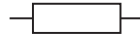
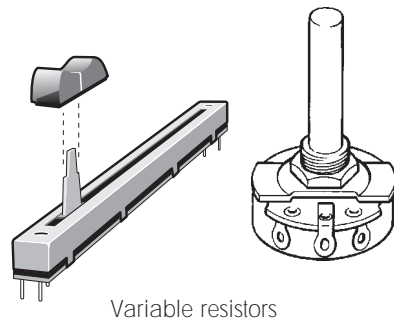
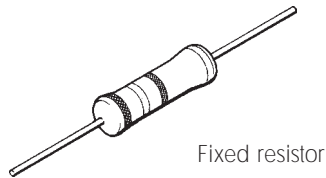


# TEP DATA SHEET 1 - RESISTORS

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## WHAT IT LOOKS LIKE



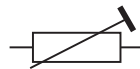
Fixed resistors



Variable resistors



Preset resistors



## WHAT IT'S USED FOR

To control the amount of current flowing in a circuit. They are the most commonly used components in electronic circuits. Each resistor has a resistance value in ohms (symbol  $\Omega$ ), a tolerance and a power rating in watts.

## WHAT IT'S MADE OF

**Fixed value** resistors can be made from, carbon rod, carbon particles in a ceramic base (carbon composition), a carbon or metal oxide film on a ceramic rod (carbon film) or from metal alloy wire wound on a ceramic tube (wire-wound).

**Variable resistors** have a track which can be made from carbon, or cermet ( a mixture of ceramic and metal oxide). The control can be rotary, preset or slider, and the relationship between the control movement and the resistance can be linear (directly proportional), logarithmic or any other mathematical function.

## HOW IT WORKS

The resistance  $R$  of a resistor is given by the equation:

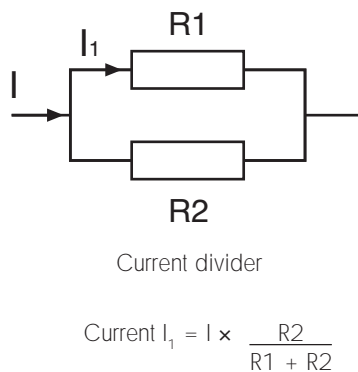
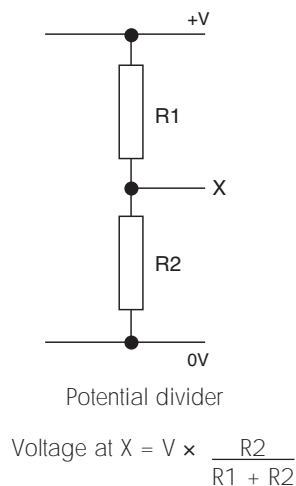
$$R = V/I$$

where  $V$  is the voltage across the resistor and  $I$  the current through it. For metals, some alloys and carbon,  $V/I$  is constant (and therefore  $R$  the resistance) regardless of the value of  $V$ .

## HOW YOU USE IT

### Fixed Resistors

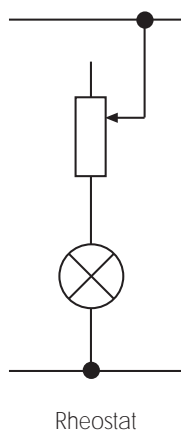
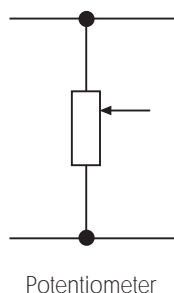
Fixed resistors have a connection at each end, and can be used singly to limit current flow, or define the voltage at a point in a circuit. Used together, resistors are connected in series or in parallel to create potential or current dividers.



### Variable resistors

Variable resistors have three connections, one at each end and one moveable contact or slider for the track. If the central moveable connection is used with both end connections the variable resistor functions as a potential divider or potentiometer (pot).

If only one end connection is used the variable resistor acts as a current controller or rheostat.



