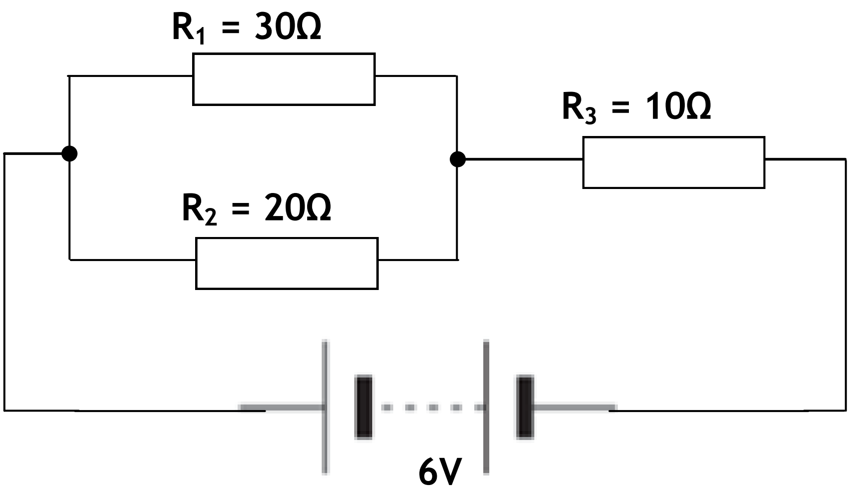
For the combined series circuit below, calculate:

A) the total resistance of the circuit

B) the circuit current

C) the voltage dropped across R_3

D) the current through resistor R_1



Assignment 15

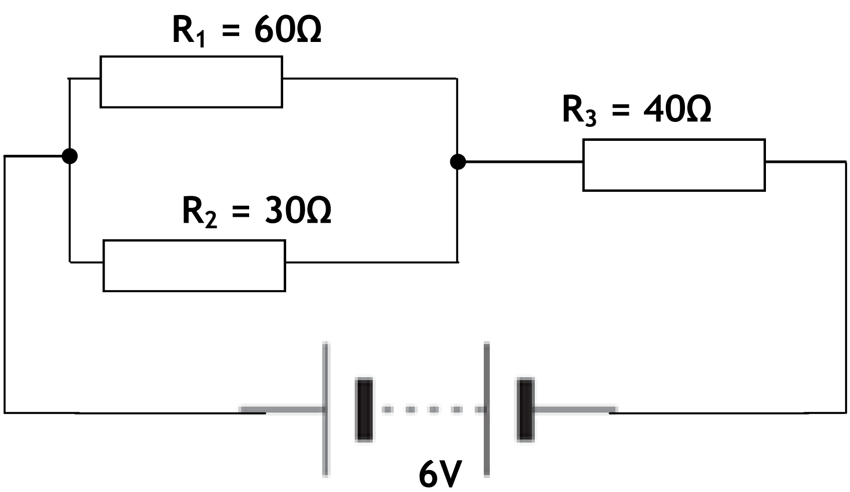
For the circuit shown below calculate:

A) the total circuit resistance

B) the circuit current

C) the voltage dropped across R_3

D) the current through resistor R_2



Electrical Power

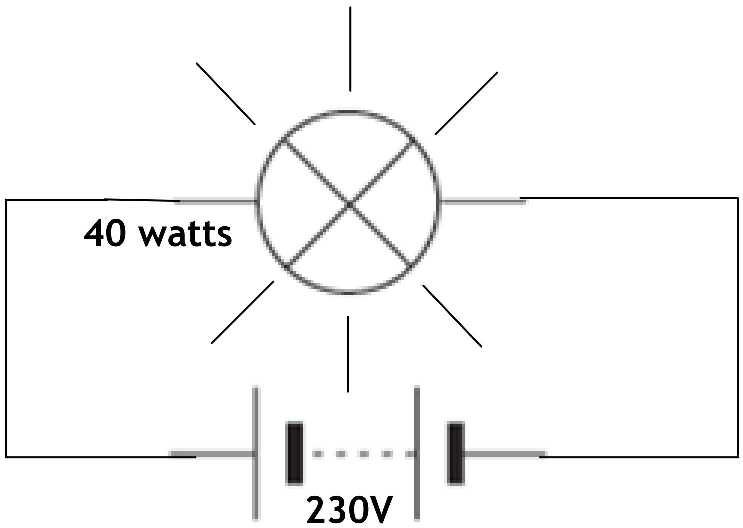
If you have reached this page, you must have at least a reasonable understanding of the importance of voltage, current and resistance in electric circuits. However, there is more to it than that. Sometimes we have to be concerned about how much power is being consumed.

