Electronics & Control

– Analogue Electronics

»

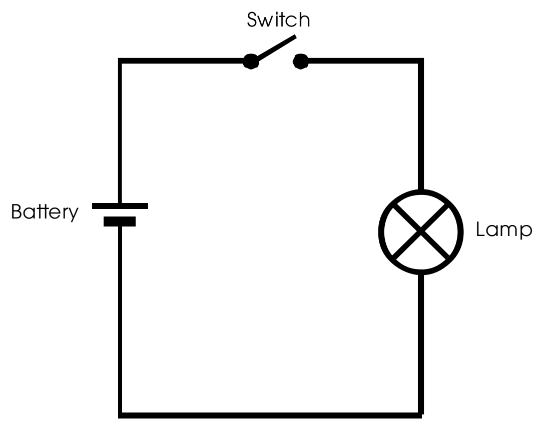
ELECTRICITY

Introduction

Electricity is one of the most important forms of energy available to man. It affects everyone's lives in many ways. If you take time to think about your everyday life you will realise that our lives are full of devices that depend upon electricity. These devices depend on the electrical circuits inside them to work. The circuits often change the electrical energy into other forms of energy such as heat, light and sound. In this area of study you will learn how these circuits work and about the different components within them.

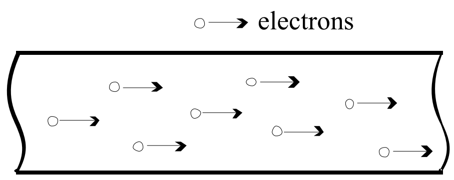
Electric circuits

An electric circuit is a closed loop or network made up of electrical components such as batteries, bulbs, switches and wires.



Electric current

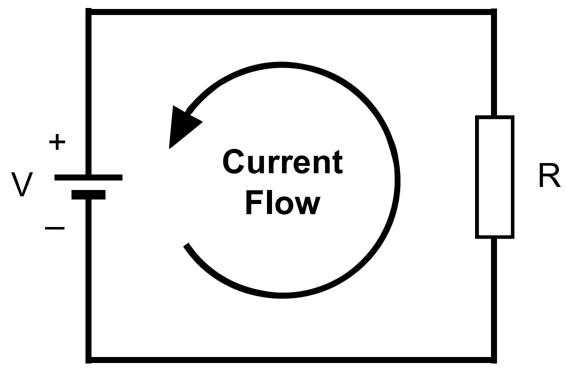
Electric current is the name given to the flow of negatively charged particles called electrons.



Current is measured in *amperes*, usually referred to as 'amps' (A). Current is the rate of flow of electrical charges (called electrons) through a circuit.

Voltage

In most circuits a battery or voltage supply is used to drive the electrons through the components.



Voltage is measured in *volts* (V).

Resistance

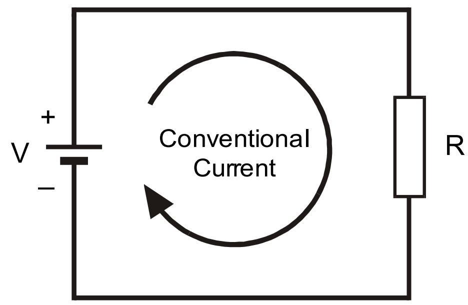
All materials conduct electricity. The materials that conduct electricity well are called *conductors* and those that are poor conductors are called *insulators*. Metals are good conductors while rubber and glass are good insulators.

A good conductor offers very little resistance to the flow of electrical current. In other words, it lets currents flow with very little voltage being applied. Resistance is therefore a measure of how much voltage is required to let a current flow. Resistance is measured in *ohms* (W).

Electron flow - conventional current

Scientists in the early nineteenth century decided the direction of conventional current flow. It seemed to them that current flowed from the positive side of power supplies to the negative side. It was not until the twentieth century that electrons were discovered and the true direction of current flow was proved.

As stated earlier, electric current is the flow of electrons but often it is more useful to consider electric current to flow in the opposite direction. This is called *conventional current*.

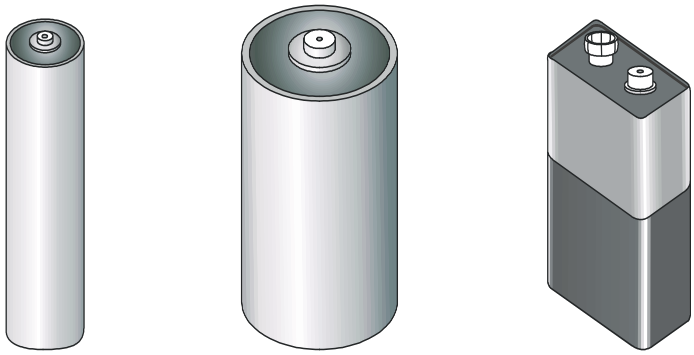


So although it is technically wrong, for convenience 'conventional current' will be used in the circuits and calculations throughout this work.

Conventional current flows from positive to negative.

One of the main reasons for maintaining this convention is that symbols and other data based on conventional current have become standard.

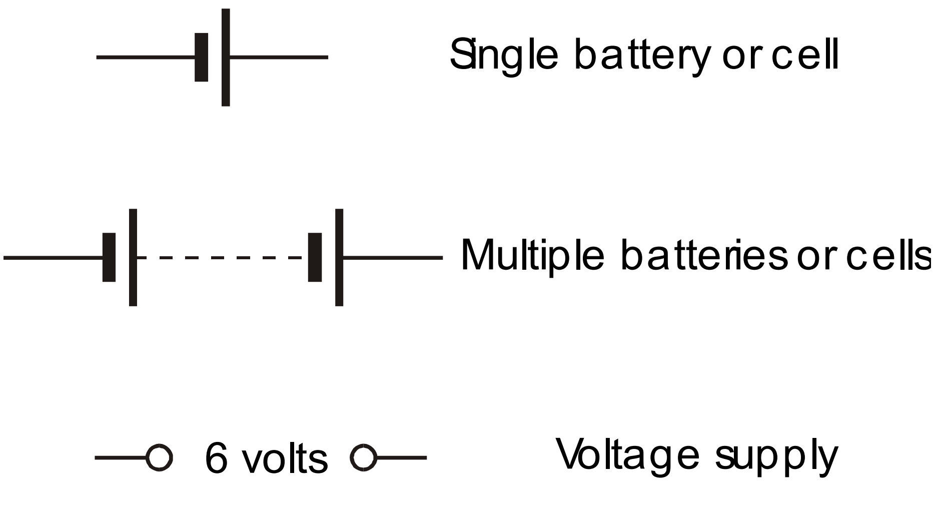
Batteries and voltage supplies



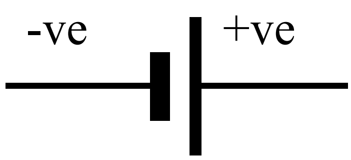
Batteries and voltage supplies are the source of power behind all electrical circuits. Without a power source, electrical circuits will not work. In your work (as in most electronic circuits) all power sources will be low-voltage - this normally means everyday batteries or a low-voltage power supply.

The low-voltage supplies and batteries will normally supply between three and 12 volts. Electronic components normally work on much lower voltages and so the circuits must be designed carefully.

The symbols for batteries and voltage supplies are as follows.



Note the positive and negative side of the battery:

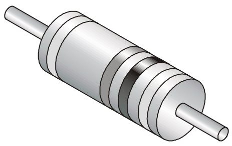


Direct current (d.c.)

The voltage supplied by batteries or low-voltage supplies is direct current (d.c.). This is the normal type of supply to low-voltage circuits. Alternating current (a.c.) supplies are high-voltage - usually 230 volts. This is the normal supply in homes and schools. Many portable electric power tools work from 110 volts for safety.

Resistors

Resistors are basic components in electrical and electronic circuits. They limit the amount of current flowing in circuits or parts of circuits. Resistors are roughly cylindrical and have coloured stripes. They also have connection wires sticking out of each end.



The stripes indicate the value of the resistors. The colours represent numerical values according to a special code.

Resistor colour code

Resistors are marked with what is known as a resistor colour code. Each band that surrounds the body of the resistor helps identify the value (in ohms) and the tolerance (in per cent). In most resistors only four colour bands are used.

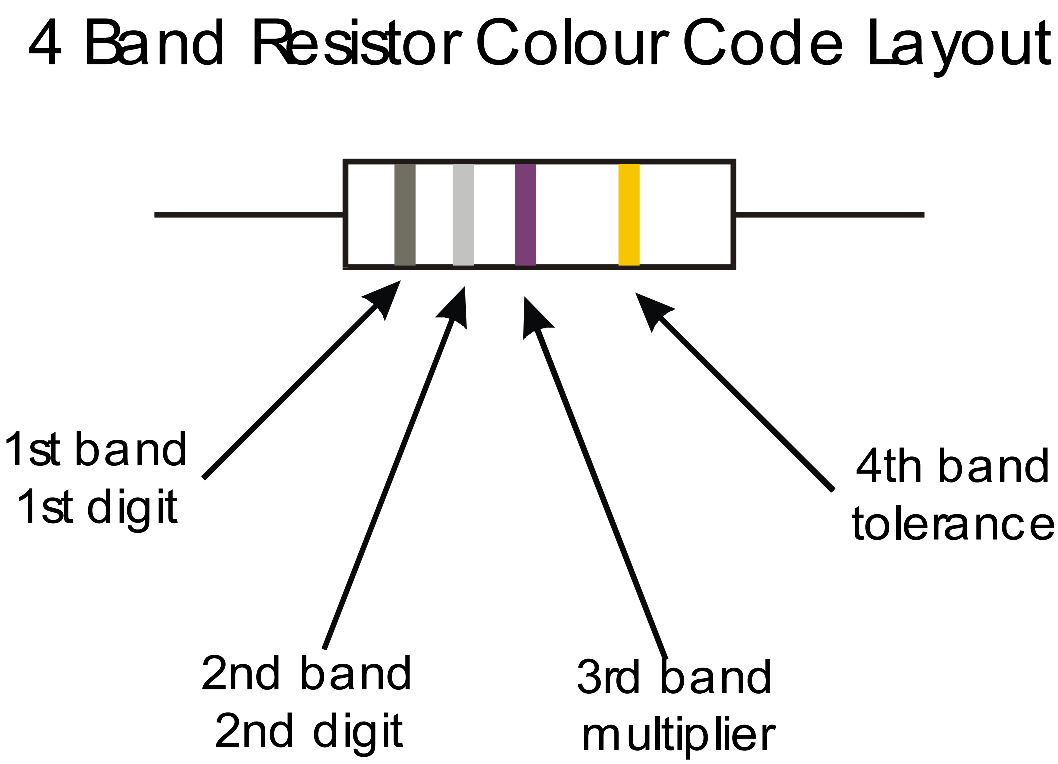
The colour code chart for resistors is shown below. The colours are used to represent different numbers, and in this way we are able to tell the value for each digit.

First and second colour band	Digit	Multiplier
Black	0	x 1
Brown	1	x 10
Red	2	x 100
Orange	3	x 1000 or 1 K
Yellow	4	x 10 000 or 10 K
Green	5	x 100 000 or 100 K
Blue	6	x 1 000 000 or 1 M
Violet	7	Silver means divide by 100
Grey	8	Gold means divide by 10
White	9	Tolerances: • brown – 1% • red – 2% • gold – 5% • silver – 10% • none – 20%

Standard values

Resistors are supplied in a range of standard values: 1.0, 2.2, 3.3, 4.7, 5.6, 6.8, 7.5, 8.2 and 9.1. These standard values can then be multiplied by 10, 100, 1000, and so on. Typical values of resistors are 220 R, 100 K, 680 R, etc. Some other popular sizes are also available, such as 270 R and 390 R.

4-band resistor colour code layout



Example

If the colours on the above resistor are:
1st band - red
2nd band - violet
3rd band - brown
4th band - gold
then using the table on the previous page, the value of this resistor is 270 Ω and its tolerance is 10 per cent. This is worked out as '2' for the red first band, '7' for the violet second band and 'times 10' for the brown third band.

For most purposes you can ignore the tolerance. In the above example the manufacturers guarantee that the resistor will not vary from the marked resistance by more than 10 per cent.

Symbol for resistance

Although the symbol for ohms is 'Ω ' it is often shown as a capital R; that is, 270 ohms can be expressed as either 270 Ω or 270 R.

Exercises

1. Using the colour-code chart, determine the colours of the first three bands of the following resistors.

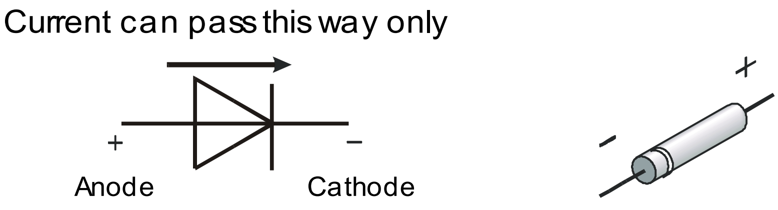
No.	Value	Colour
1	270Ω	
2	1.5kΩ	
3	33kΩ	
4	1.2MΩ	
5	330Ω	
6	150Ω	
7	82Ω	
8	560Ω	
9	6.8kΩ	
10	750Ω	
11	390Ω	
12	2.1MΩ	
13	82Ω	
14	4700Ω	
15	9100Ω	

2. Using the colour-coding code, calculate the values of the following resistors.

No	Value	First three colour bands		
1		red	red	red
2		yellow	violet	black
3		grey	red	red
4		yellow	violet	orange
5		red	red	orange
6		orange	orange	orange
7		green	blue	brown
8		red	violet	black
9		grey	red	brown
10		brown	green	green
11		brown	grey	yellow
12		brown	black	yellow
13		green	blue	orange
14		brown	grey	black
15		brown	grey	green
16		blue	grey	orange
17		orange	orange	yellow
18		red	red	brown
19		grey	red	black
20		violet	brown	orange

Diodes

Diodes are devices that allow current to flow in one direction only.

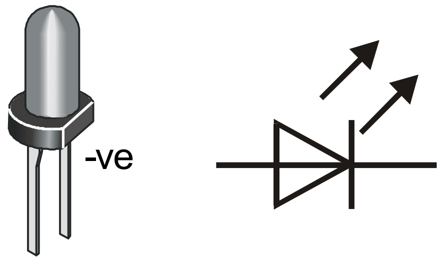


Symbol for Diode

Current will flow through the diode only when the anode (positive side) is connected to the positive side of the circuit and the cathode (negative side) is connected to the negative side of the circuit.

Light-emitting diodes

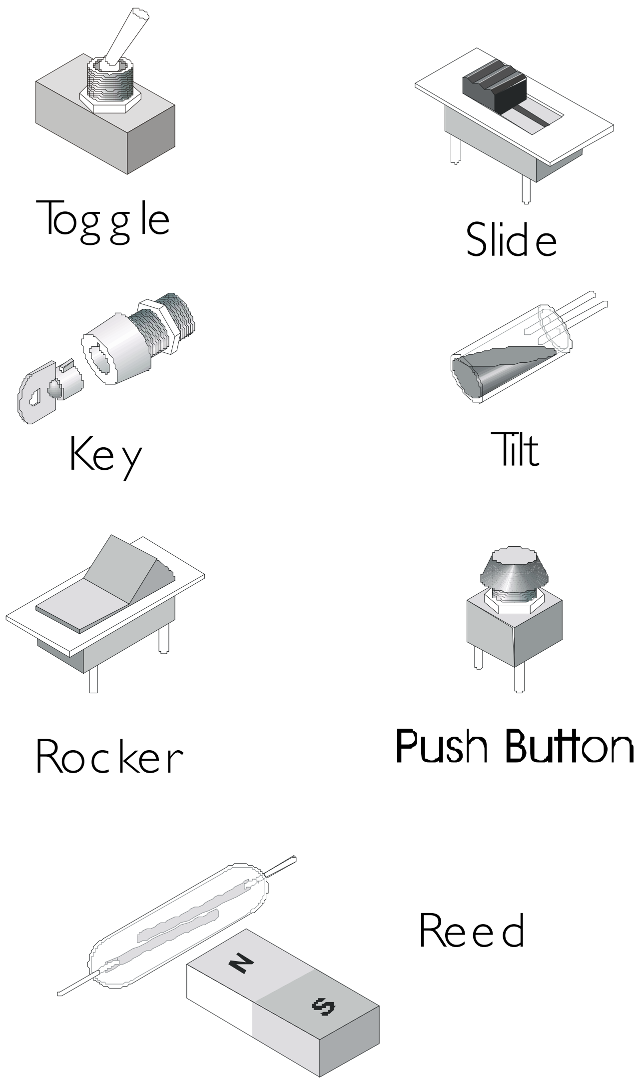
A light-emitting diode is a special diode that gives out light when current is flowing though it. LEDs are used as indicators to tell when a circuit (or part or a circuit) is working. You can tell the cathode of an LED as it is the short leg and there is a 'flat' on the plastic casing.



As with the normal diode, the current can only pass one way.

Switches

Switches are useful input devices (or transducers) that have metal contacts inside them to allow current to pass when then they are touching. There are several ways in which the contacts in mechanical switches can be operated. The main types are - push-button, toggle, key, slide, magnetic (reed) and tilt. These switches are 'digital' input devices as they can only be on or off.



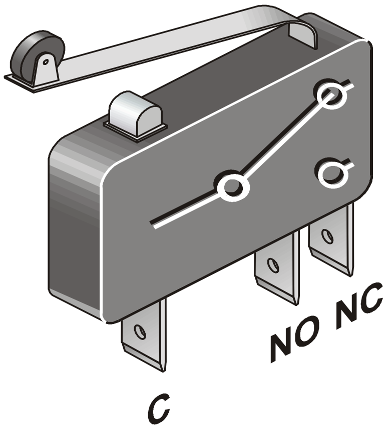
The switches shown above are all single pole with single or double throws. These are known as SPST and SPDT switches. The symbols are shown below.

SPST
Single Pole Single Throw

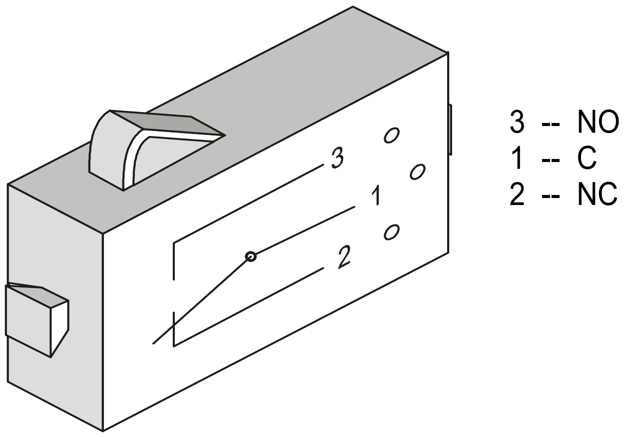
SPDT
Single Pole Double Throw

Microswitches

Microswitches are small switches that are useful for detecting motion. They are especially good as sensors and limit switches. Typical systems that use microswitches are traffic barriers and lift systems.



The microswitch above has a roller fixed to a lever that detects movement and throws the switch. It has three terminals: *common*, *normally open* (NO) and *normally closed* (NC).



The microswitch below is commonly used in schools.

Like most microswitches, this one can be wired in three ways.

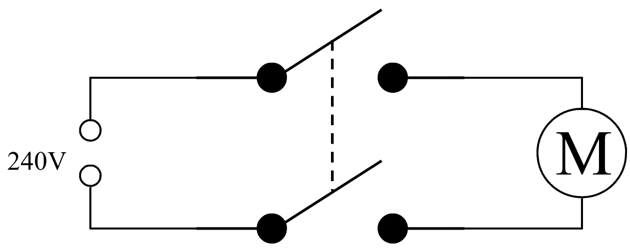
- C and NO: this is a normal on/off switch.
- C and NC: this allows current to flow when the switch is not operated.
- C, NC and NO: when wired like this it acts as a changeover switch.