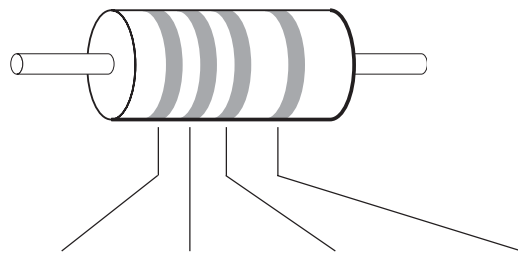
## NOTES

Resistors are available with power ratings from 1/8 W to 2 W, and values ranging from fractions of ohms to several megohms

# TEP DATA SHEET 1A - RESISTOR VALUES

## COLOUR CODE

The value of a resistor can be worked out from a colour code which consists of a number of coloured bands. The bands are 'read' from left to right and give the resistance value in ohms ( $\Omega$ ). The first two bands state the first two digits of the value and the third band, the number of zeros.



Colour	Band 1	Band 2	Band 3	Tolerance
Black	0	0	$\times 1$	
Brown	1	1	$\times 10$	
Red	2	2	$\times 100$	
Orange	3	3	$\times 1000$	
Yellow	4	4	$\times 10,000$	
Green	5	5	$\times 100,000$	
Blue	6	6	$\times 1,000,000$	
Violet	7	7		
Grey	8	8		
White	9	9		
Silver				$\pm 10\%$
Gold				$\pm 5\%$

For example: yellow, violet, red = 4700 ohms  
brown, black, brown = 100 ohms

## WRITTEN VALUES

Instead of writing out several zeros for high value resistors, we use larger units of resistance:

1 kilohm ( $k\Omega$ ) = 1000  $\Omega$   
1 megohm = 1 000 000  $\Omega$   
so 4 700  $\Omega$  = 4.7  $k\Omega$  and 2 200 000  $\Omega$  = 2.2  $M\Omega$

The 'k' can be thought of as a multiplier i.e.  $\times 1000$  and the M as  $\times 1\,000\,000$ .

This is the most commonly used method of writing resistor values and the most easily understood.

## PRINTED CODE

This code gives the value of a resistor by using letters and numbers. Manufacturers print the code on fixed and variable resistors where it would be difficult to use the colour code. Sometimes it is also used in circuit diagrams and books.

'R' stands for 1  
'K' stands for 1,000  
'M' stands for 1 000 000 and the position of the letter gives the decimal point.

For example:

A 10  $\Omega$  resistor is written as 10R.

A 2 000  $\Omega$  resistor is written as 2K0 (sometimes the 0 is left out so this becomes 2K).

A 4.7  $M\Omega$  resistor is written as 4M7.

Letters are added to the end of this code to give the manufacturer's tolerance on the value.

J =  $\pm 5\%$   
K =  $\pm 10\%$

For example:

6K8K = 6.8  $k\Omega \pm 10\%$

## WHICH K

Remember that lower case k's are used in written values to mean  $\times 1000$  **but** capital K's are used in the printed code to mean both  $\times 1000$  and a tolerance of  $\pm 10\%$ .

**TOLERANCES ON RESISTORS**

Electronic components are not manufactured to have an exact value. For example, a resistor can have a stated resistance of 1 kΩ and a tolerance of ±5%. This means that the value quoted is not exact. It could be 5% more or 5% less than 1 kΩ. The tolerance is the accuracy to which the resistor has been made. The tolerance is given by the coloured band on the end of the resistor.

*Gold band = 5% tolerance.  
Silver band = 10% tolerance.*

Here is an extract from a catalogue.

**Tolerance ±5%**

- 10 Ω
- 15 Ω
- 22 Ω
- 33 Ω
- 47 Ω
- 68 Ω
- 100 Ω

If you use a 47 Ω resistor, what is the greatest resistance this could have?

The catalogue says there is a 5% tolerance on these, so we need to find 47 + 5% of 47 Ω.

$$5\% \text{ of } 47 \Omega = 2.35 \Omega.$$

So the greatest value is

$$47 + 2.35 = 49.35 \Omega.$$

**PREFERRED VALUES**

Manufacturers of resistors cannot supply every possible value of resistor, so they make available preferred values only.