Electrical Power is measured in **watts (W)**. You can find the amount of **power (P)** consumed in a component or in any electrical appliance by multiplying the **voltage (V)** applied and the **current (I)** flowing through it.

$$P = I \times V$$

Worked Example

A small table lamp has a power rating of 40W and is connected to the 230V mains supply. Calculate the current flowing through the lamp and its resistance.



$$P = I \times V$$

$$I = \frac{P}{V} = \frac{40}{230} = \underline{\underline{0.174A}}$$

$$V = I \times R$$

$$R = \frac{V}{I} = \frac{230}{0.174} = \underline{\underline{1320\Omega}}$$

Assignment 16

An electric drill draws a current of 2A when connected to a 110 volt supply. Calculate the power rating of the drill.

Assignment 17

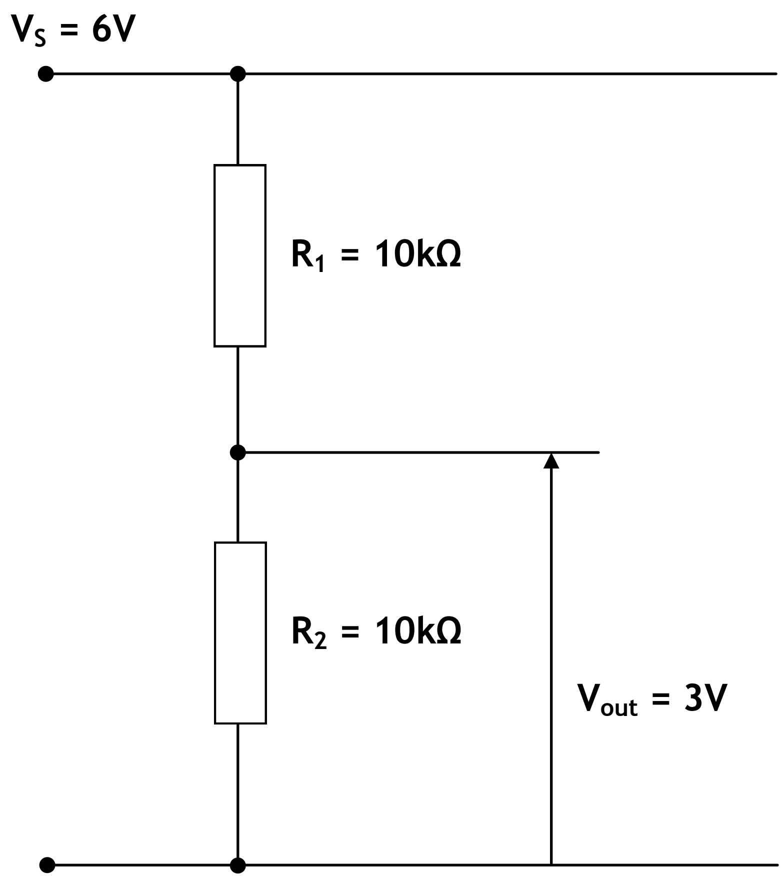
An electric iron is rated at 2100W and is designed to be operated in the UK using mains voltage. Calculate the current drawn by the iron. Suggest which size of fuse should be used in the plug.

Assignment 18

A technology student has a choice of using resistors rated at 0.25W and 0.5W respectively. Calculate the maximum current that each one can safely take when connected to a 6V supply voltage.

Voltage Dividers

Look at this new circuit below and see how the two resistors in series divide the voltage. As both resistors are equal in value, the supply voltage (V_S) is divided in two with half of it dropped across the top resistor and the other half dropped across the bottom one. We always take the voltage dropped across the bottom one as the output voltage (V_O) of the voltage divider.