These microswitches are single-pole double-throw (SPDT) switches.

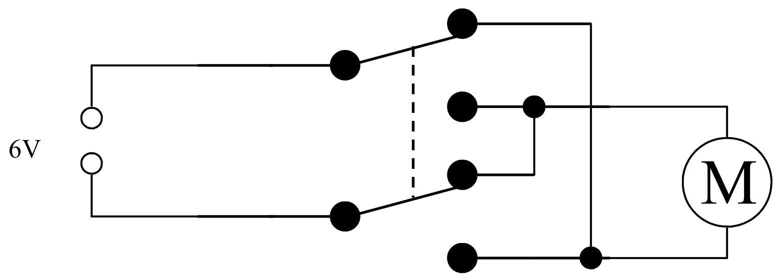
DPST and DPDT Switches

More complex switches exist to do more specialised tasks.

The ***DPST*** switch (***Double Pole Single Throw***) is commonly used to isolate a piece of equipment or machinery from the power supply.



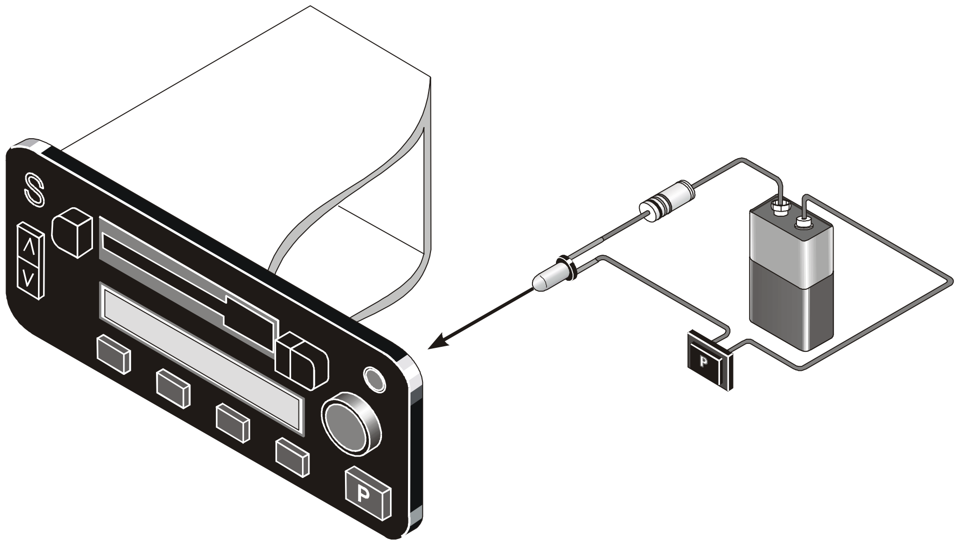
The DPDT switch (Double Pole Double Throw) is commonly used to allow a motor to switch directions.



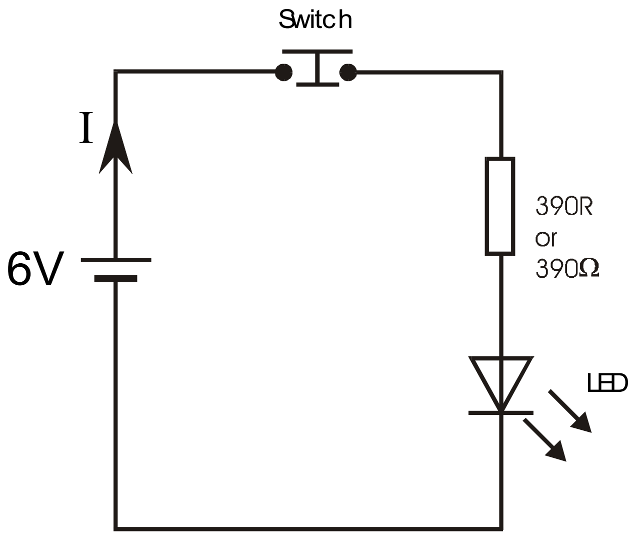
Prototype circuit boards
Simple Circuits

Series circuits

The diagram below shows a typical use for an LED circuit, where the LED indicates that the car radio/cassette is on. The diagram also shows a simplified series circuit layout for the LED indicator. The resistor is necessary to protect the LED from drawing too much current and 'blowing'.



The diagram below shows the above circuit using the component's symbols. This is called the *circuit diagram*.

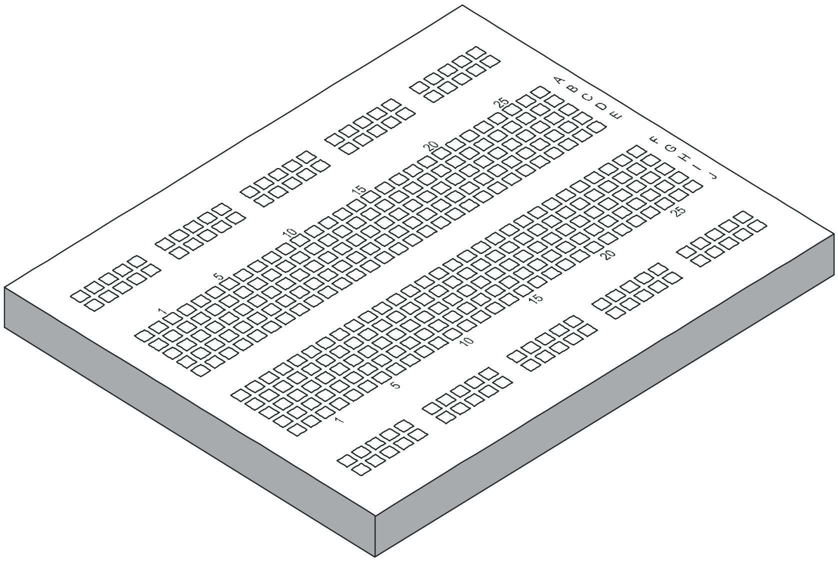


The components in this circuit are connected in *series*. This means that they are connected up in a line, one after the other (or end to end).

Series circuits are the simplest to deal with as the same current flows through all of the components. The voltage, however, is divided up between the components – more of this later.

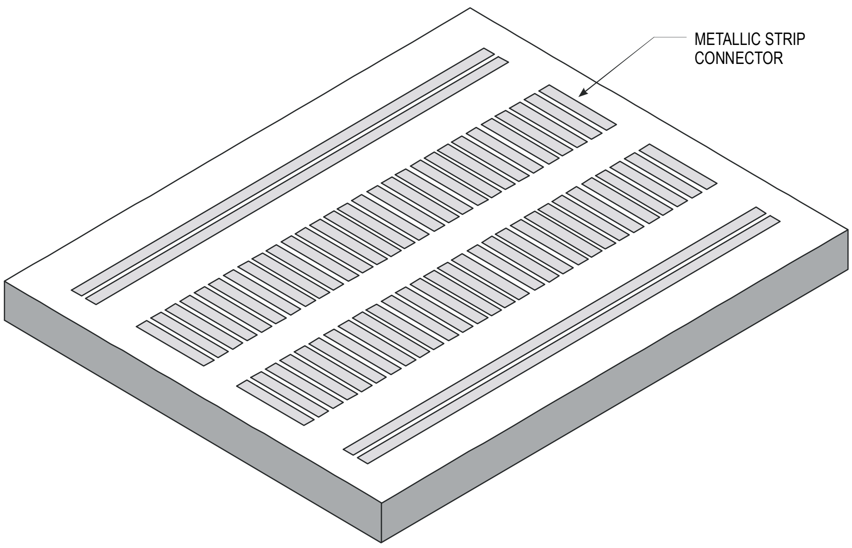
Prototype circuit boards

Prototype circuit boards (often called breadboards) are used to build and test circuits. They have the advantage that they are non-permanent: that is, the components can be moved and used again. This makes it easy to make alterations or corrections to circuits. Once a circuit has been proved on a prototype circuit board it is usually built by a more permanent method on stripboard or printed circuit board (PCB).



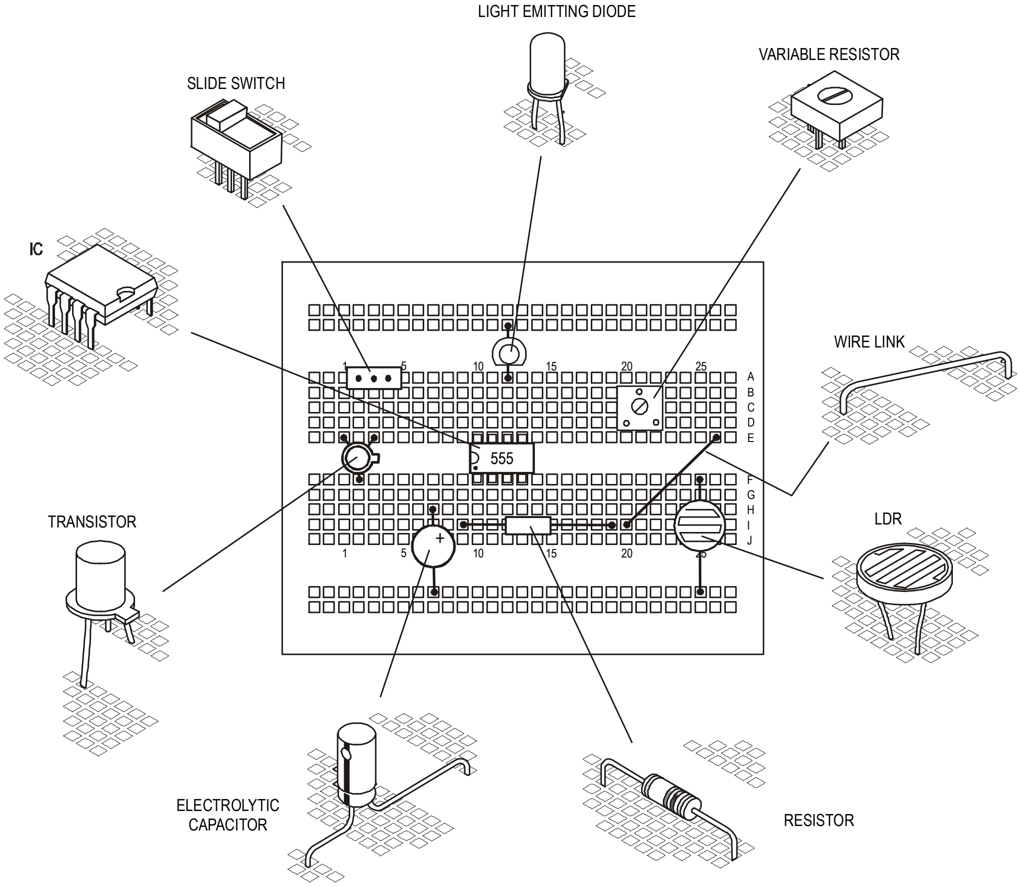
The board above shows four mains sections of connection holes. The two centre areas, separated by a gutter, are where most of the components are placed. The two outer rows are used for the power connections.

The uncovered reverse side, seen below, shows how the connection holes are interconnected.



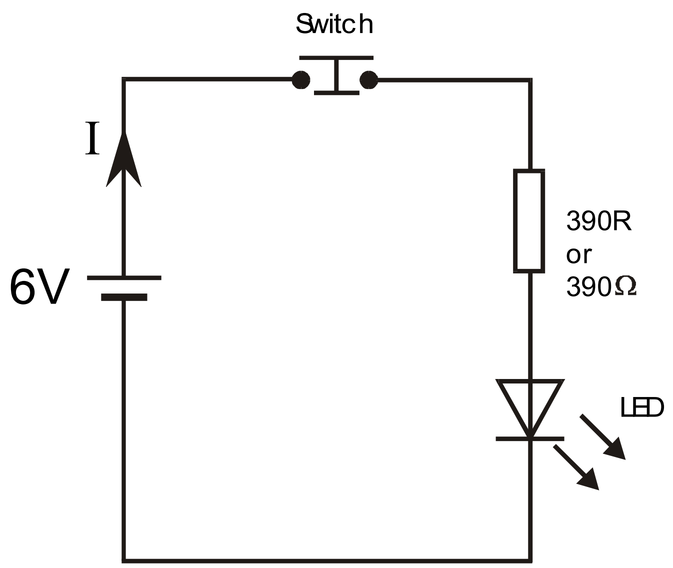
The metallic strips connect the middle sections in columns of five, while the two sets of outer rows are connected horizontally.

The diagram below shows how most common components can be inserted. Note that the most complicated components are usually connected over the centre gutter. This is especially true for transistors and integrated circuits (ICs).

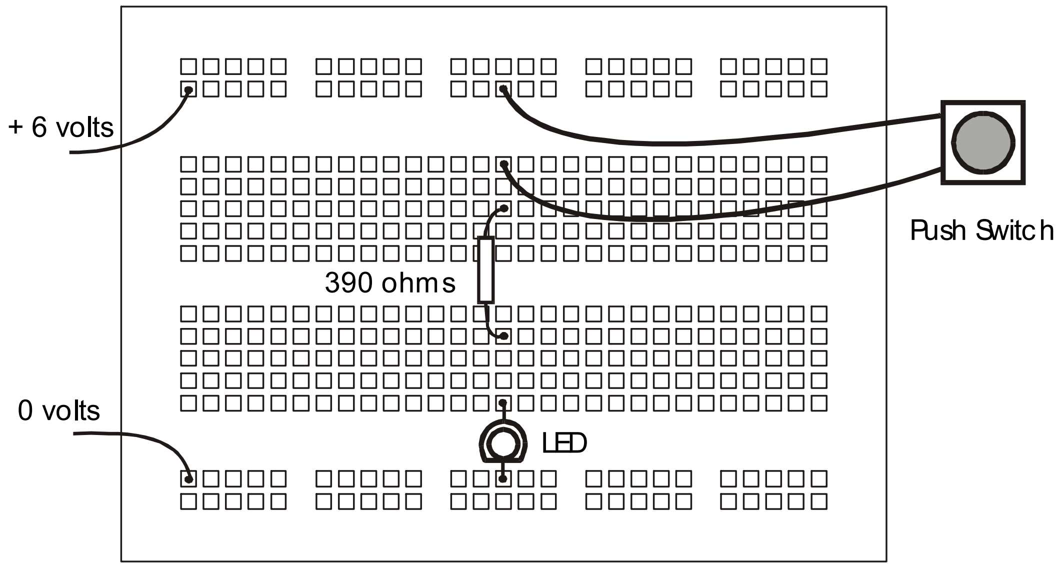


Example 1
Build the LED series circuit for the car radio/cassette. It can be built on a prototype circuit board or simulated on computer software such as *Crocodile Technology*.

Circuit diagram



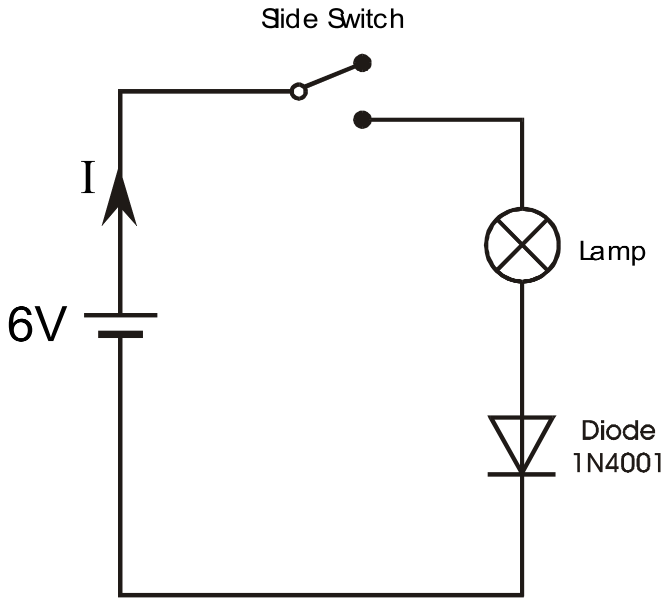
Prototype board circuit layout diagram



Remember to connect the LED 'the right way round'; that is the short lead (cathode) is connected to the zero volt line or negative battery terminal. The LED should light when the switch is pressed.

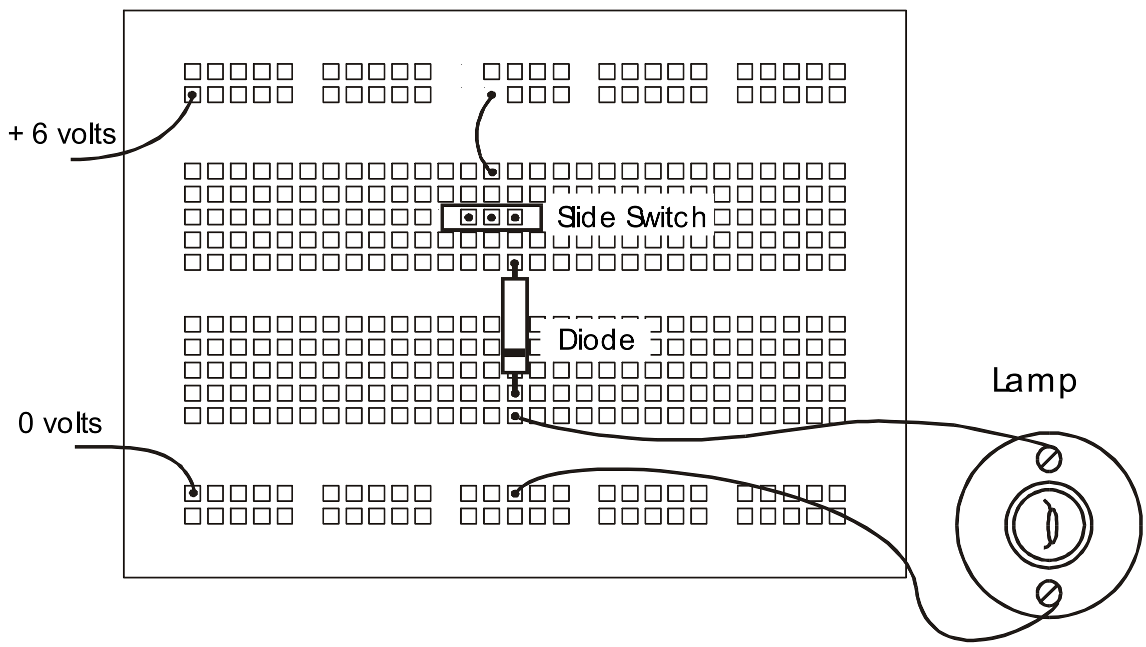
Example 2

Build the lamp circuit below. It can be built on a prototype circuit board or simulated or computer software such as Crocodile Technology.



Circuit diagram

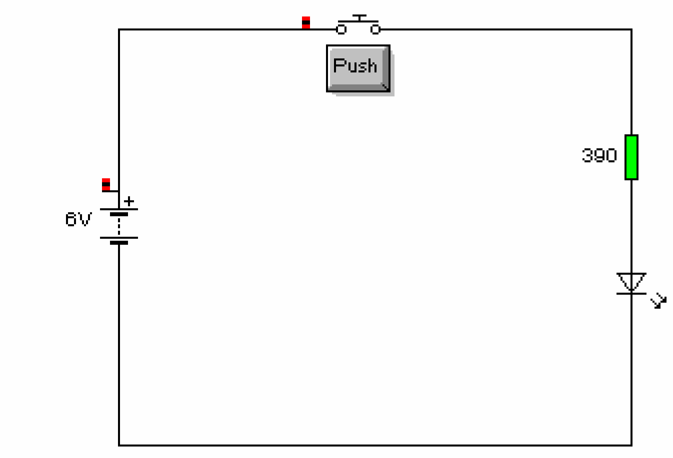
Layout diagram



Remember to connect the diode 'the right way round'; that is, the negative lead (cathode) is connected to the zero volt line or negative battery terminal. The lamp should light when the switch is moved to the right. Try connecting the diode 'the other way round' to confirm its operation.