The E12 and E24 series of preferred values start as follows:

E12	E24
10R	10R
	11R
12R	12R
	13R
15R	15R
	16R
18R	18R
	20R
22R	22R
	24R
27R	27R
	30R
33R	33R
	36R
39R	39R
	43R
47R	47R
	51R
56R	56R
	62R
68R	68R
	75R
82R	82R
	91R
100R	100R
	110R
120R	120R
	130R
150R	150R
	160R
180R	180R
	200R
220R	220R
	240R
270R	270R
	300R
330R	330R
	360R
390R	390R
	430R
470R	470R
	510R

E12	E24
560R	560R
	620R
680R	680R
	750R
820R	820R
	910R
1K	1K
	1K1
1K2	1K2
	1K3
1K5	1K5
	1K6
1K8	1K8
	2K0
2K2	2K2
	2K4
2K7	2K7
	3K0
3K3	3K3
	3K6
3K9	3K9
	4K3
4K7	4K7
	5K1
5K6	5K6
	6K2
6K8	6K8
	7K5
8K2	8K2
	9K1
etc	etc

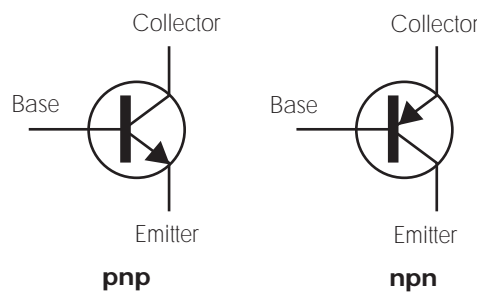
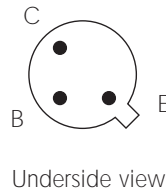
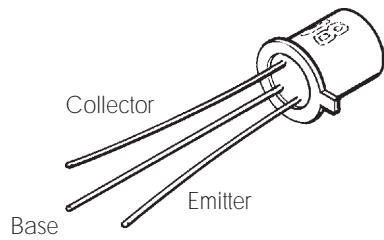
**POWER RATING**

Resistors heat up when they pass current. If they get too hot, they burn out. All resistors are given a power rating in watts (W). Higher wattage resistors are physically larger and can dissipate or get rid of more heat. The normal size resistor used in electronics work is rated at 0.25 W.

# TEP DATA SHEET 2 - TRANSISTORS (1)

## THE JUNCTION TRANSISTOR

### WHAT IT LOOKS LIKE



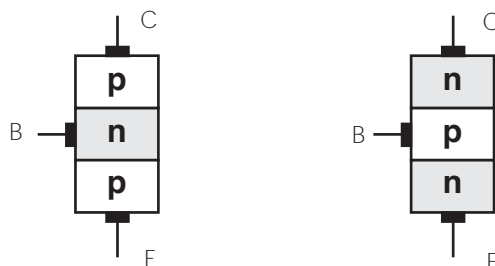
### WHAT IT'S USED FOR

- As a current amplifier
- As a high speed switch

Transistors are available as separate (discrete) components or can be part of an integrated circuit. Amplification range 20 - 800. Switching speed typically 5 ns.

### WHAT IT'S MADE OF

A sandwich of p-type and n-type silicon where the **base** is between the **collector** and **emitter**. It has three connections, one to each layer.

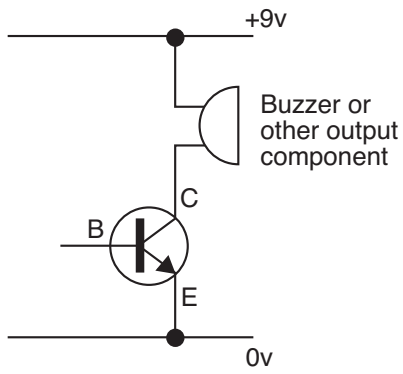


### HOW IT WORKS

A small current flowing into the base controls a large current flow between the collector and the emitter. A voltage > 0.6 volts between the base and the emitter is needed to switch the transistor on. When the transistor is switched ON it is as if a link is placed between the collector and emitter, allowing current to flow freely through. When the transistor is OFF, the connection is broken so that no current flows.

## HOW YOU USE IT

Connect the device to be switched ON or OFF in the collector circuit of the transistor. This arrangement is often used in the process stage of simple electronic systems.