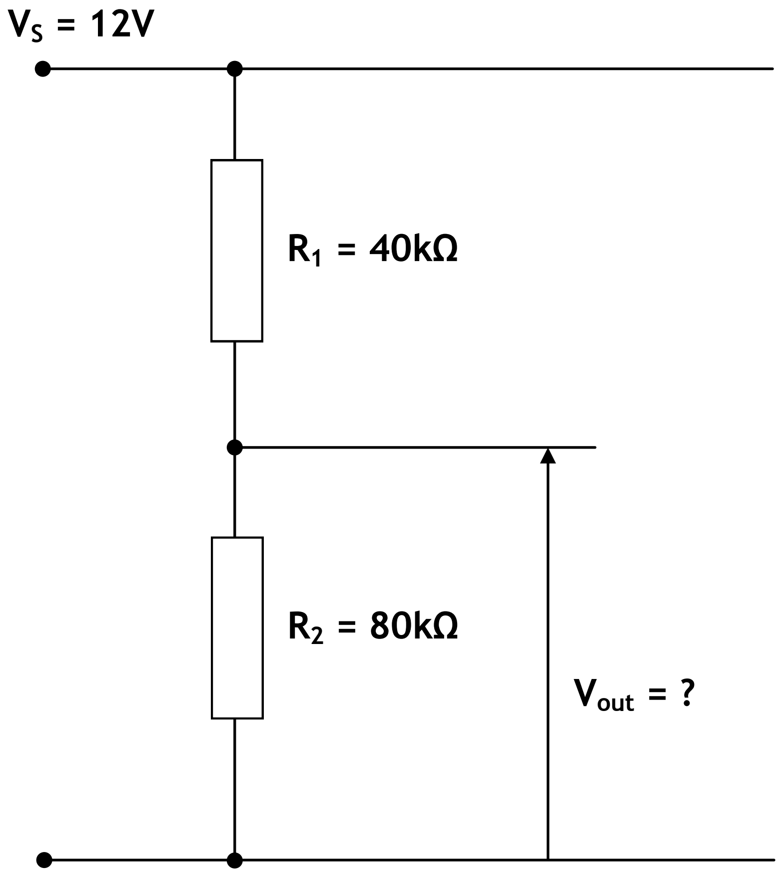
The way we calculate the voltage is as follows:

$$V = I \times R_T$$
$$I = \frac{V}{R_T}$$
$$I = \frac{6}{20000}$$
$$\underline{\underline{I = 0.0003A}}$$

$$V = I \times R_2$$
$$V = 0.0003 \times 10000$$
$$\underline{\underline{V = 3V}}$$

Worked Example

In the circuit shown below, calculate the voltage dropped across R_2.