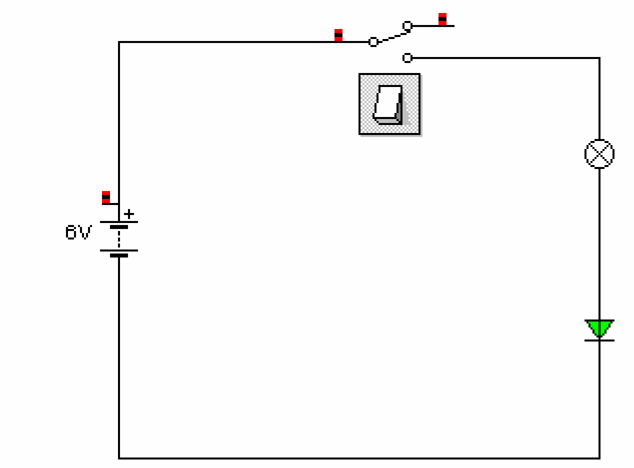
Computer simulation

The two series circuits can be built and simulated in a computer programme such as *Crocodile Technology*.



LED circuit

As in the prototype circuit, when the switch is 'pressed' the LED should light.

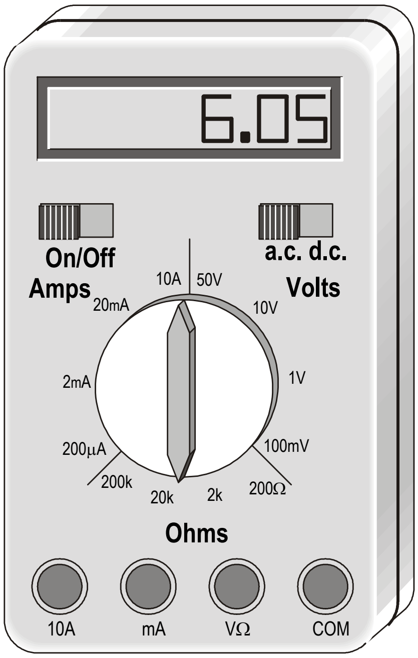


Lamp circuit

As in the prototype circuit, the lamp should light when the switch is pressed/moved and it will not light when the diode is reversed. Note: Crocodile Clips uses a rocker switch to represent the action of a slide switch.

Digital multimeters

The digital multimeter is used to measure voltage, current and resistance. It is very simple to use and easy to read.

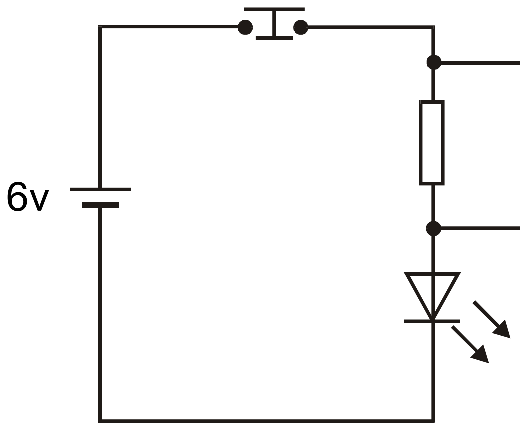


To measure d.c. voltage:
- connect the black lead to the 'COM' socket
- connect the red lead to the 'VW' socket
- make sure that 'd.c.' is selected
- move the dial into the voltage (volts) range
- select a suitable range (always slightly higher than the expected measurement)
- place the lead probes on the points where the voltage is to be measured.

To measure direct current:
- connect the black lead to the 'COM' socket
- connect the red lead to the 'mA' socket
- make sure 'd.c.' is selected
- move the dial into the current (amps) range
- select a suitable range (always slightly higher than the expected measurement)
- connect the probes to the wire in which the current is to be measured.

To measure resistance:
connect the black lead to the 'COM' socket
connect the red lead to the 'VΩ' socket
make sure 'd.c.' is selected
move the dial into the resistance (ohms) range
select the range (always slightly higher than the expected measurement)
connect the probes to the ends of the component being measured.

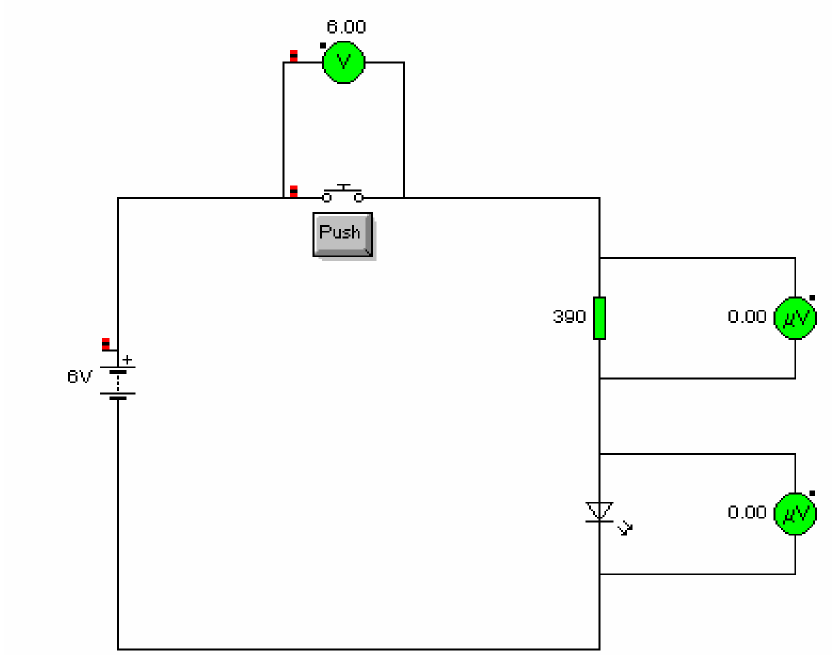
Measuring d.c. voltage



Voltage is measured across components or parts of circuits as shown in the circuit diagram below.

This can be done in actual circuits or simulated with *Crocodile Technology*.
'Across' means in 'parallel' as opposed to 'series'. Parallel circuits will be dealt with later.

Practical task

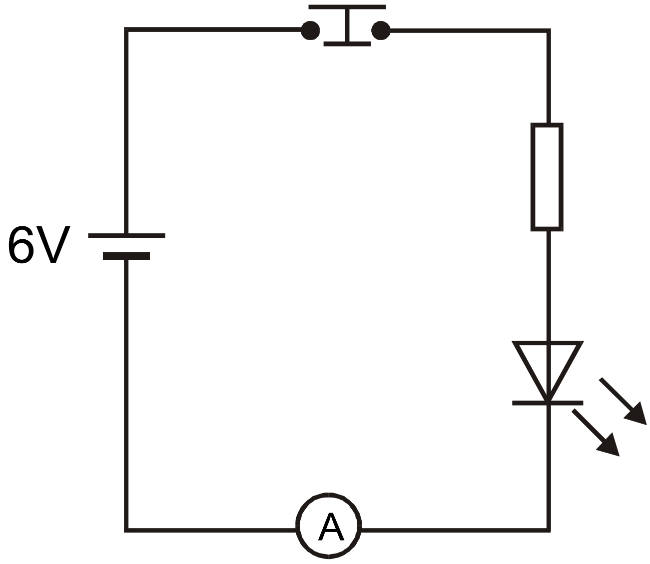


Using circuit simulation measure the voltage across all three components in the LED circuit.

The voltage across each component is known as the *voltage drop* across the component. This is the amount of voltage 'used up' or 'dropped' by each. The total voltage dropped in the circuit should equal the total supply voltage as stated in Kirchoff's second law.

Record your results.

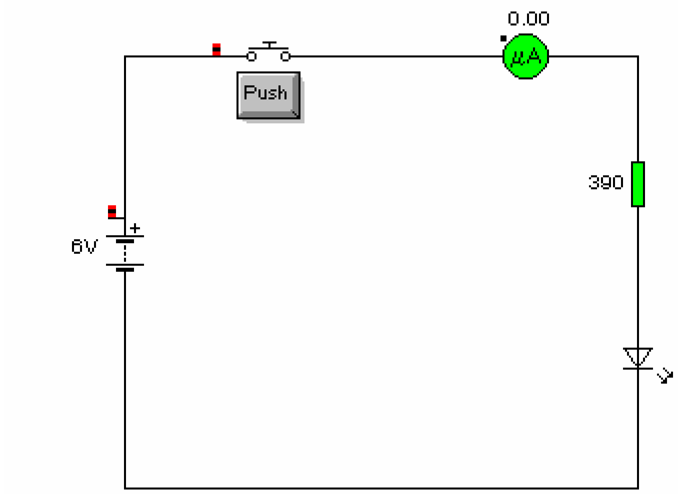
Measuring direct current



Current is measured through components or parts of circuits, as shown in the circuit diagram below. Note that it is necessary to 'break' the circuit and connect the meter in series with the components.

Practical tasks

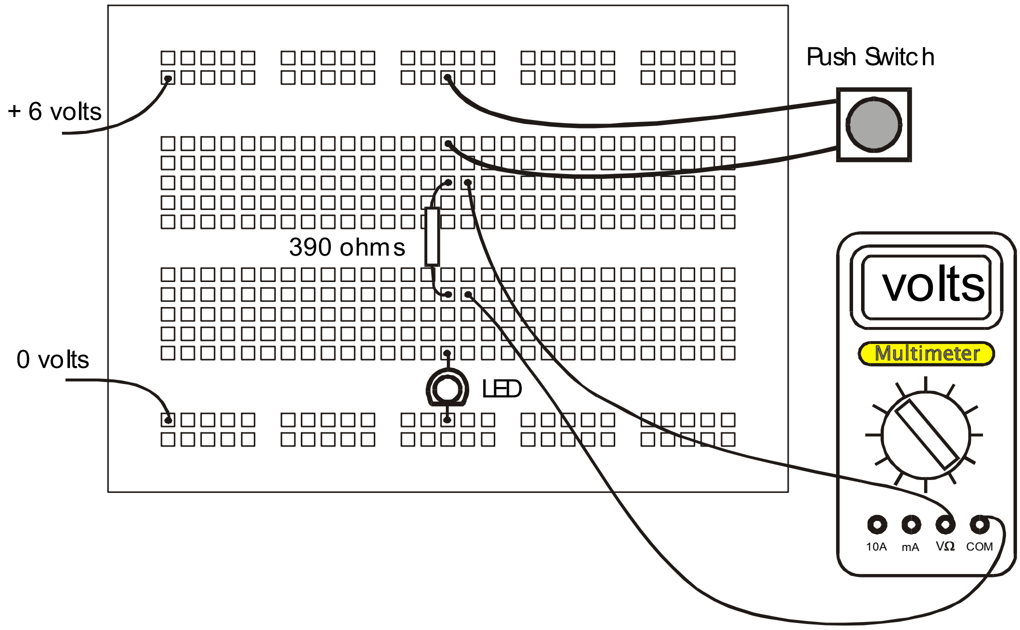
1. Using circuit simulation, measure the current flowing through all three components in the LED circuit.

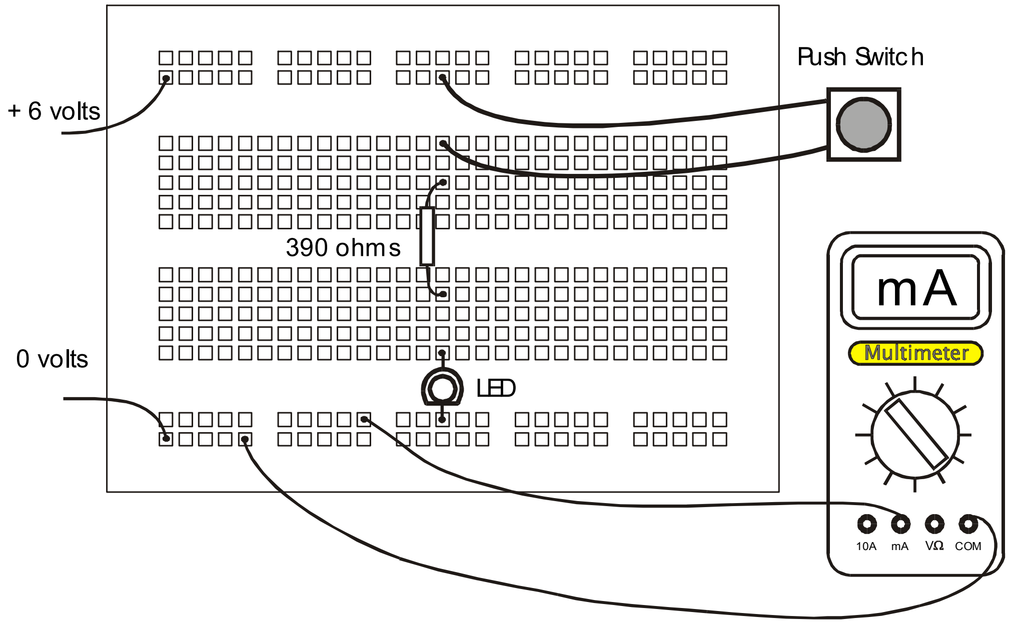


In a *series* circuit the current flowing through all components is the same. Try placing the meter at different parts of the circuit to prove this. In parallel circuits the same current does *not* always flow through each component - you will find out about this later.

Record the current flowing in this circuit.

2. Using the prototype LED circuit, measure the voltages (potential difference, p.d.) across each of the components.



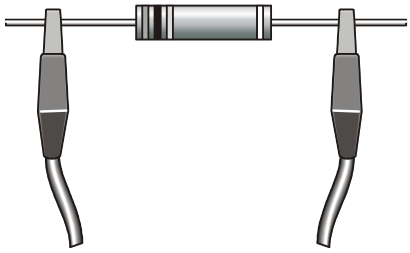


Alter the position of the zero volt connection and measure the current flowing in the circuit. Set the meter to 'mA'.

Record all results.

Measuring resistance

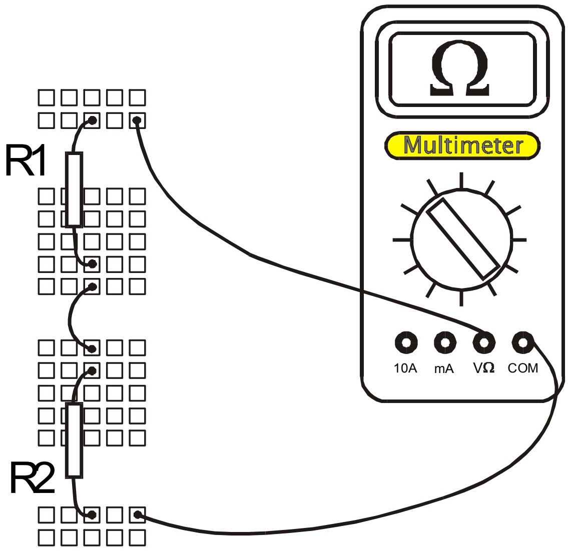
When measuring resistance make sure that your circuit is disconnected from the supply, otherwise this will affect the reading. Do not touch the meter probes or the components when measuring, as your own electrical resistance will then be included.



Resistors connected in series

As resistors come in standard sizes, they are often connected in series to obtain a specific size that is otherwise unavailable.

Practical tasks



1 Connect two resistors in series on a prototype circuit board and measure the overall resistance.

You should find that if R_{total} (or R_T) is the total resistance measured across both resistors then the equation for adding resistances in a series circuit is

$$\mathbf{R_{total} = R_1 + R_2}$$

For three resistors in series

$$\mathbf{R_{total} = R_1 + R_2 + R_3}$$

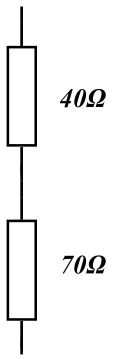
and so on.

2. Using two unknown resistors, measure the resistance of each and calculate R_{total}. Check your answer by measuring R_{total} as shown in the above diagram.

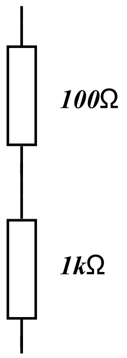
Problems

Calculate the combined resistance of the following resistors in series.

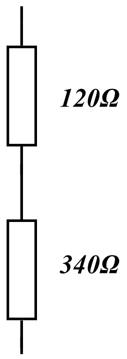
a)



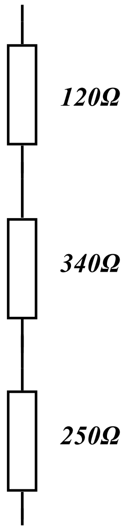
b)



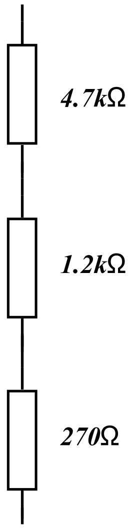
c)



d)

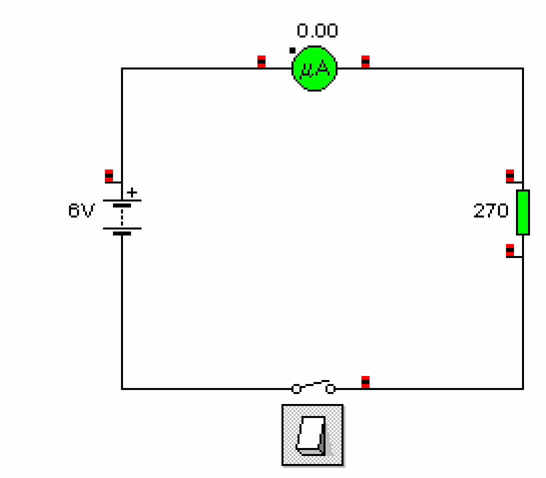


e)



Ohm's law
You have already found that applying a voltage to a circuit results in a current flowing through the circuit.

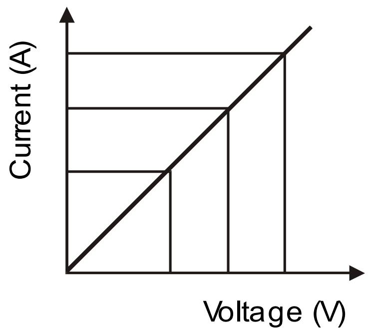
In the simple Crocodile Technology circuit below, double the voltage and you will see that the current doubles as well. In other words if you double the voltage across a component, the current flow through that component will also double.



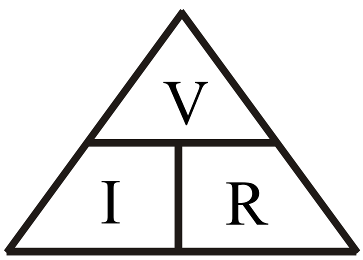
Thus we can say that the current is *proportional* to the voltage drop across a resistor. This rule is known as *Ohm's law*. The rule applies to all metals, provided that their temperature does not change.