## NOTES

General purpose transistors:

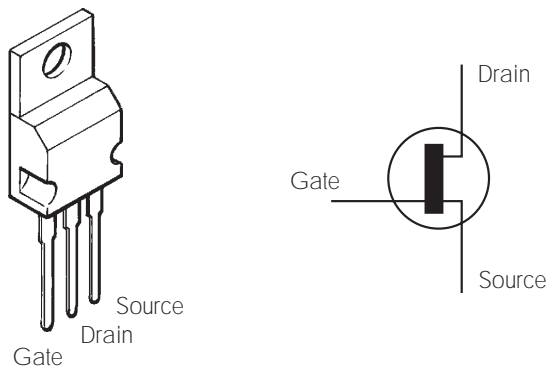
- BFY51
- BC 108
- 2N3053

## TEP DATA SHEET 3 - TRANSISTORS (2)

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### THE FIELD EFFECT TRANSISTOR

#### WHAT IT LOOKS LIKE



#### WHAT IT'S USED FOR

To supply large currents or switch large-current devices on or off. When it is used in electronic systems kits it is called a transducer driver. The two main types are MOSFET and JUFET. FET means Field Effect Transistor. Typical current range 2-12 A.

#### WHAT IT'S MADE OF

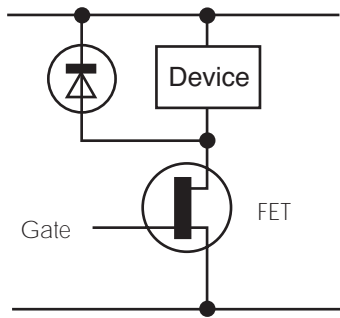
P-type or n-type semiconductor material with two metal contacts called the drain D and the source S - one at each end. A third contact, gate G connects to the side.

#### HOW IT WORKS

The voltage at the gate G controls the flow of current between the drain D and source S. Very little current flows into the gate because it has a high impedance ( $> 10^9$  ohms). A voltage of 4.5 V at gate G turns the FET on - less than 4.5 V turns it off so no current flows. The voltage creates a field which determines the current flow.

## HOW YOU USE IT

Connect in series with the device you need to control. MOSFETs give high power, high speed switching for power supplies, motor speed controllers, and audio amplifiers.



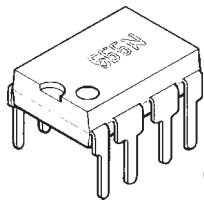
## NOTES

- FETs are sensitive to static.
- A heat sink is needed for a current flow of 2-4 A.
- The MPT3055A switches up to 12 A.
- MOSFET general purpose IR 530.
- JUGFET general purpose 2N3819.

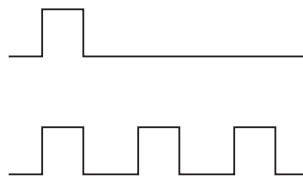
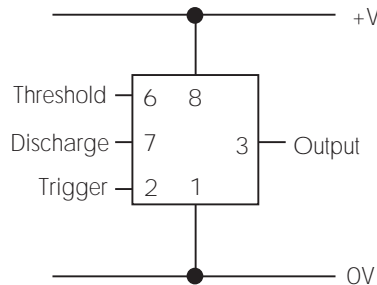
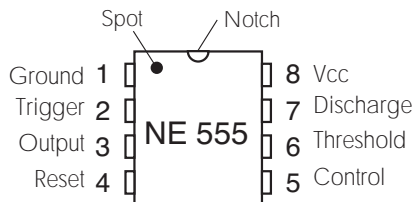
# TEP DATA SHEET 4 - INTEGRATED CIRCUITS (1)

## THE 555 TIMER

### WHAT IT LOOKS LIKE



8 pin dual in line package



Output can be a single pulse or a series of pulses

### WHAT IT'S USED FOR

- to switch something on or off at a precise time e.g. 0900 hrs.
- to switch something on or off after a certain time delay.
- as a pulse generator e.g. to provide a series of clock pulses for a counter.

### WHAT IT'S MADE OF

An integrated circuit consisting of a silicon chip in a plastic 8-pin package. The circuit contains two comparators, a bistable, resistors, and transistors. It is also available in a dual package which has two 555's on one chip, called a 556.