$$V = I \times R_T$$

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

$$I = \frac{12}{120000}$$

$$\underline{I = 0.0001A}$$

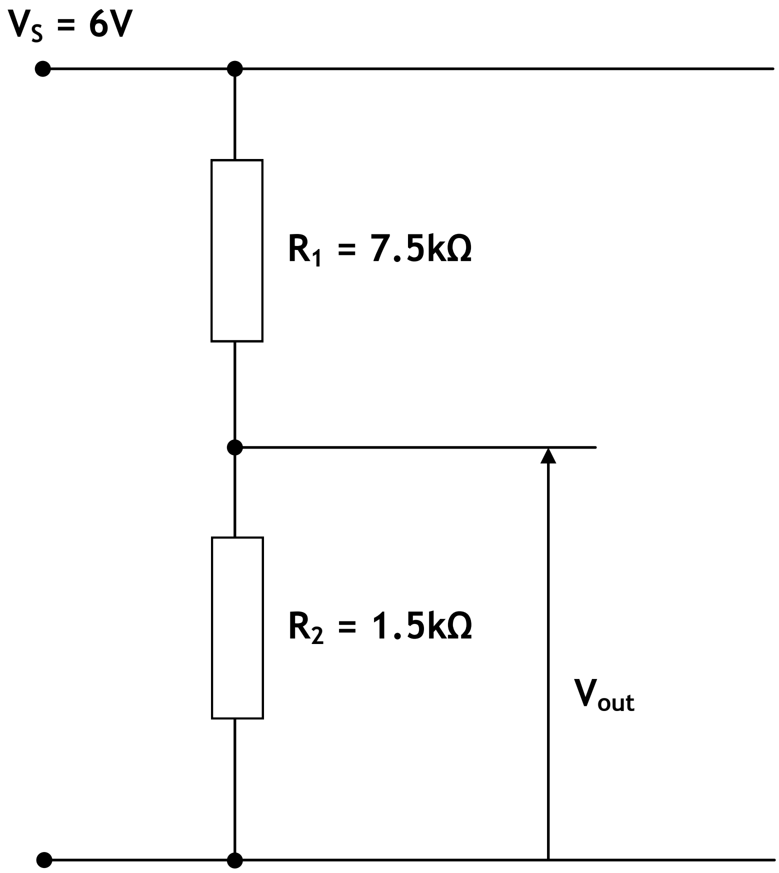
$$V = I \times R_2$$

$$V = 0.0001 \times 80000$$

$$\underline{\underline{V = 8V}}$$

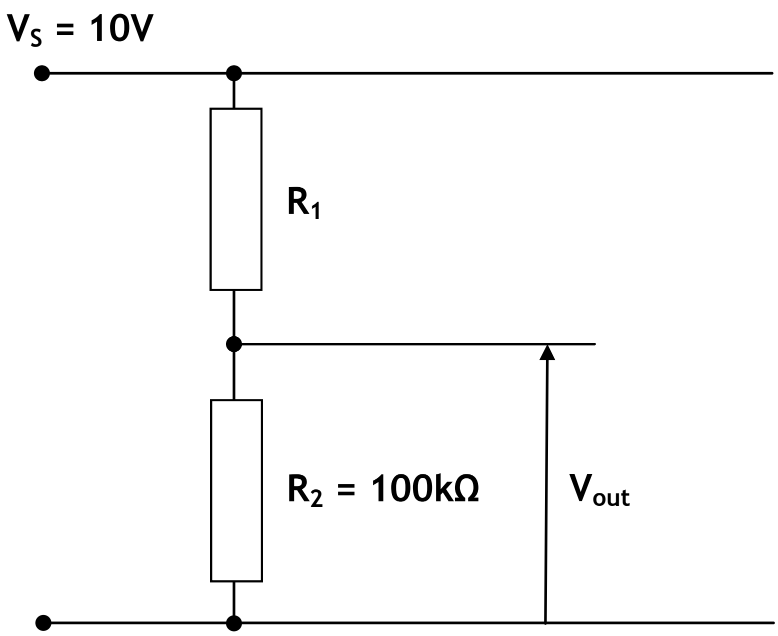
Assignment 19

Calculate the output voltage from the voltage divider sub-system shown below.



Assignment 20

If the output voltage in the circuit shown below is 3.2 volts, calculate the value of the resistance of the variable resistor R_1.

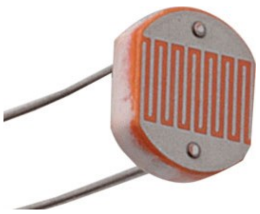


The Light Dependant Resistor (LDR)

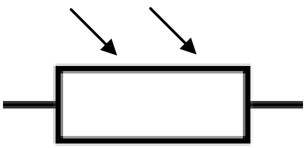
So far our voltage divider doesn't actually sense anything. What we need is an input transducer. Let's start sensing light level by using a **Light Dependent Resistor (LDR)**.

An LDR is just what is says, a resistor whose resistance changes according to how much light shines on it (it is sometimes called a photoresistor). The most common one is called an ORP12 and it is shown below.