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

This relationship gives rise to the Ohm's law formula:

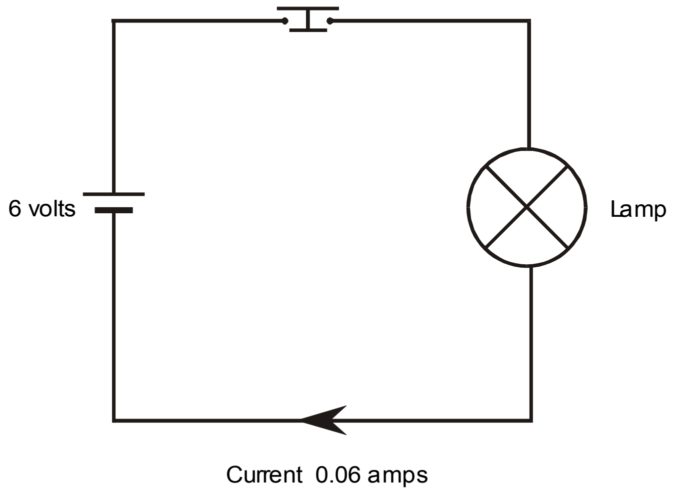


which is more easily remembered as: **V = I x R**



We can use the triangle trick to help transpose this formula. Cover up the quantity that you are trying to find and the other two will be in the form that is needed.

Ohm's law in practice



For this exercise a simple series circuit is used.

The task is to calculate the resistance of the lamp using Ohm's law.

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

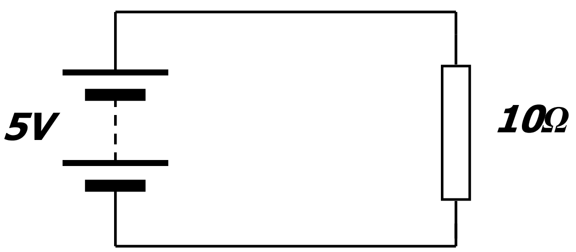
$$\mathbf{R} = \frac{\mathbf{6}}{\mathbf{0.06}}$$

$$\therefore \mathbf{R} = \mathbf{100\Omega}$$

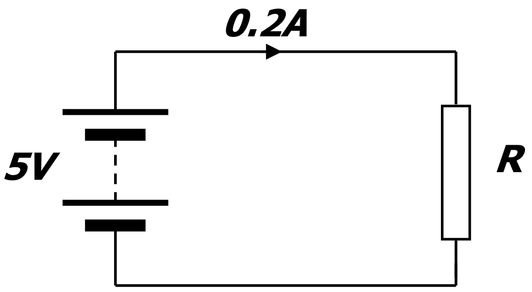
Tasks

1. Calculate the missing quantity in the following circuits. You can verify your answer by physical measurement or with Crocodile Technology.

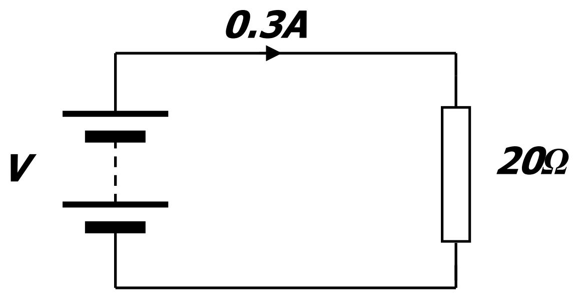
a) find the current



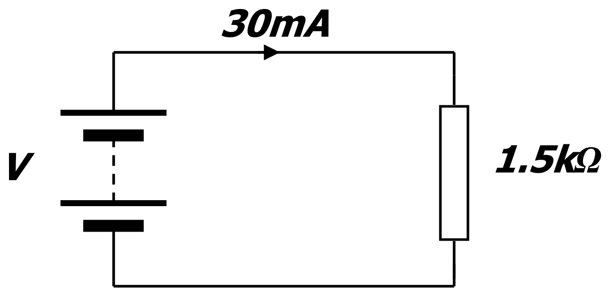
b) find the resistance of the resistor R



c) find the battery voltage

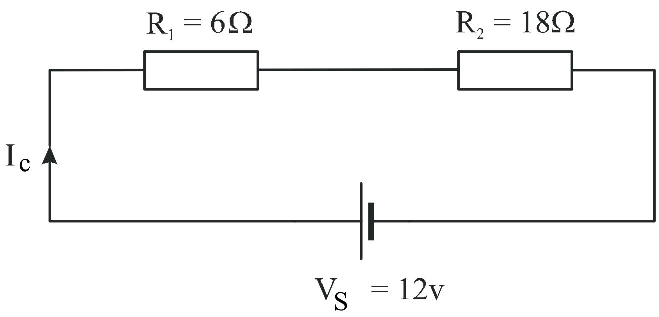


d) find the battery voltage



Worked example: series circuit

For the series circuit shown, calculate:
(a) the total resistance (R_T)
(b) the circuit current (I_C)
(c) the potential difference across both resistors (V_1 and V_2)



a)

$$R_T = R_1 + R_2$$
$$= 6 + 18$$
$$R_T = 24\Omega$$

b)

$$V_S = I_C \times R_T$$
$$I_C = \frac{V_S}{R_T}$$
$$= \frac{12}{24}$$
$$I_C = 0.5\ A$$

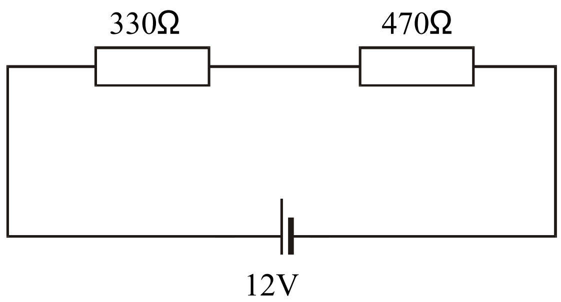
c) We can use Kirchoff's second law to check the answers calculated for the potential difference across the resistors:

$$V_2 = I_C \times R_2$$
$$= 0.5 \times 18$$
$$V_2 = 9\ V$$

$$V_T = V_1 + V_2$$
$$= 3 + 9$$
$$V_T = 12\ V$$

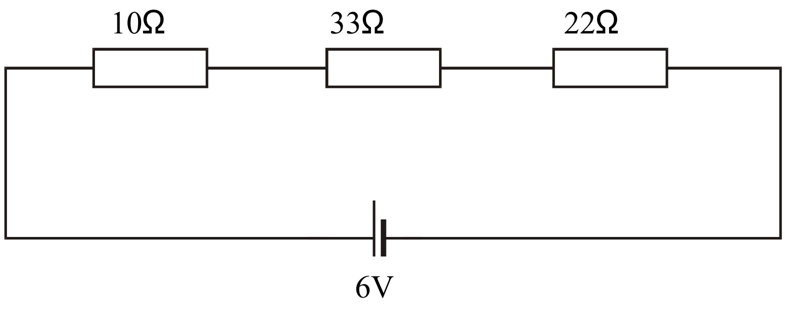
Exercises: resistors in series

1. For the circuit shown below calculate:

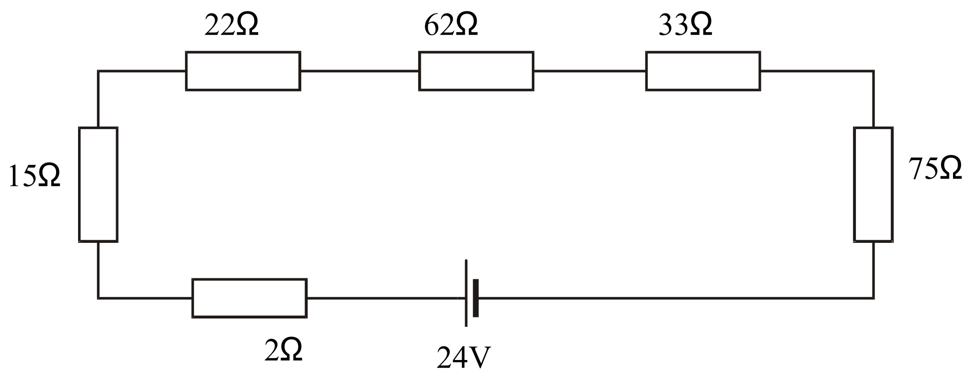


(a) the total resistance of the circuit
(b) the circuit current.
(c) the voltage drop across each resistor.

2. For the circuit shown below calculate:
   (a) the total resistance
   (b) the circuit current
   (c) the voltage drop across each resistor.
   (d) Use Kirchoff's second law to verify your answers to (c).



3. For the circuit shown below calculate:
   (a) the total resistance of the circuit
   (b) the circuit current.
   (c) he voltage drop across each resistor.
   (d) Use Kirchoff's second law to verify your answers to (c).

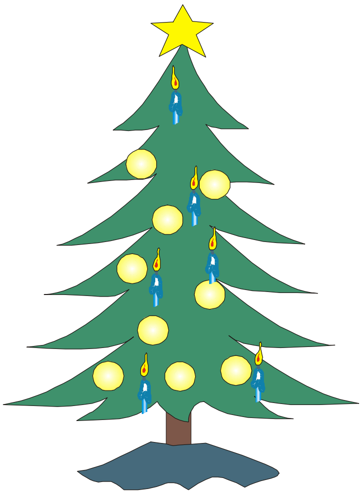


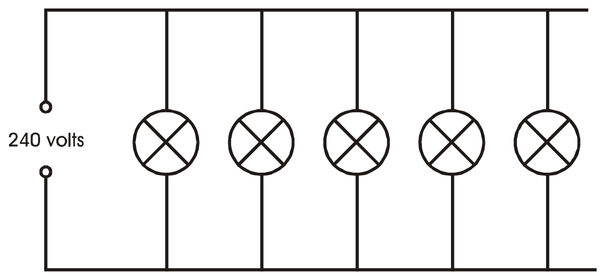
4. A circuit has three resistors in series. Their values are 15Ω, 24Ω and 60Ω. Calculate the total resistance of the circuit.

5. Two resistors are connected in series. Their values are 25Ω and 75Ω. If the voltage drop across the 25Ω resistor is 4 volts, determine the circuit current and the supply voltage.

Parallel circuits

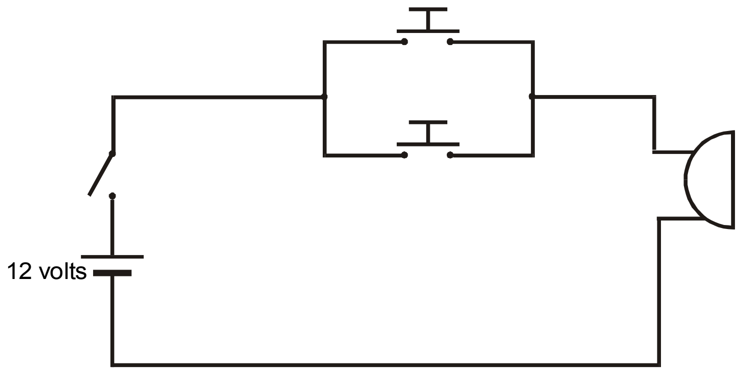
Parallel circuits are circuits where there is more than one path for electricity to flow along or that have more than one 'branch'. Each branch receives the supply voltage, which means that you can run a number of devices from one supply voltage. A good example of a simple parallel circuit is a set of Christmas-tree lights where all the bulbs require a 230 volt supply.





This arrangement ensures that if one or two bulbs 'blow' then the rest of them continue to function and, importantly, you know which are faulty. In a series circuit if one bulb blew then all the bulbs would go out and you would have to test them all to see which one was faulty.

Parallel circuits can be arranged in many ways, but are normally set out so that you can easily see the parallel 'branches'. A simple parallel car-alarm circuit is shown below with the switches wired up in parallel.



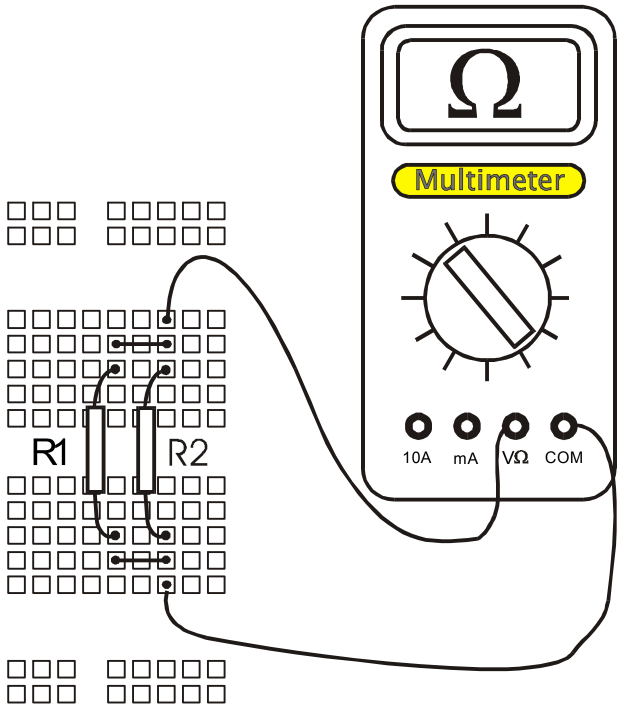
The two switches in parallel represent the sensor switches connected to the doors.

Resistors in parallel

As resistors come in standard sizes, they are often connected in parallel to obtain a specific size that is unavailable. This practice of combining resistors has already been seen in series circuits.

Practical tasks

1. Connect two resistors in parallel on a prototype circuit board and measure the overall resistance.



You should find that if R_{total} (or R_T) is the total resistance measured across both resistors then the equation for adding resistances in a parallel circuit is

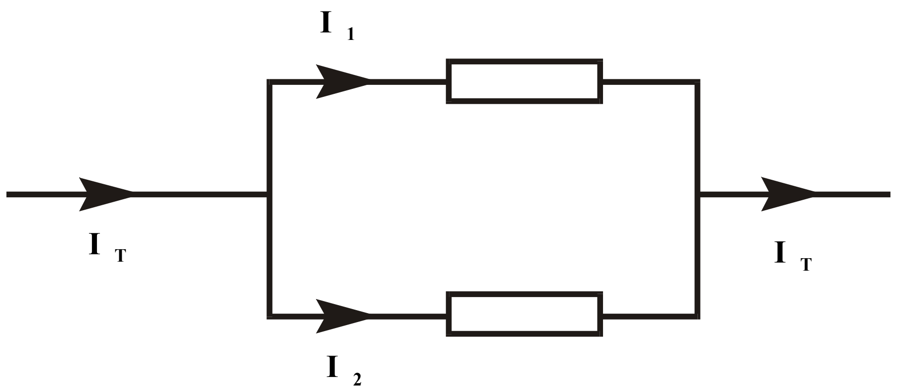
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

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

For three or more resistors, the equation can be extended:

2. Using two unknown resistors, measure the resistance of each and calculate R_{total} when the resistors are connected in parallel. Check your answer by measuring the total resistance as shown in the above diagram.

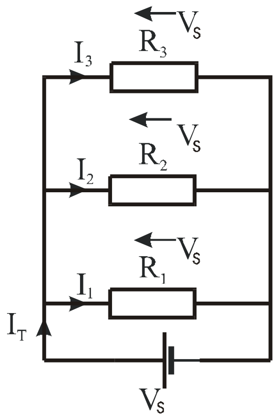
As stated earlier, each branch of a parallel circuit receives the supply voltage. Each branch has its own current; that is, when the current reaches a junction it splits up, with some current flowing into each branch. The total supply current is therefore the sum of the currents flowing in the branches.



When resistors or resistive components are connected in parallel, the effect is to reduce the resistance in the circuit.

There are two important points to remember about resistors in parallel.

(a) The voltage drop across each resistor is the same.



(c) The sum of the currents through each resistor is equal to the current flowing from the voltage source.

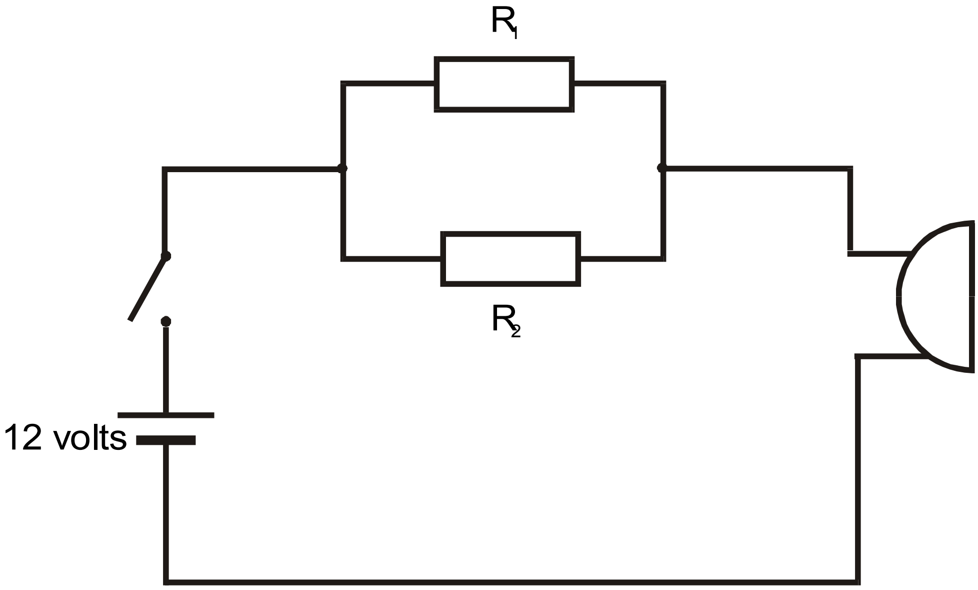
Special case: two resistors in parallel

There is a special rule that can be applied when adding *two* resistors in parallel only:

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

total resistance (R_T) = product/sum.

Worked examples: resistors in parallel



2. For the circuit below, calculate the total resistance of the parallel part of the circuit and the total resistance in the circuit.

The resistance values are R_1 = 270Ω, R_2 = 100Ω and for the buzzer 240Ω.

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

$$\frac{1}{R_T} = \frac{1}{270} + \frac{1}{100}$$

$$\frac{1}{R_T} = \frac{270 + 100}{270 \text{ x } 100}$$

$$\frac{1}{R_T} = \frac{370}{27000}$$

$$\therefore R_T = \frac{27000}{370}$$

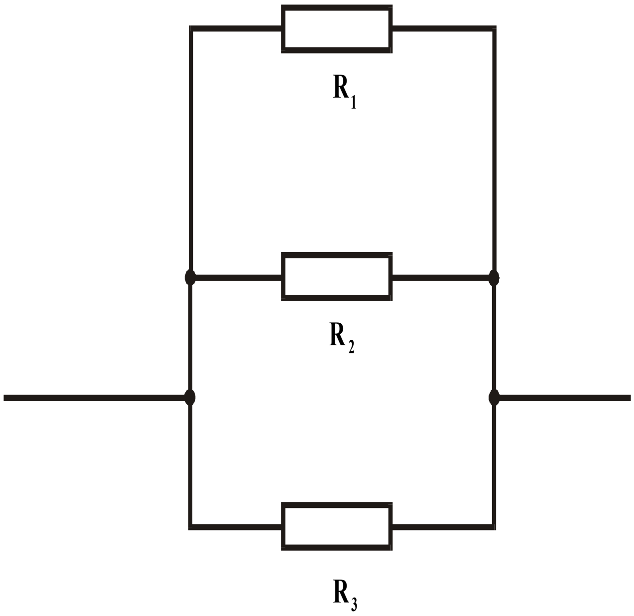
$$\therefore R_T = 73\Omega$$

$$R_T = R_1 + R_2$$

$$R_T = 73 + 240$$

$$\therefore R_T = 313\Omega$$

3. For the circuit below, calculate the total resistance of the resistors in parallel.
   The resistance values are R_1 = 220Ω, R_2 = 100Ω and R_3 = 330Ω.