### Typical Characteristics:

Max. supply voltage	16V
Max. output current	200 mA
Max power	600 mW
Reset Current	0.1mA
Trigger voltage	1.6-5 V

## HOW IT WORKS

The way it works in a circuit depends on the external components connected to the 555. Its two ways of operating are:

- as an **astable** (produces a series of pulses)
- as a **monostable** (produces a single pulse)

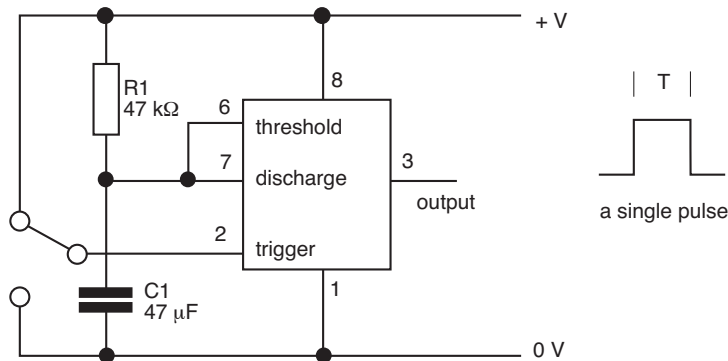
The following describes how it works as an astable:  
 If the voltage on the trigger is less than one third of the supply voltage V, the output (pin 3) goes high, and pin 7 is disconnected from the ground. When the voltage on the threshold is greater than two thirds of V the output goes low, and pin 7 is grounded.

## HOW YOU USE IT

### As a monostable:

The length of the pulse 'T' is given approximately by multiplying the value of R1 by C1.

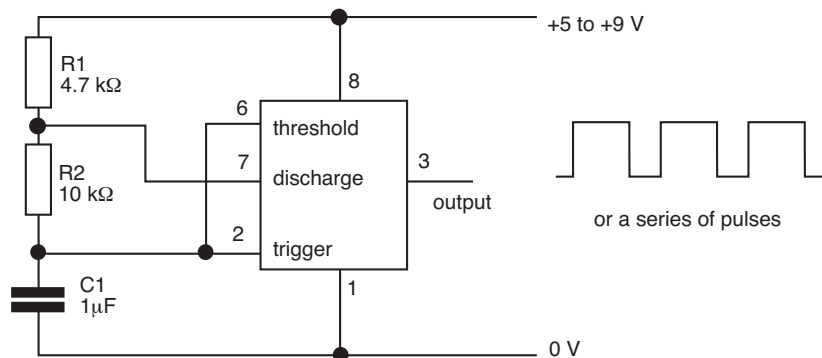
e.g.  $47 \text{ k}\Omega \times 47 \text{ }\mu\text{F}$   
 $= 47\ 000 \times .000047$   
 $= 2.2 \text{ secs}$



### As an astable:

The number of pulses every second (the frequency) is given approximately by :

e.g.  $0.7 / (R2 \times C1)$  if  $R2 > R1$   
 $0.7 / (10000 \times .000001)$   
 $= 0.7/.01$   
 $= 70 \text{ Hz}$



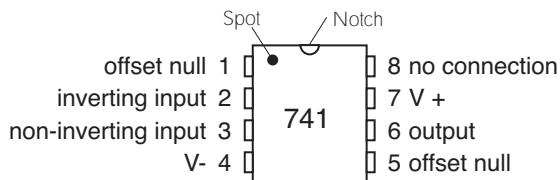
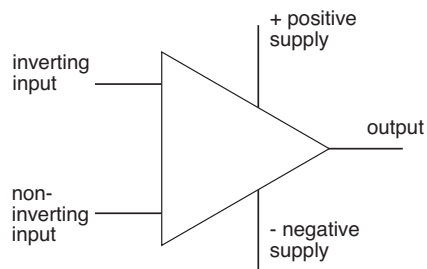
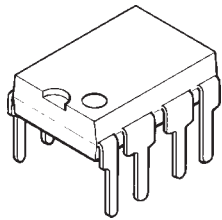
## NOTES

In both cases, the values of the resistances and capacitor can be changed to meet a particular design specification. Using variable resistors and looking at the output on an oscilloscope allows the circuit to be 'tuned'.