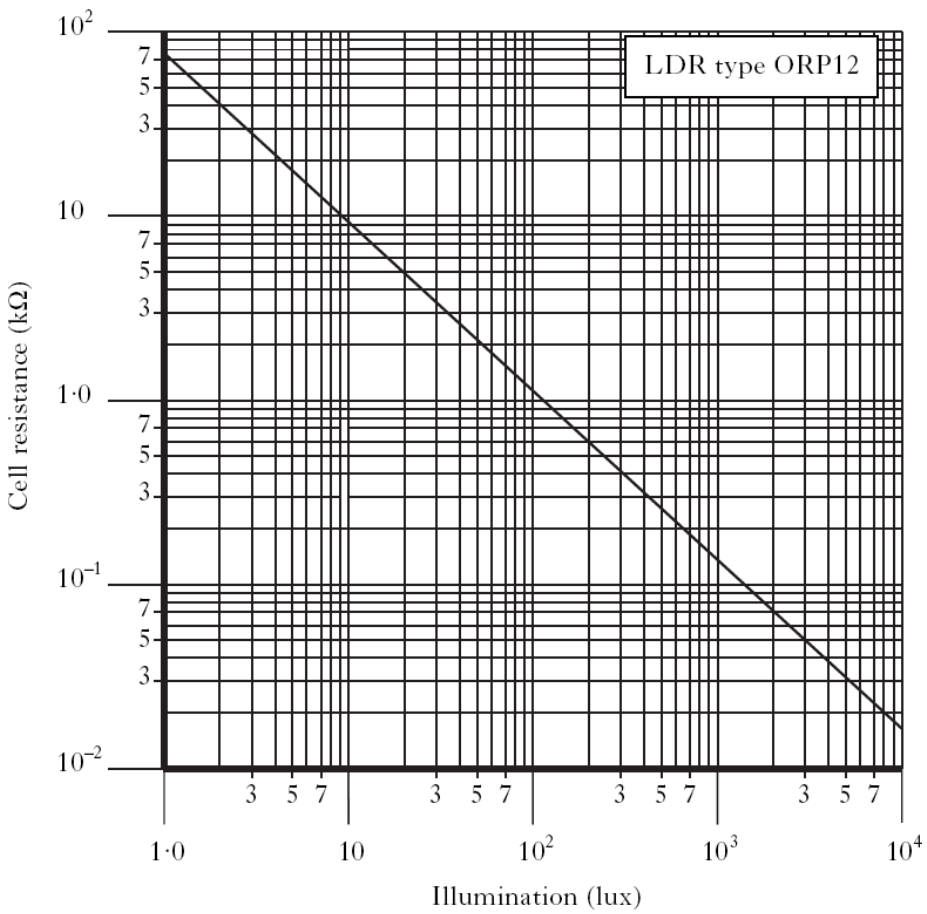
Light level is measured in a unit called lux and a graph of light level plotted against resistance is given below. In bright sunlight (for example) the LDR's resistance is very low and in complete darkness it is very high.



A Light Dependant Resistor (LDR)



Circuit Symbol



Assignment 21

Find the light levels for the LDR at each of these resistances:

A) 3kΩ

B) 40kΩ

C) 0.9kΩ

D) 7kΩ

E) 20kΩ

Assignment 22

Find the resistances for the LDR at each of these light levels:

A) 10 lux

B) 40 lux

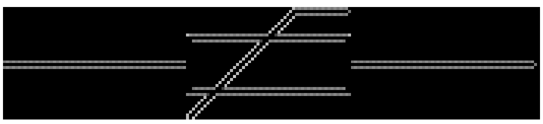
C) 100 lux

D) 400 lux

E) 900 lux

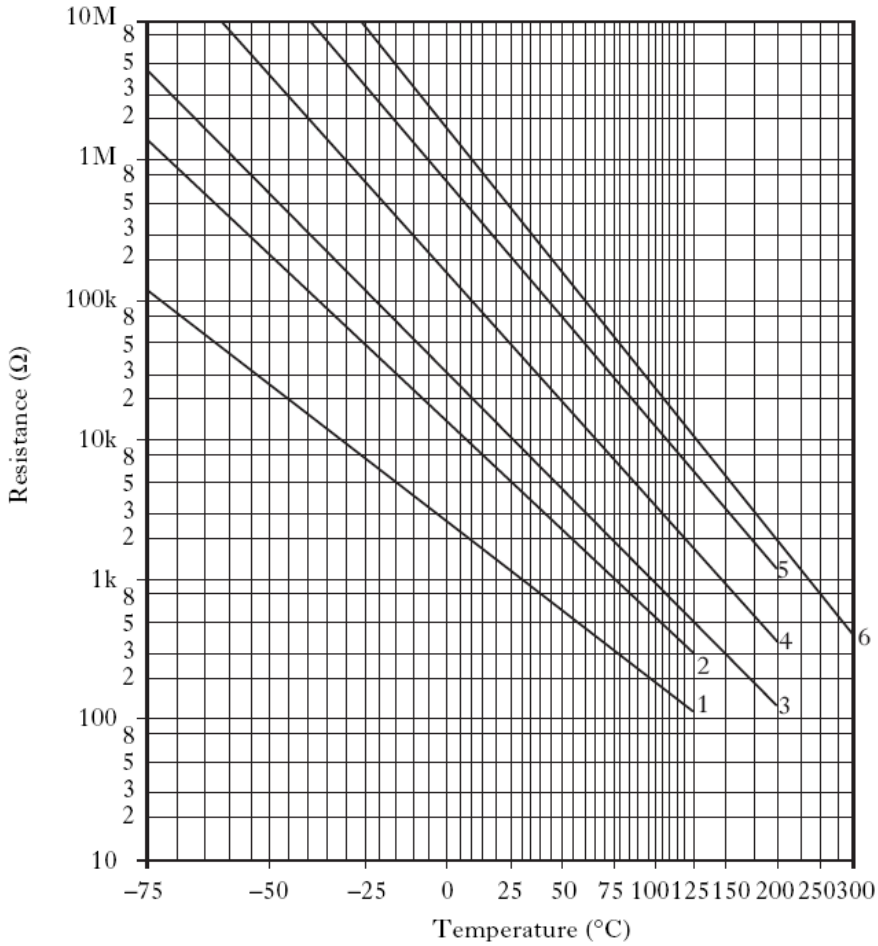
The Thermistor

Another commonly used analogue input transducer is the **Thermistor**. The thermistor is a device whose resistance varies with temperature and it could be called a temperature dependant resistor. If it is very hot, for example, the thermistor resistance is very low and when it is very cold the resistance is very high. A typical one and its circuit symbol are both given below.



Circuit Symbol

A typical Thermistor



Assignment 23

Using the graph for the Thermistor, find the temperature for each of these resistances:

A) Type 2 at 1kΩ

B) Type 4 at 20kΩ

C) Type 5 at 300kΩ

D) Type 1 at 200Ω

E) Type 3 at 800Ω

Assignment 24

Find the resistances for each of these temperatures:

A) Type 1 at –50°C

B) Type 2 at 30°C

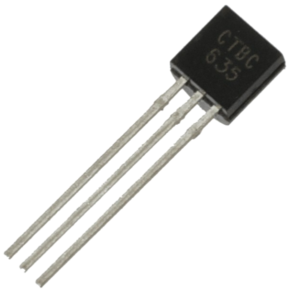
C) Type 4 at 200°C

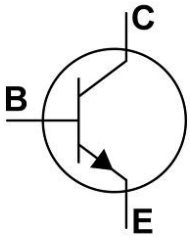
D) Type 5 at –10°C

E) Type 1 at –25°C

The Transistor

The transistor can be used as an electronic switch and it can be used as a current amplifier. A typical one and its circuit symbol are shown below.





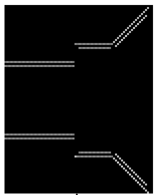
A typical transistor

Circuit Symbol

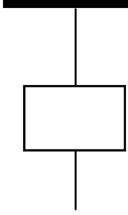
Notice that the circuit symbol has three letters on it. They stand for Collector, Base and Emitter. The transistor will switch on, or saturate, once the voltage between the base and the emitter reaches 0.7V. This is known as the saturation voltage.

Output Devices

We have already met several output transducers such as lamps, motors and buzzers. Other output devices might include loudspeakers, solenoids and relays. Relays are especially useful in electronic and electrical engineering.



Loudspeakers are needed in radios, televisions and mobile phones to convert the amplified output from the transistor into sound.



A **Solenoid** is like an electric bolt. When a current is applied to the copper coil inside the solenoid, it becomes magnetic and the central core, or bolt, is shot outwards.

A **Relay** is used when you need a small signal voltage to control a much larger voltage. A transistor is a great current amplifier but there is a limit to how much it can amplify.