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

$$\frac{1}{R_T} = \frac{1}{220} + \frac{1}{100} + \frac{1}{330}$$

$$\frac{1}{R_T} = \frac{33000 + 72600 + 22000}{7260000}$$

$$\frac{1}{R_T} = \frac{127600}{7260000}$$

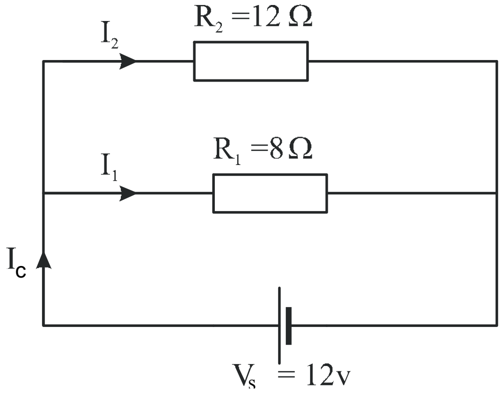
$$\therefore R_T = \frac{7260000}{127600}$$

$$\therefore R_T = 57\Omega$$

3. For the parallel circuit shown calculate:

(a) the total resistance (R_T)
(b) the circuit current (I_C)

(d) the current in each resistor (I_1 and I_2).



(a)

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

$$= \frac{8 \times 12}{8 + 12}$$

$$= \frac{96}{20}$$

$$R_T = 4.8\Omega$$

(b)

$$V_S = I_C \times R_T$$

$$I_C = \frac{V_S}{R_T}$$

$$= \frac{12}{4.8}$$

$$I_C = 2.5\ A$$

(c)

$$I_C = I_1 + I_2$$

$$= 1.5 + 1$$

$$I_C = 2.5\ A$$

(d)

$$I_1 = \frac{V_S}{R_1}$$

$$= \frac{12}{8}$$

$$I_1 = 1.5\ A$$

$$I_2 = \frac{V_S}{R_1}$$

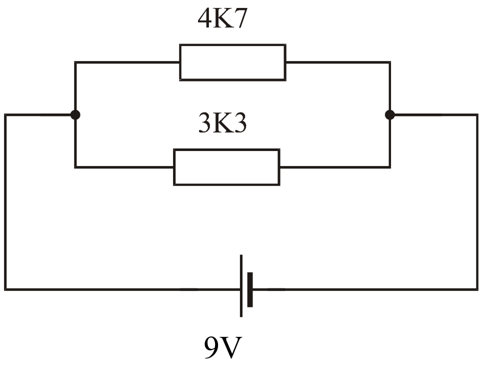
$$= \frac{12}{12}$$

$$I_2 = 1\ A$$

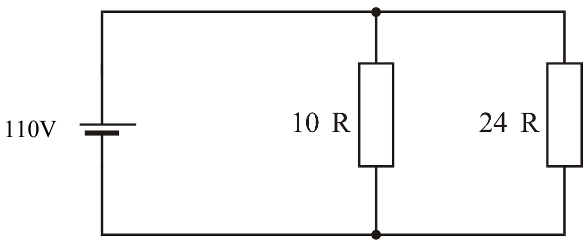
Exercises: resistors in parallel

1. For the circuit shown below calculate:
(a) the total resistance of the circuit

(b) the circuit current.

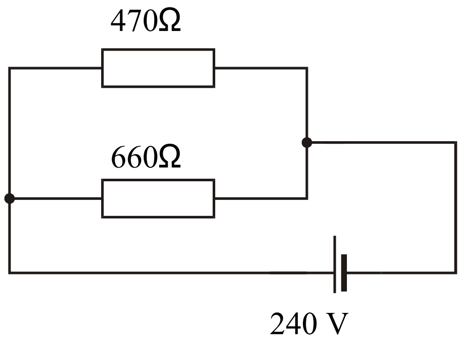


2. For the circuit shown below calculate:
(a) the total resistance of the circuit
(b) the circuit current
(c) the current flowing though R_1 (10Ω)
(d) the current flowing through R_2 (24Ω).



3. For the circuit shown below calculate:
(a) the total resistance of the circuit
(b) the circuit current
(c) the current flowing through R_1 (660 Ω)
(d) the current flowing through R_2 (470 Ω).

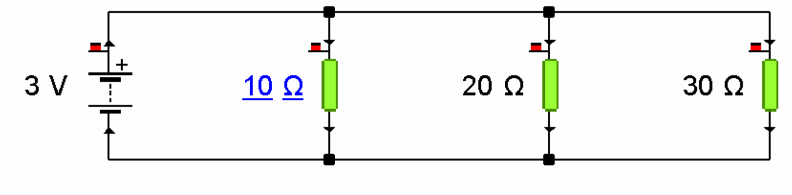
Use Kirchoff's second law to verify your answers to parts (c) and (d).



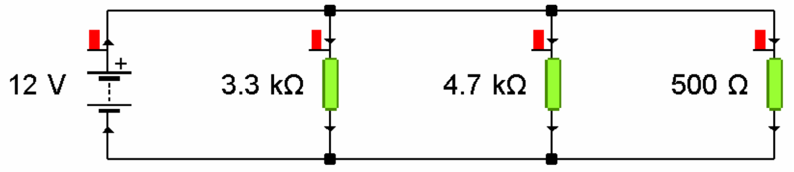
4. A 6 Ω resistor and a 75 Ω resistor are connected in parallel across a voltage supply of 12 V. Calculate the circuit current.

5. A 440Ω resistor is connected in parallel with a 330Ω resistor. The current through the 440Ω resistor is 300mA. Find the current through the 330Ω resistor.

6. For the following circuit calculate
   a) the combined resistance
   b) the current from the battery
   c) the current in each branch



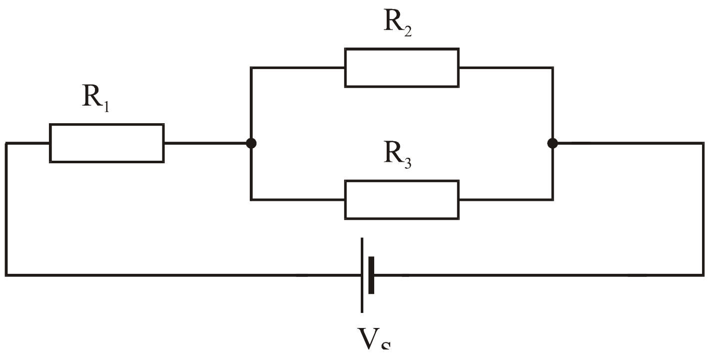
7. For the following circuit calculate
   a) the combined resistance
   b) the current from the battery
   c) the current in each branch



Combined series and parallel circuits

Until now we have been looking at series or parallel circuits individually. It is possible, and quite common, to have series and parallel connections in the same circuit.

Consider the combined series and parallel circuit shown in the figure below.



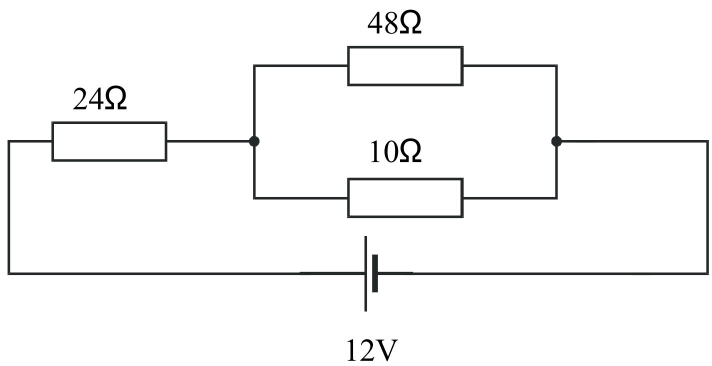
You can see that R_2 and R_3 are connected in parallel and that R_1 is connected in series with the parallel combination.

Some points to remember when you are dealing with combined series and parallel circuits are:

- the voltage drop across R_2 is the same as the voltage drop across R_3
- the current through R_2 added to the current through R_3 is the same as the current through R_1
- the voltage drop across R_1 added to the voltage drop across R_2 (which is the same as across R_3) would equal the supply voltage V_s.

Worked example: combined series and parallel circuits

1. For the combined series and parallel circuit shown, calculate:
   (a) the total circuit resistance (R_T)
   (b) the circuit current (I_C)
   (c) the voltage drop across resistor R_1 (V_{R1})
   (d) the current through resistor R_2 (I_2).



(a) In the first instance you must calculate the equivalent resistance of the parallel arrangement (R_P) of R_2 and R_3. It is possible to use the special case formula for two resistors in parallel:

$$R_P = \frac{R_2 \times R_3}{R_2 + R_3}$$

$$R_P = \frac{10 \times 48}{10 + 48}$$

$$R_P = \frac{480}{58}$$

$$R_P = 8.28\Omega$$

The total circuit resistance (R_T) is then found by adding R_P to R_1:

$$R_T = R_1 + R_P$$

$$R_T = 24 + 8.28$$

$$R_T = 32.28\Omega$$

(b) It is now possible to calculate the circuit current:

$$V_S = I_C \times R_T$$

$$I_C = \frac{V_S}{R_T}$$

$$I_C = \frac{12}{32.28}$$

$$I_C = 0.37A$$

(c) The voltage drop across R_1 is found by using the resistance across and the current through R_1.

$$V = I \times R$$

$$V_{R1} = I_C \times R_1$$

$$V_{R1} = 0.37 \times 24$$

$$V_{R1} = 8.88V$$

(d) The current through R_2 is found by using the resistance of R_2 and the voltage drop across R_2. By using Kirchoff's second law we know that the voltage drop across the parallel arrangement must be:

$$V_S = V_{R1} + V_P$$

$$V_P = V_S - V_{R1}$$

$$V_P = 12 - 8.88$$

$$V_P = 3.12V$$

By using Kirchoff's first law we know that the circuit current I_C will 'split' or divide between the two resistors R_2 and R_3. In order to find the current through R_2 we use:

$$V = I \times R$$

$$V_P = I_2 \times R_2$$

$$I_2 = \frac{V_P}{R_2}$$

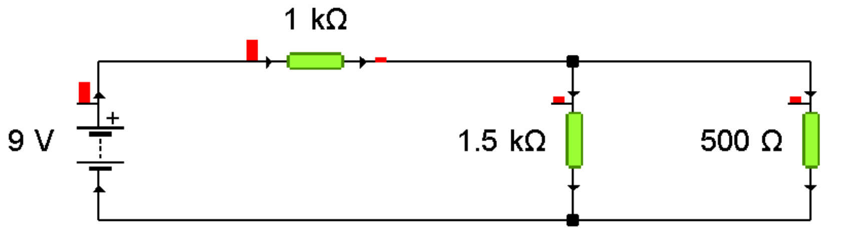
$$I_2 = \frac{3.12}{10}$$

$$I_2 = 0.312\text{A}$$

Exercises Combined Series and Parallel Resistors

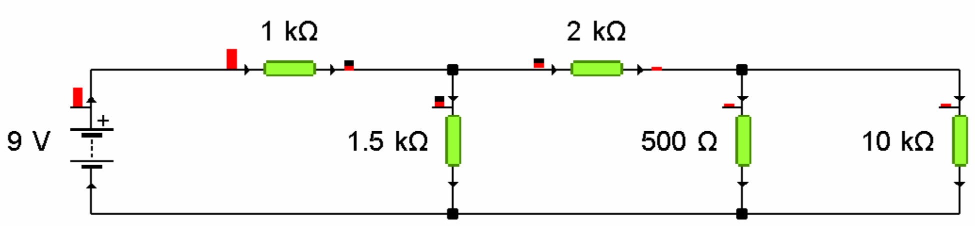
1. For the following circuit calculate

a) the combined resistance
b) Current from the battery
c) Voltage across the 1KΩ resistor
d) The current through the 500Ω resistor.

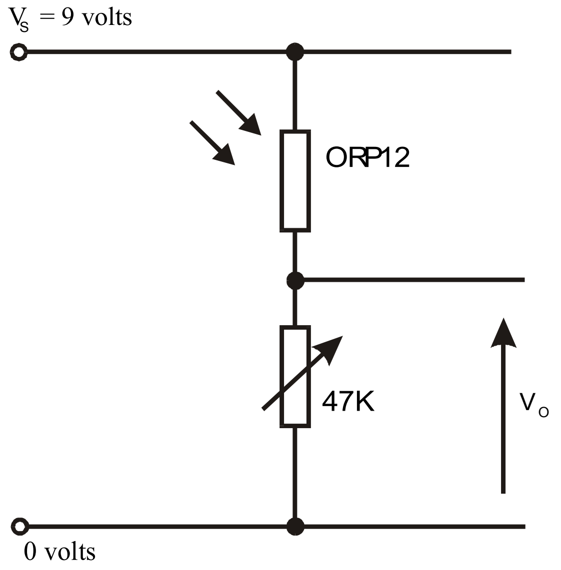


2. For the following circuit calculate

a) the combined resistance
b) Current from the battery
c) Voltage across the 10kΩ resistor
d) The current through the 500Ω resistor.



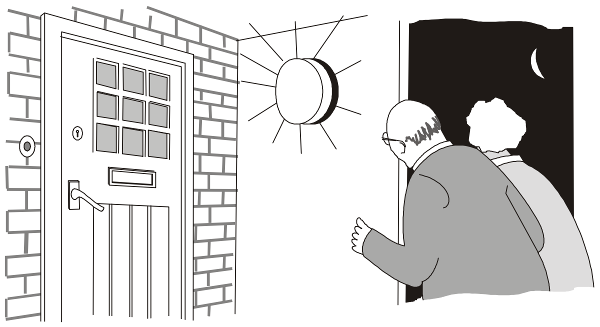
Sensitivity



With an analogue sensor it is normally desirable to adjust the sensitivity of the circuit. Rather than using a fixed resistor we can replace it with a *variable resistor* (or potentiometer).

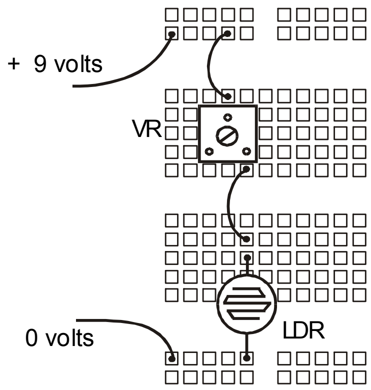
Practical task: voltage divider circuits

The picture below shows a typical situation where a light sensor circuit could be useful.



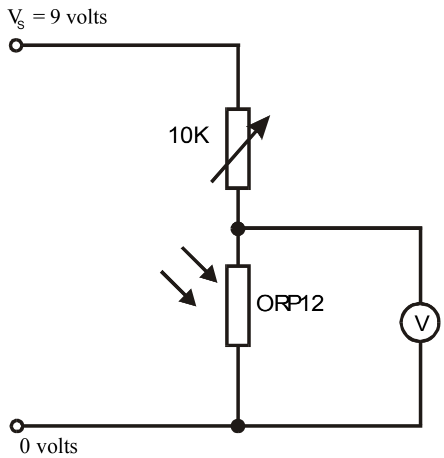
To save money and inconvenience the residents want the outside light to come on when it gets dark. They also want to be able to adjust the sensitivity from summer to winter nights.

Build the following circuit using a prototype circuit board. The variable resistor is rated at 10 kΩ.



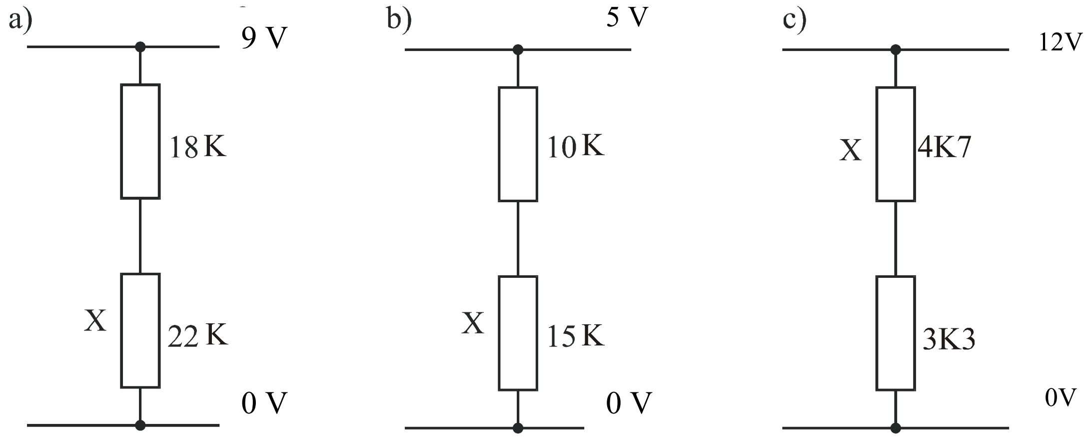
Adjust the sensitivity so that the output voltage (V_o) goes higher when your hand is moved across the LDR at a distance of approximately 100 mm. You will have to attach a multimeter to the circuit to see *when* this is happening.

Check this out using *Crocodile Technology*.

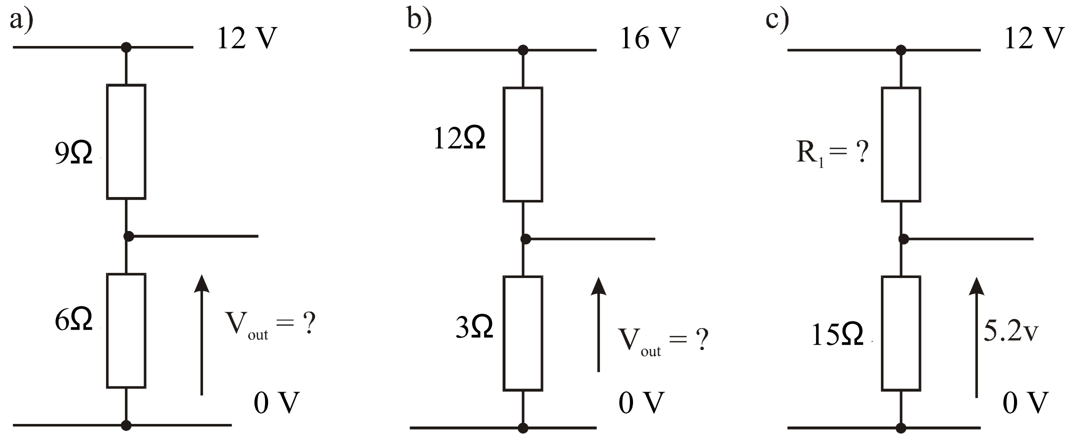


Exercises: voltage divider circuits

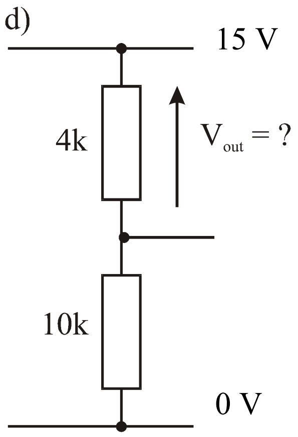
1. Calculate the voltages that would appear across each of the resistors marked 'X' in the circuits below.

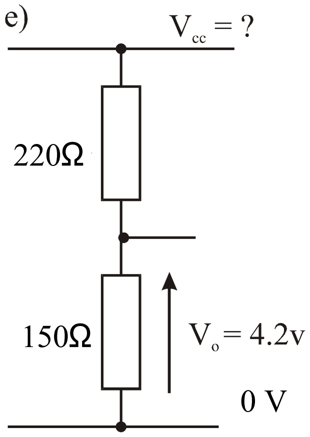


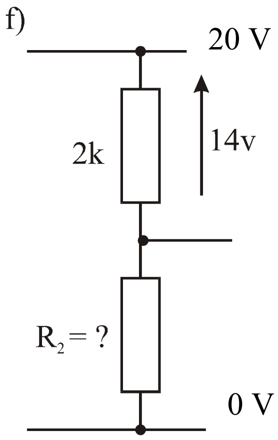
2. Find the output voltage from the voltage divider circuits below.