# TEP DATA SHEET 5 - INTEGRATED CIRCUITS (2)

## THE 741 OP AMP

### WHAT IT LOOKS LIKE



### WHAT IT'S USED FOR

Op-amps have many uses, depending on the components connected to it. The main uses are:

- as a **high gain amplifier**,
- as a **mathematical operator** on electrical voltages.

### Typical circuits:

- Inverting amplifier
- Non-inverting amplifier
- Summing amplifier
- Voltage comparator
- Integrator

### WHAT IT'S MADE OF

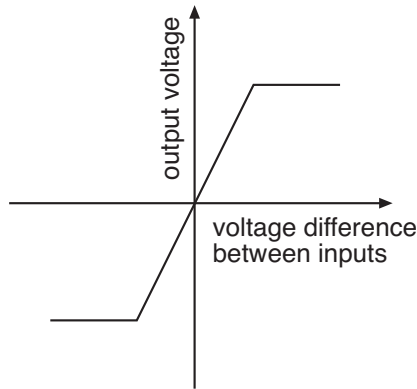
An integrated circuit (IC) consisting of a silicon chip in a plastic 8-pin package. The circuit contains about 20 transistors, eleven resistors and a capacitor.

### Properties:

- a high open -loop gain ( $10^5$ )
- a high input impedance ( $10^6$  ohm)
- a low output impedance

**HOW IT WORKS**

The 741 amplifies the difference in voltage between its two inputs, and provides the result on the output. The output is high or low depending on which input is higher. If the (+) input is higher the output is high. If the (-) input is higher the output is low.



**HOW YOU USE IT**

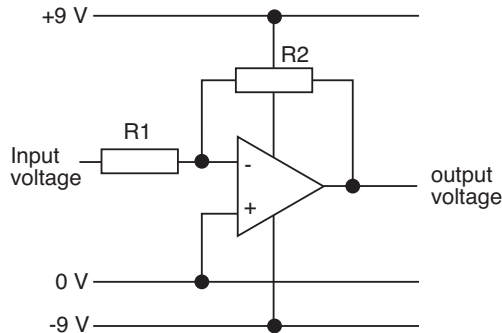
**Inverting amplifier**

Voltage gain,  $A_v =$

$$A_v = \frac{\text{output voltage}}{\text{input voltage}}$$

$$A_v = - \frac{R_2}{R_1}$$

The minus sign means that the output is positive when the input is negative and vice versa. The output is inverted with respect to the input.



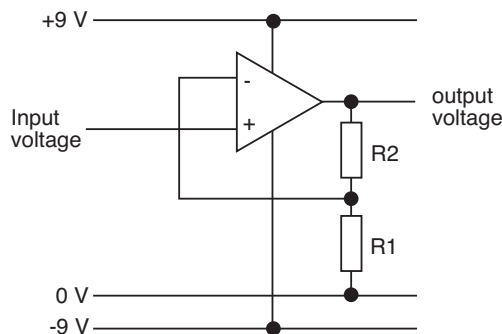
**Non-inverting amplifier**

The voltage gain,  $A_v =$

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

For example, if  $R_2 = 100 \text{ k}\Omega$  and  $R_1 = 10 \text{ k}\Omega$  then

$$A_v = 1 + \frac{100}{10} = 11$$

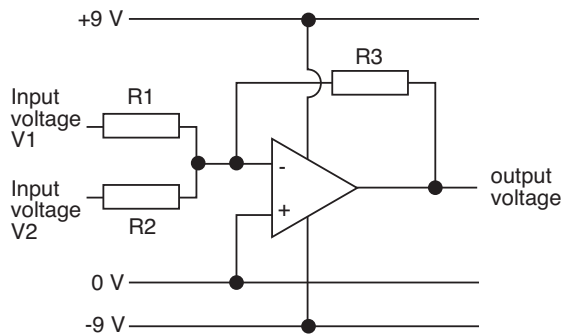


### Summing amplifier

If  $R_1 = R_2 = R_3$ ,

Output voltage =  $-(V_1 + V_2)$

The output voltage equals the sum of the two input voltages.