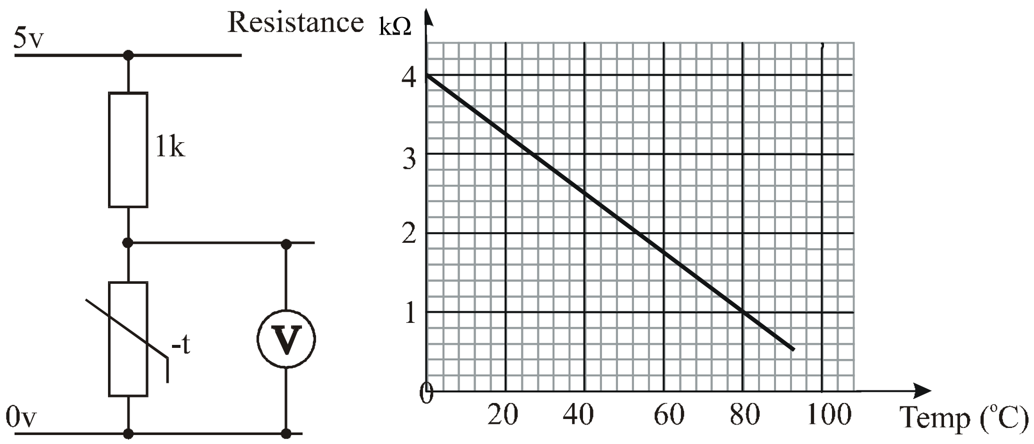
3. In each of the following voltage divider circuits determine the unknown quantity.







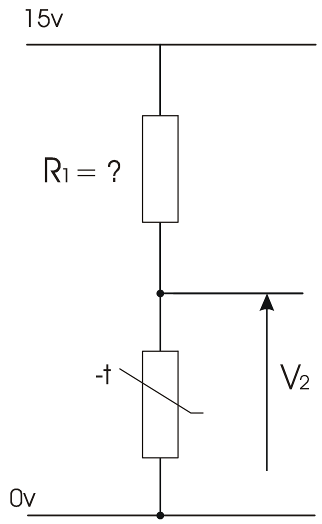
4. An NTC (negative temperature coefficient) thermistor is used in a voltage divider circuit as shown below. Using information from the graph shown, determine the resistance of the thermistor and hence calculate the voltage that would appear across it when it is at a temperature of:
   (a) 80°C
   (b) 20°C.



4. What would happen to the voltage across the thermistor in the circuit shown above as the temperature increased?

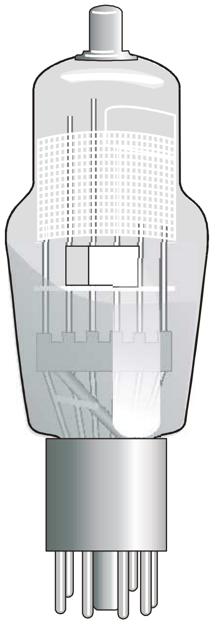
5. What would happen to the voltage across the resistor in the circuit shown above as the temperature increased?

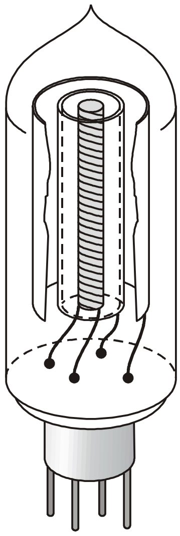
6. A thermistor (type 5) is used in a voltage divider circuit as shown below. The characteristics of the thermistor are shown in the Databook. If the voltage V_2 is to be 4.5 V at 100 °C, determine a suitable value for R_1. State whether V_2 will increase or decrease as the temperature drops. Explain your answer.



Transistors

The first major breakthrough in electronics came with the invention of the diode valve at the beginning of the twentieth century. This was the first real electronic component and was to lead to the modern diode and transistor.

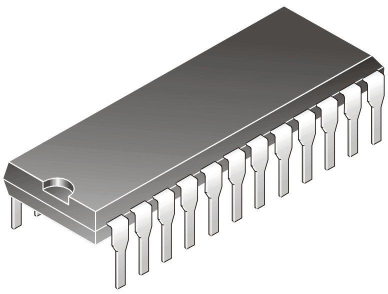


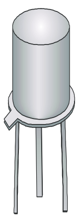


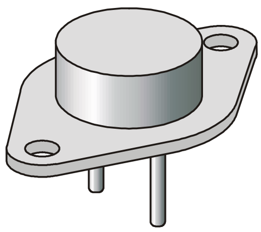
A diode valve consisted of a heater inside a hollow rod that had been coated with a substance which released electrons when heated. This was surrounded by a thin metal cylinder, with all of this being contained in a bulb-like glass container. When the rod was heated, electrons were released but, as in any diode, the electrons could only go in one direction.

The diode was followed by the triode, which allowed the current flow to be controlled. These valves could act as electronic switches or amplifiers. Radio and television were developed using these amplifier valves. In the 1940s the first computer was built using valves - it contained over 20,000 valves and filled a large room.

In 1947 the transistor was invented. The transistor had many advantages over valves, the main ones being size, efficiency, durability and cost. The next big advance in electronics was the integrated circuit in 1958: two transistors were fitted on a silicon chip. The developments since then have been rapid and chips now contain over a million transistors.



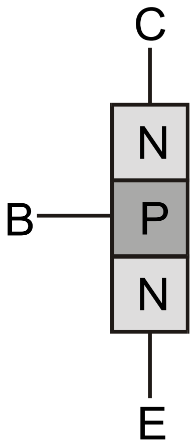




Transistors (bipolar)

The transistor is a semiconductor device. This means that it is sometimes a good conductor of electricity and sometimes a poor one. A transistor is made up of three layers of semiconductor materials that are either 'n type' or 'p type'.

There are two types of bipolar transistor available: pnp or npn. We will deal only with the npn type for convenience. (The only real difference is that the voltages and currents should be reversed for a pnp transistor.)

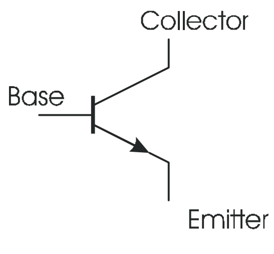


When a positive voltage of about 0.6 volts is applied across the base and emitter, the resistance between the collector and the emitter of the transistor drops from very high to very low. In other words the transistor changes from being a very poor to a very good conductor.

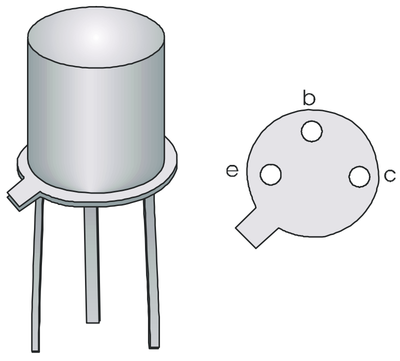
This means that to *switch* the transistor 'on' a small voltage of about 0.6 volts is applied to the base. When the voltage reaches 0.7 volts the transistor is fully 'switched on'. In this condition the transistor is said to be fully 'saturated'.

General-purpose transistor

The BC 108 is common general-purpose transistor. The diagram below shows the position of the legs when viewed from underneath the case.

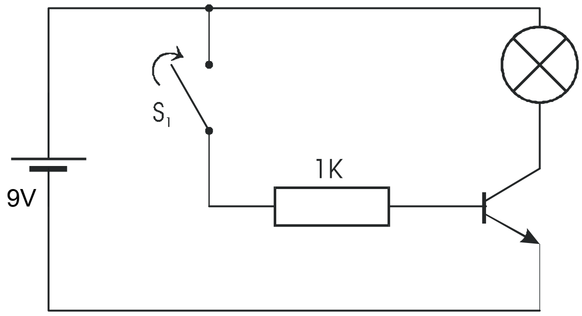


npn Type



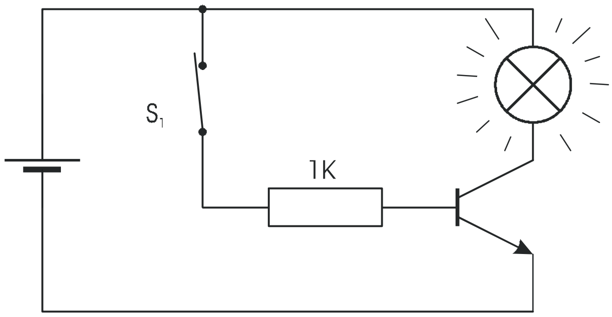
The transistor has to be connected into circuits correctly. The arrowhead on the emitter indicates the direction of 'conventional' current flow - that is, opposite to the electron flow.

How does the transistor work?

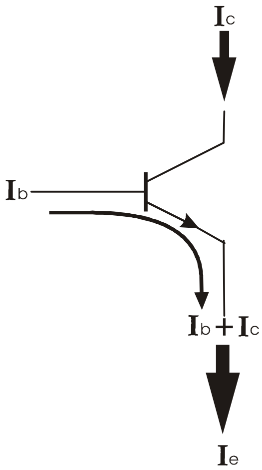


Consider the circuit shown below.

When the switch S_1 is open, no current can flow in any part of the circuit. This may seem strange since a 'complete' circuit appears to be made from the voltage source, through the bulb, the transistor and back to the voltage source. But, as no voltage is being applied to the base of the transistor, it is acting as a barrier to electric current.



When switch S_1 is closed, a very small voltage is applied to the base of the transistor. When this happens the transistor allows current to flow through it and the bulb will light; the transistor is said to 'switch on'.



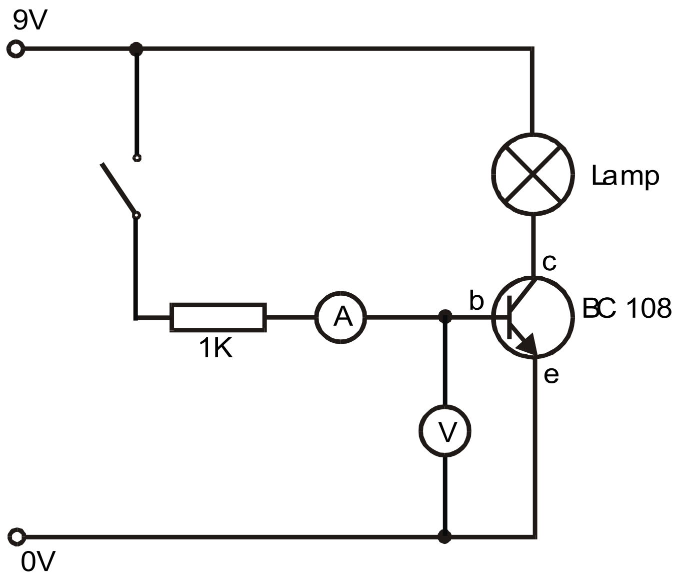
Bipolar transistors amplify current. A small current flowing through the base of a transistor causes a much larger current to flow from the collector to the emitter.

The transistor as a switch

One of the main uses of a transistor is that of a very sensitive switch.

Assignment

Use *Crocodile Technology* or another circuit simulation package to set up the circuit below. Begin with a value of 2200 K for the base resistor R and then reduce the resistance using the values given in the table below. This can be carried out manually if a suitable package is unavailable.



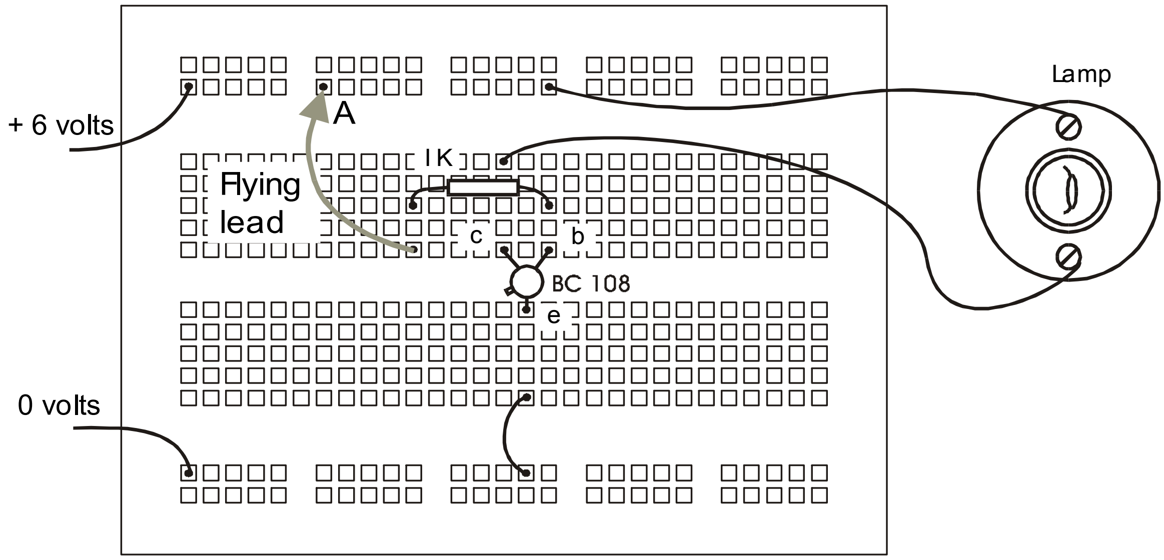
Complete the following table during your investigation.

Base resistor value (K)	Base/Emitter Voltage (mV)	Base current (μA)	Lamp on/off
2200			
1000			
470			
220			
100			
47			
33			
22			
10			
1			

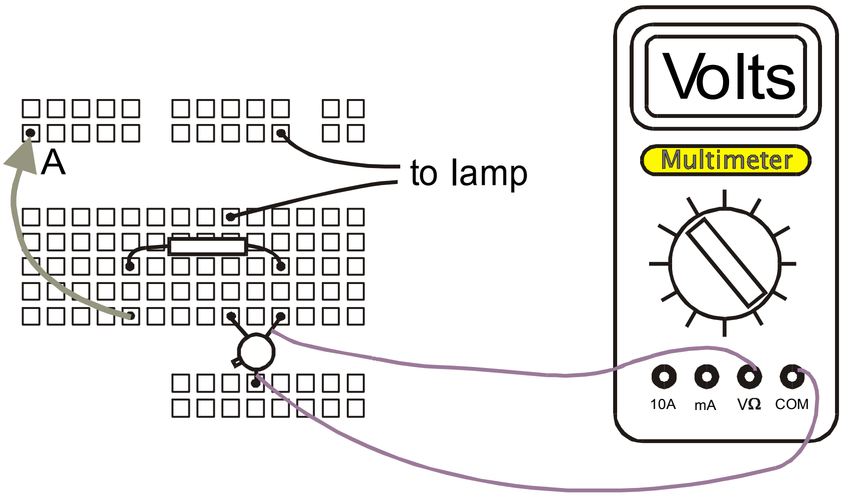
You should find that the circuit will 'switch on' the lamp when the base/emitter voltage drop of the transistor is 0.7 volts. You will also have noted that as the base/emitter voltage drop rises above 0.7 V the brightness of the lamp does not increase. This is because once this level has been reached, the transistor is fully 'switched on', or *saturated*.

Practical tasks

1. Build the circuit below to demonstrate the operation of a transistor switch.



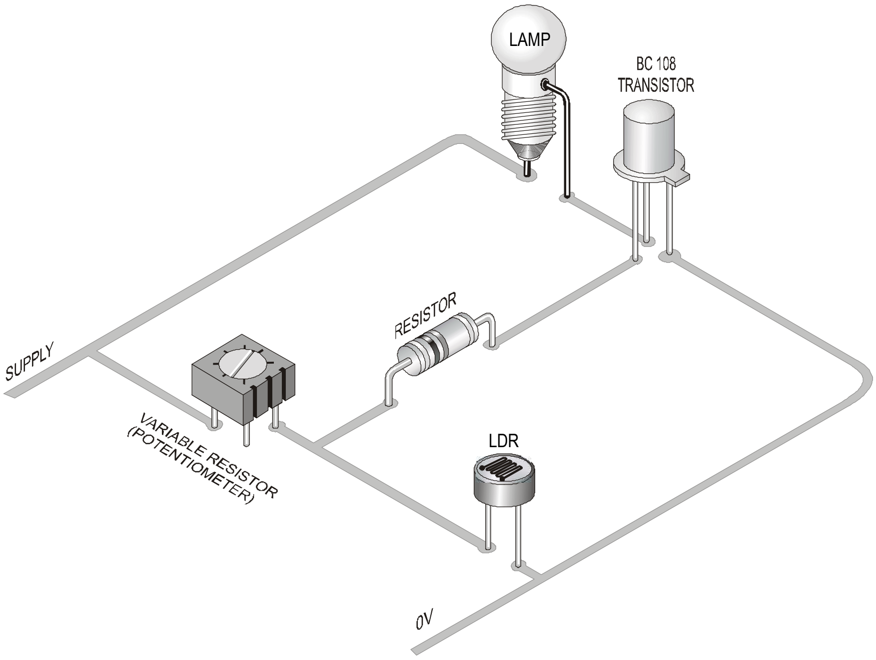
When the flying lead (a wire connected at one end only) is connected to hole 'A' the transistor should switch and the lamp should light.



Connect a multimeter (set at voltage) across the base and emitter of the transistor.

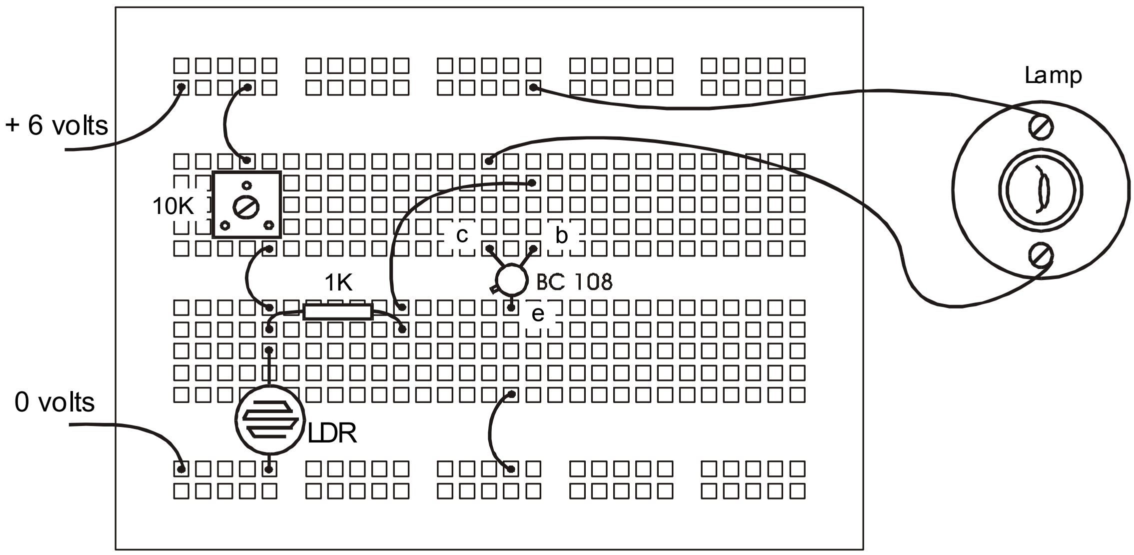
The multimeter should measure approximately 0.7 volts. As explained earlier, this will switch the transistor 'on' and the lamp should light.

If this reading is incorrect or the lamp does not light when the flying lead is connected to hole A, check all the connections and fix any faults until the circuit works as expected.



To make the circuit even more sensitive, a voltage divider with an LDR and variable resistor can be used. This will enable small changes in the LDR resistance to switch the transistor.

3. Build the transistor switching circuit below.

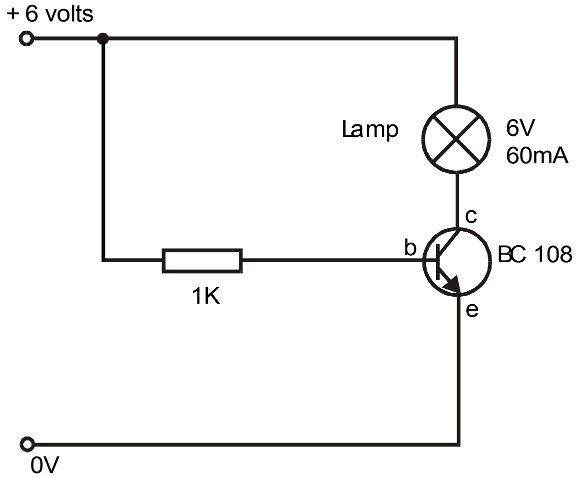


Instructions

- Place all components as shown in diagram.
- Insert all connection wires.
- Make the 0 volt connection.
- Make the +6 volt connection.
- Set the variable resistor to mid-value.
- Cover the LDR and observe what happens.

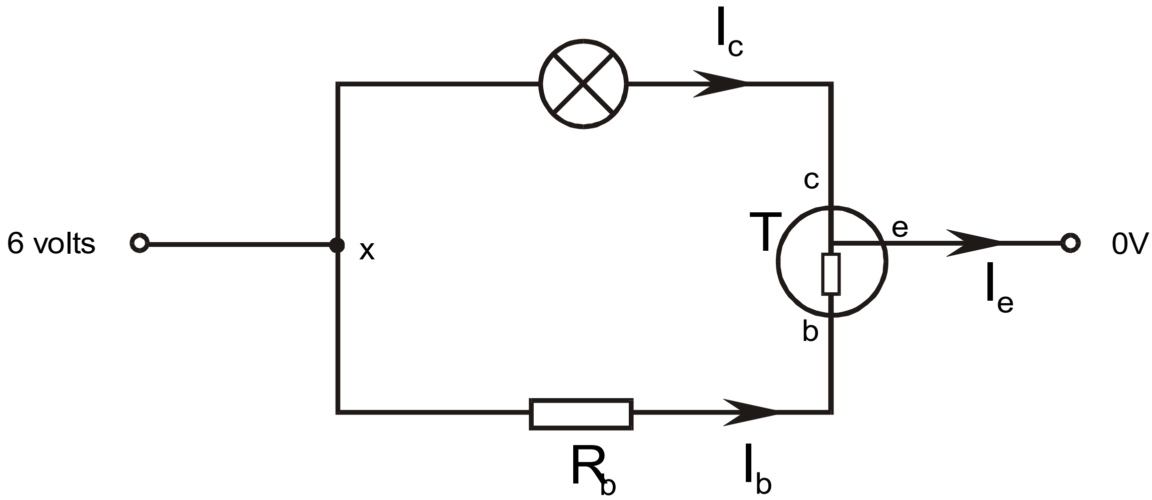
Transistor circuits calculations

Ohm's law, Kirchoff's second law, series circuit and parallel circuit calculations are just as important and appropriate in transistor circuits as they were in the previous ones.



Example circuit

The transistor circuit above is basically a parallel circuit. If the circuit is rearranged slightly this becomes obvious.



The transistor (marked T) is at the junction of the parallel circuit. If we assume that no voltage drops across the collector/emitter in the transistor then

$$V_{xe} = 6 \text{ volts (in the bulb branch)}$$

As the two branches between x and e are in parallel, V_{xe} across the resistor branch must also be 6 volts. Thus

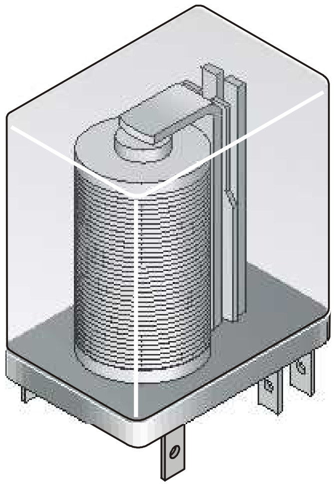
$$V_{Rb} + V_{be} = 6 \text{ volts}$$

We know that V_{be} must be 0.7 volts to switch the transistor on; therefore

$$V_{Rb} = 5.3 \text{ volts}$$

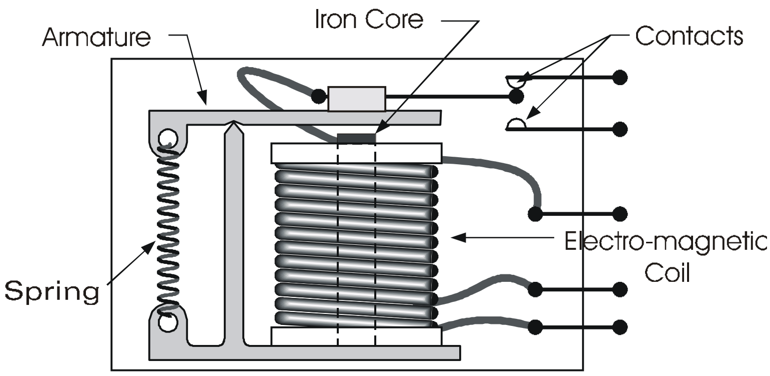
It is now possible to calculate all other currents and resistance values.

Relays



Although relays are often considered to be output devices, they are really output switches from electric or electronic circuits. These output switches are used as inputs for other circuits. In practice you can hear relays clicking on and off when a car's indicators are used.

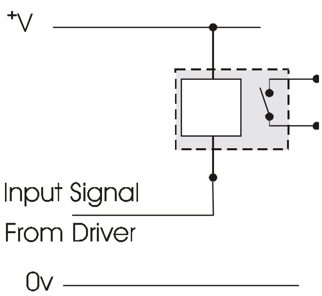
How the relay works

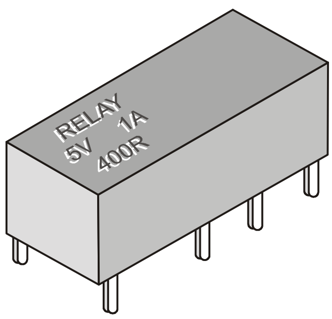


RELAY

When an electric current flows into the relay coil, the coil becomes an electromagnet. This electromagnet attracts the armature and moves the contacts. This movement provides the switching, just as the contacts in any other switch do.

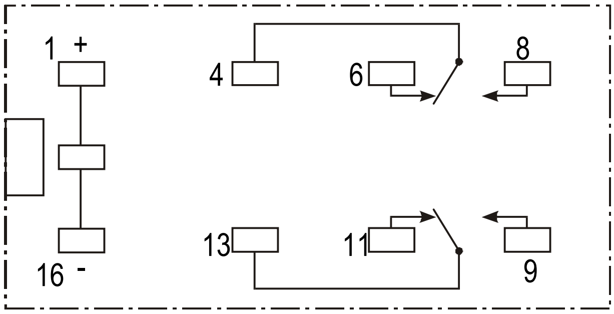
The relay is a very useful device because it is the vital link between microelectronics and high-energy systems that require substantial amounts of current. The relay is perhaps the most commonly used switch for driving devices that demand large currents.





Relays - connections

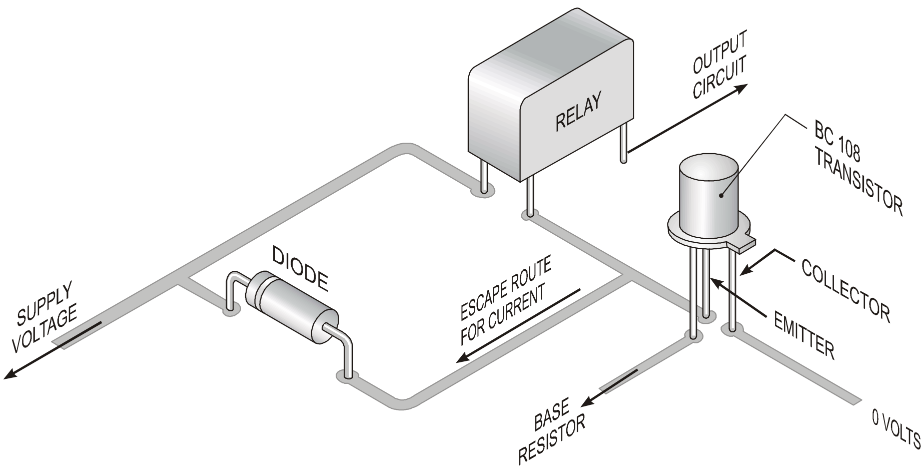
The connections for a typical miniature relay are shown below.



- Connections 1 and 16 are those from the sensing or input circuit.
- Connections 4 and 13 are the supply voltage to run the output.
- Connections 6 and 11 are the *normally closed* output terminals.
- Connections 8 and 9 are the *normally open* output terminals.

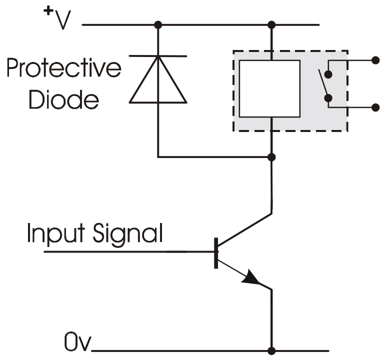
Relays - protective diodes

As seen earlier, relays have a coil that is energised and de-energised as the relay switches on and off. During this process of switching, the coil can generate a large reverse voltage (called a back e.m.f.). This reverse voltage can cause considerable damage to components, especially transistors.

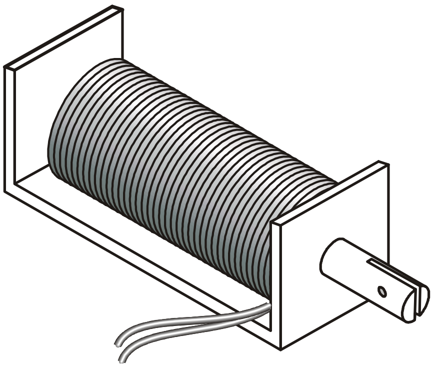


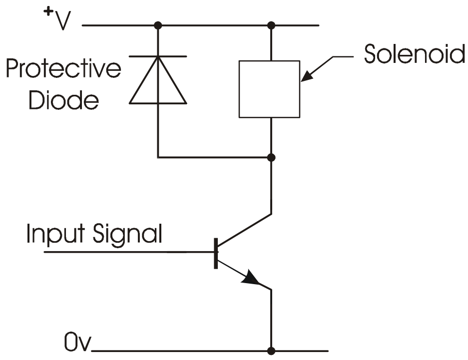
The transistors and other sensitive components can be protected by the inclusion of a diode that provides a path for the current caused by the reverse voltage to escape.

The circuit diagram is shown below.



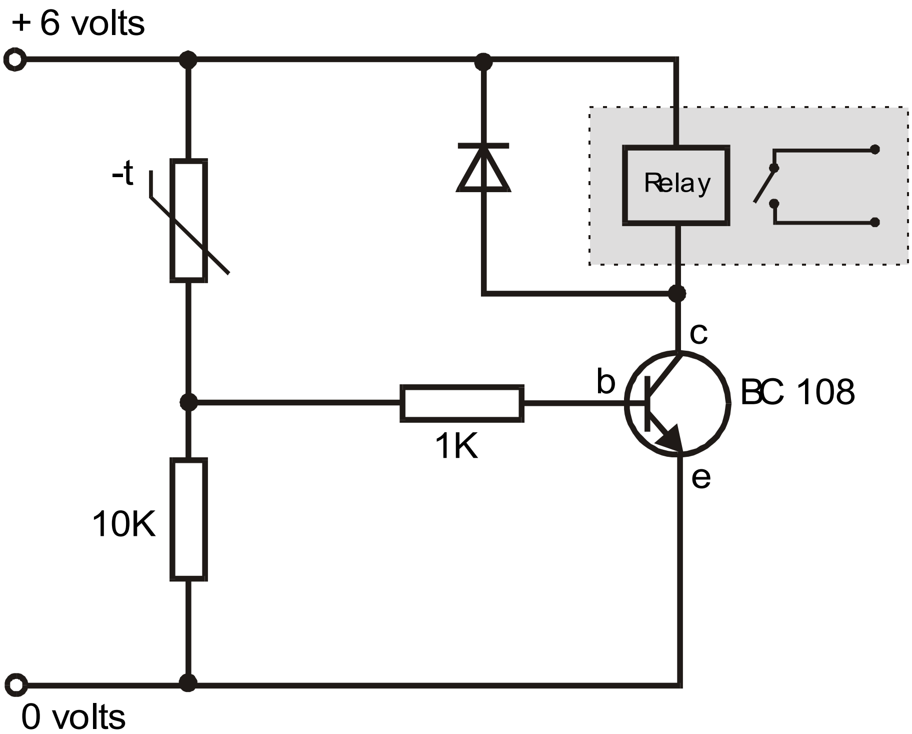
A solenoid is another output transducer that has a coil inside. Circuits containing a solenoid require a protective diode as well.





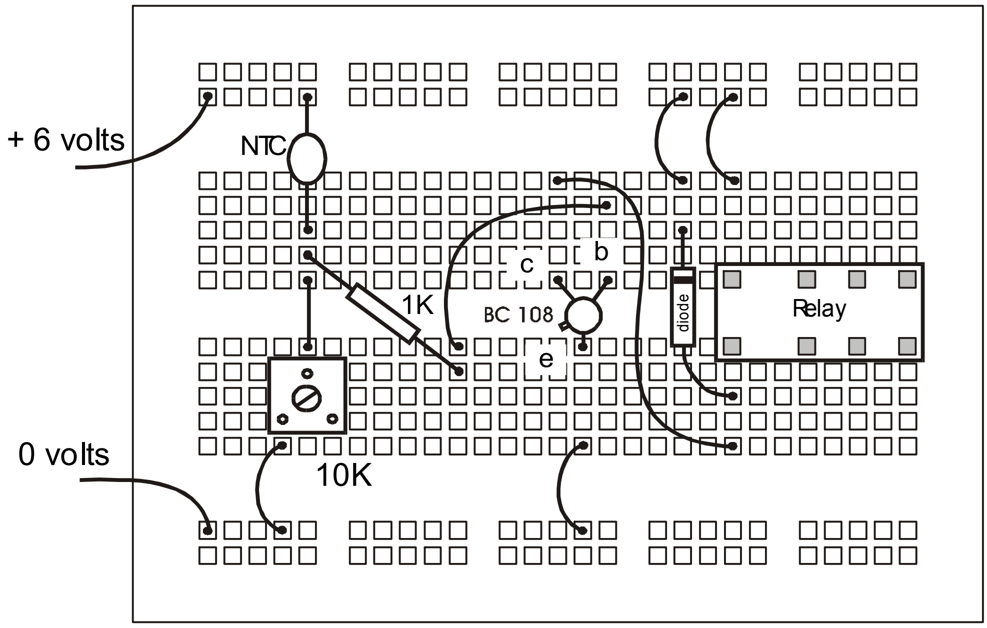
Relay circuit

The circuit below shows a typical transistor circuit with a relay as an output.



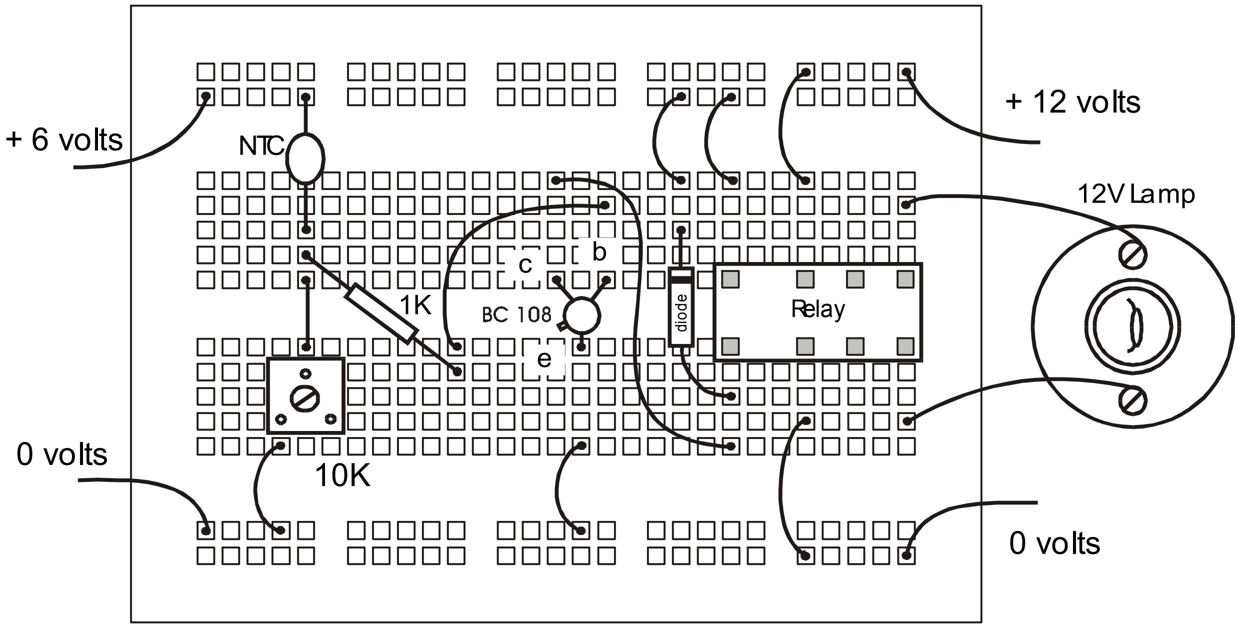
Practical tasks

1. Build the relay circuit below. When the temperature of the thermistor is increased you should hear the relay switching and then switching once more as the temperature decreases again. Note the diode, which is used to protect the transistor (see later for more information).

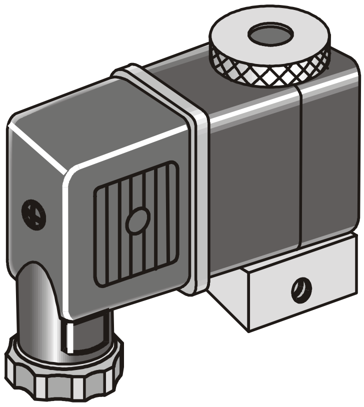


2. This task requires you to connect a 12 volt lamp to the normally open output of the relay so that when the temperature of the thermistor rises the light will switch on.

Note the 12 volt supply for the bulb. Do not mix up the supplies or the 0 volt lines.

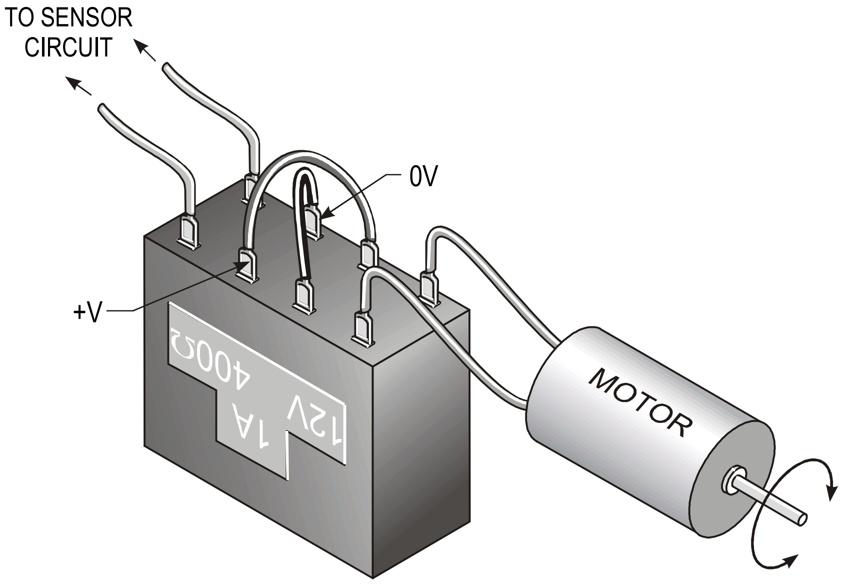


Alter the circuit so that the lamp comes on when it gets dark. Draw the circuit diagram before you alter the prototype circuit above.

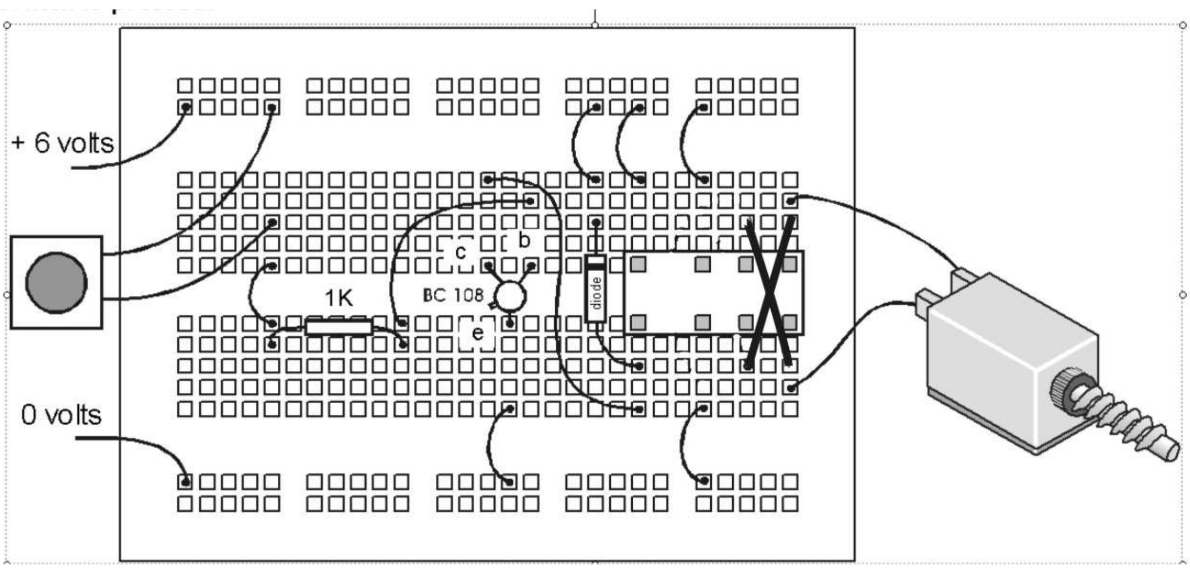


Relays can also be used to switch on (and off) solenoid-actuated pneumatics valves. These normally run on a 12 volt supply. This is a method of controlling pneumatic circuits and systems with microelectronics.

3. As electric motors normally draw larger currents, relays are ideal devices for such circuits. By using DTDP switching, relays can control the direction of rotation of motors.

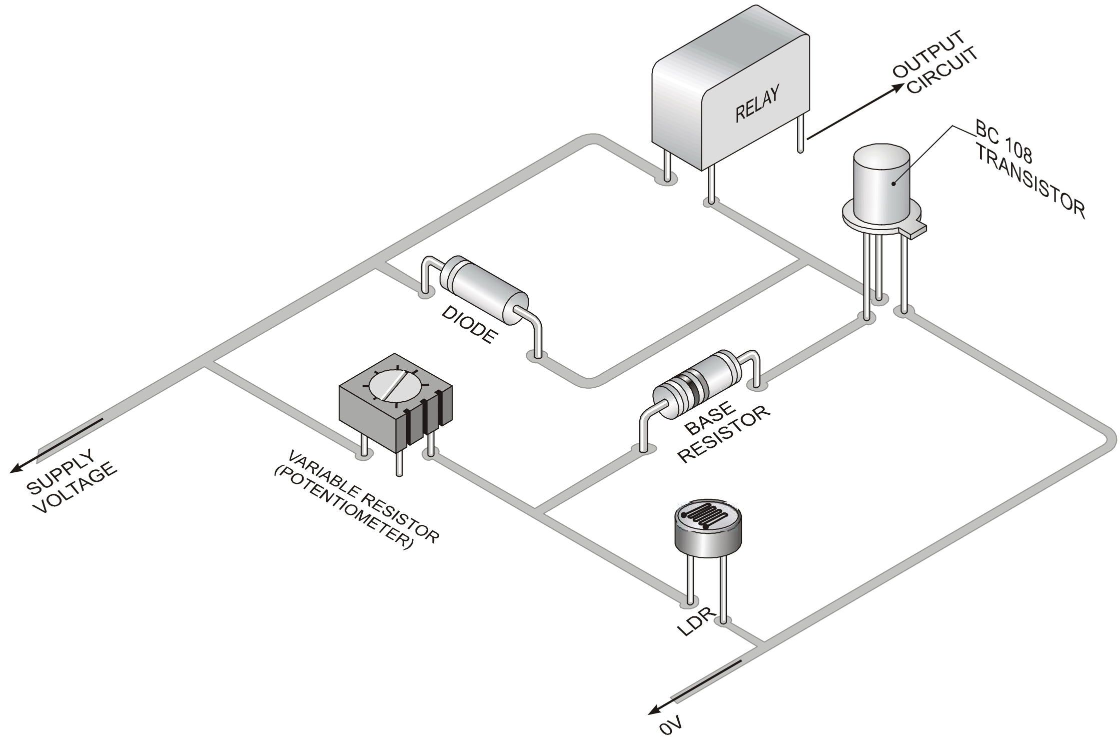


The circuit below shows a motor control circuit. The motor will reverse direction when the input switch is pressed.



Change the circuit so that a change in temperature will automatically change the direction of the motor. Draw the circuit diagram before making any alterations.

4. The partial circuit below shows a transistor switch circuit with a relay as an output and an LDR voltage divider circuit as an input.



Build and test a complete circuit showing the relay connected to a motor.

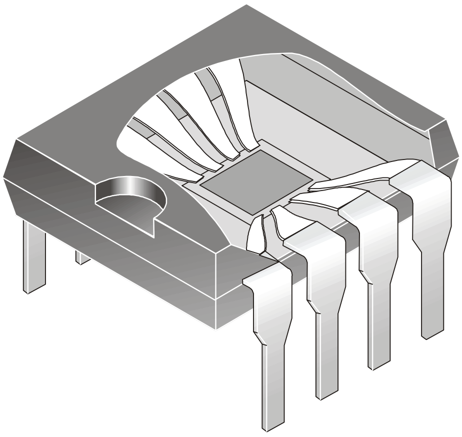
Instructions

Draw a full circuit diagram.
Investigate from earlier work the value of the potentiometer.
Make a layout diagram for building the circuit on a prototype circuit board.
After checking, build and test your circuit.

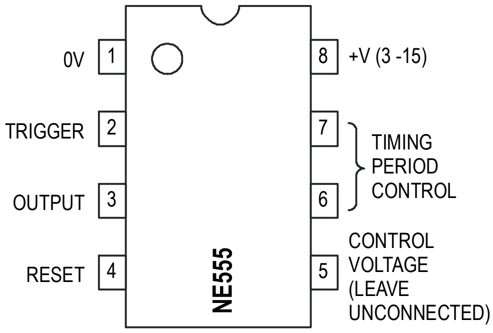
Note: Alternatively, this circuit could be built and tested using circuit simulation software such as *Crocodile Technology*.

Integrated Circuits: 555 timer

An integrated circuit (or IC) is simply an electronic package that contains a number of components on a silicon 'chip'. The 555-timer IC that you are going to use is a very versatile chip that has many applications.

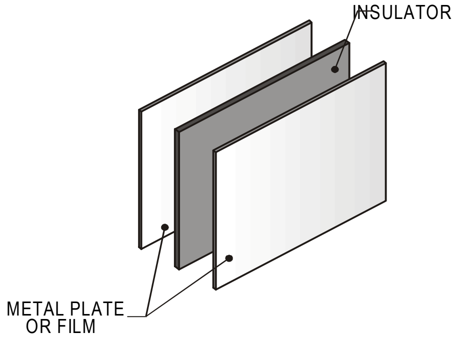


As you can see, the 555 chip has eight pins. The pin functions are shown below.



555 timer - capacitors

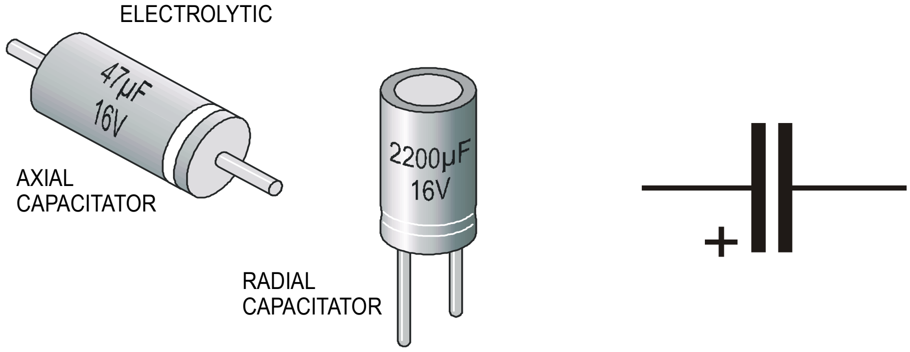
Capacitors are electronic components that store electricity for short periods of time within electronic circuits or networks. They are made from two metal plates or films separated by an insulator. In many capacitors, film is used so that the layers of metal film and insulator can be wound into a cylinder. Capacitors are especially useful in timer circuits with the 555-timer chip.



There are two basic types of capacitor normally used in timer circuits: electrolytic and polyester.

Electrolytic capacitors are polarity conscious. This means that they must be connected 'the right way round'. The negative lead must be connected to zero volts with the positive terminal towards the higher voltage side of the circuit.

It is very dangerous to reverse connect capacitors.



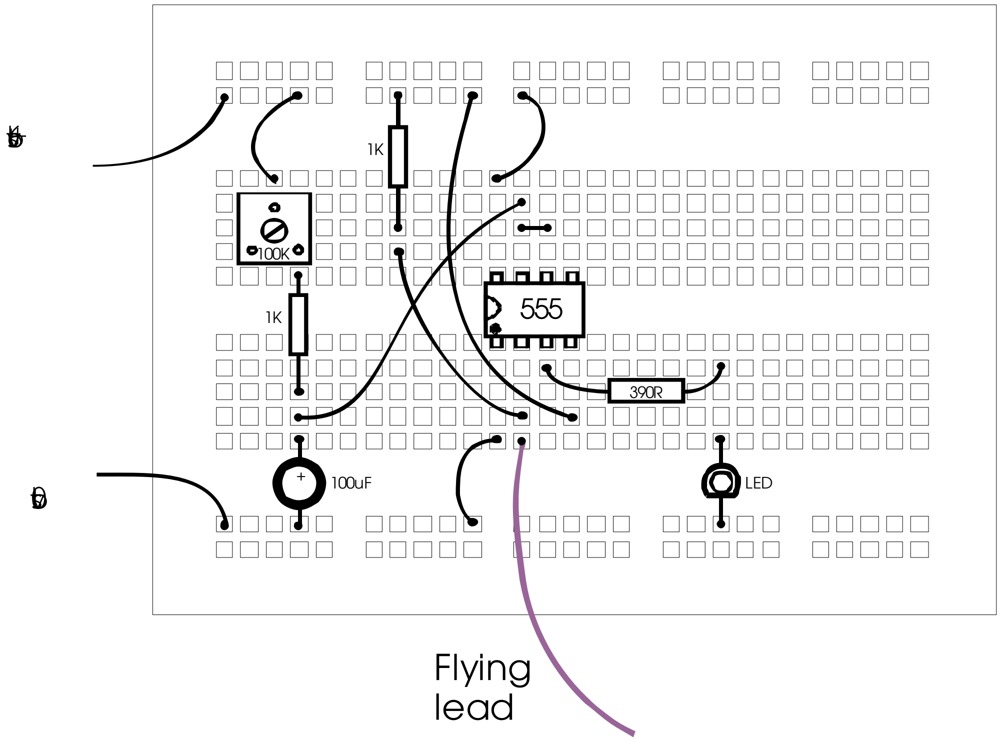
Polyester capacitors are for small-value uses and can be connected without regard to polarity.

Capacitance in measured in farads, but because this is a very large measurement most capacitors are rated in mF (microfarads) or in nF (nanofarads).

555 timer - practical tasks

This 555-timer circuit is used to switch an LED on for a specific time when the chip is 'triggered'. A typical application for this would be an egg timer.

Build the prototype circuit shown below.



Instructions

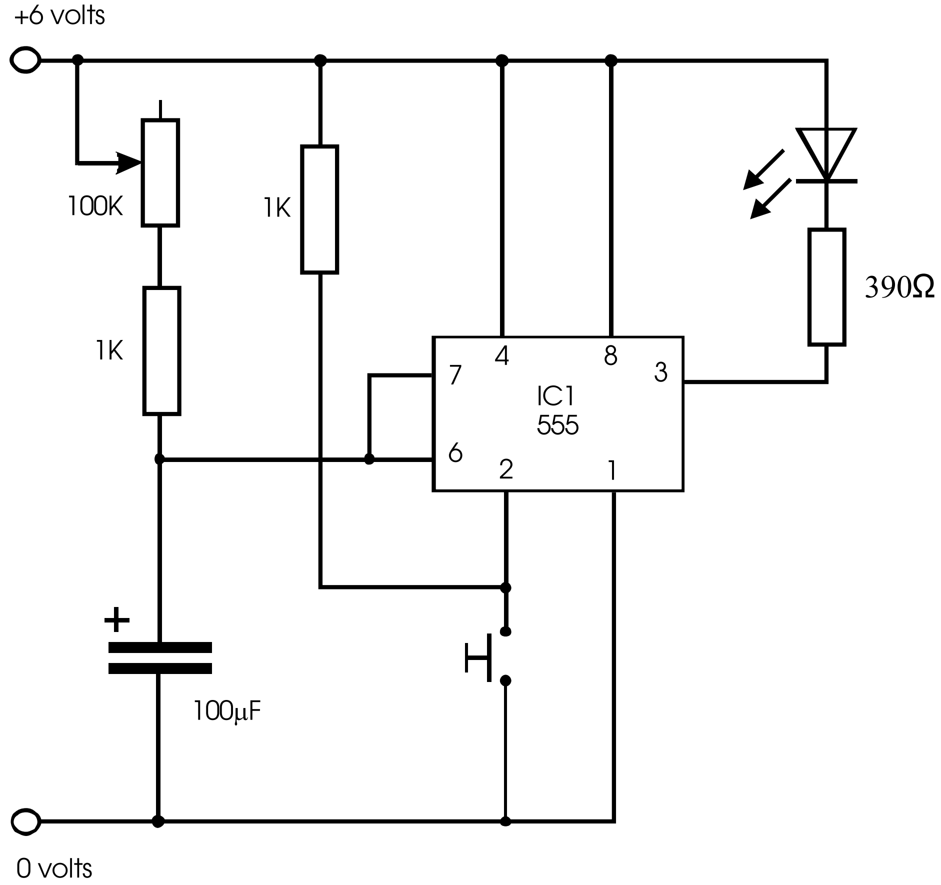
- Briefly touch the bare end of the flying lead to 0 volts. The LED should light for a fixed period.
- Adjust the variable resistor to obtain the longest fixed time for which the LED will stay on.
- Change the capacitor to the values in the table below and record the maximum time period for which the LED lights. *Crocodile Clips* or similar software could be used for this task.

Capacitor value (μF)	**Maximum time**
100	
470	
1000	
2200	
4700	

- Draw a graph to illustrate your answers.
- Estimate what value of capacitor would give a time of approximately 60 seconds.

The 555-timer circuit already built made an LED go on for a specific time when the chip was triggered. The circuit diagram below shows the altered circuit with the LED going off when the chip is triggered.

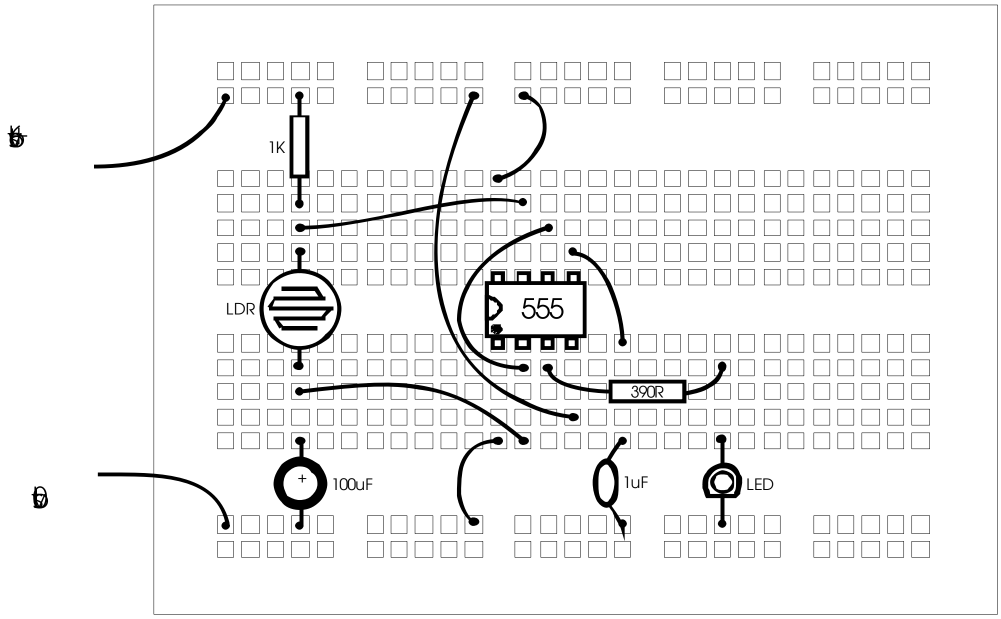
Alter your circuit to show this effect.



This circuit shows the 555 chip operating as a *monostable* device. This means that it is stable in only one state, that is, it 'jumps back' to its initial state after a set time.

Note: As an alternative, build this new system using circuit simulation software.

2. This 555-timer circuit is used to make an LED flash on and off at a set frequency. Build the prototype circuit shown below.



Instructions

- On powering up the circuit, the LED should flash on and off at a steady rate (frequency).
- Cover the LDR to see what effect this has.
- Expose the LDR to bright light and observe the effect.
- Complete a table to show your findings.

Light conditions	Frequency
Dark	
Normal	
Bright	

This circuit shows the 555 chip operating as an *astable* device. This means that it is unstable in both states; that is, it flips constantly from one state to the other.

Frequency

Frequency is the regular rate at which a physical event repeats itself. In this circuit it is the rate at which the LED flashes. In electronic circuits the common events are the flashing of optical devices (LEDs and lamps) and the sounding of buzzers/speakers. These outputs are driven by an electrical pulse from the electronic system or circuit.