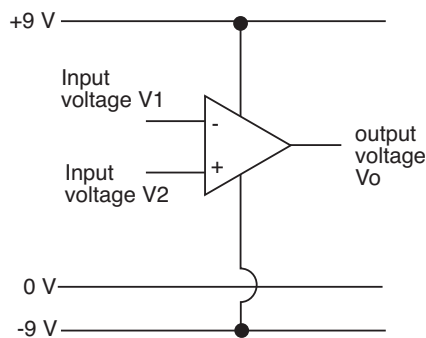


### Voltage comparator

If  $V_2$  is greater than  $V_1$  then  
 $V_o = +9 V$ .

If  $V_1$  is greater than  $V_2$  then  
 $V_o = 0 V$ .

The comparator compares two voltages and amplifies the difference between them.



### NOTES

The maximum current available from a 741 is about 5 mA, which means it must be connected to a resistive load of greater than 2 k (on a 9 V supply) to prevent overload. To provide a higher current drive capability (up to 2 A), the output is fed to the base of a transistor, with the load in its collector circuit.

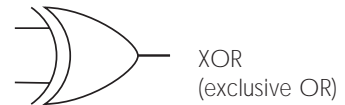
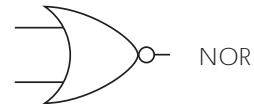
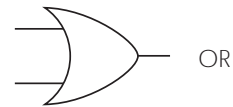
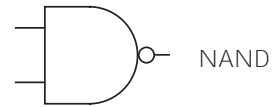
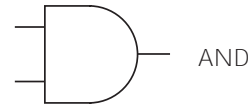
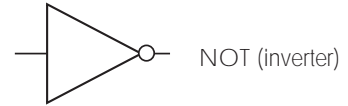
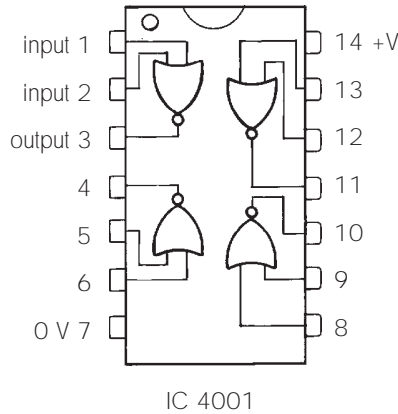
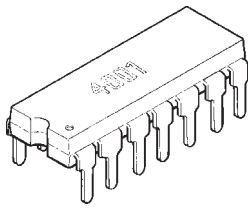
However a transistor needs  $< 0.6 V$  to turn it off and the output voltage of a 741 only drops to approx. 2 V at its lowest. This problem is overcome by using a potential divider on the output.

The other possibility is to use a 3140 Op-amp which works from a single polarity voltage supply, and whose output is close to 0 V.

# TEP DATA SHEET 6 - INTEGRATED CIRCUITS (3)

## LOGIC GATES

### WHAT IT LOOKS LIKE



### WHAT IT'S USED FOR

In digital circuits:

- Where the output of a circuit depends on more than one thing happening on the input.
- To control the flow of data from one part of a circuit to another. Logic gates are circuits which have a logical function such as: AND, OR, NAND, NOR, NOT.

e.g. A drilling machine will only operate (output), if it is switched on (input), AND the guard is in place (input).

### WHAT IT'S MADE OF

The integrated circuit (IC) is a silicon chip in a plastic package. It can have 8 or 14 pins depending on the number of logic gates on the chip. In general, logic gate ICs belong to one of two logic families:

- TTL (transistor-transistor logic) which uses junction transistors.
- CMOS (complimentary metal oxide semi-conductor) which uses FET's.

The silicon chip is normally no bigger than 0.2 mm<sup>2</sup> small enough to pass through the eye of a needle!

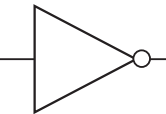
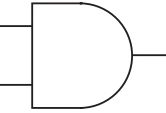
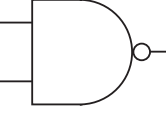
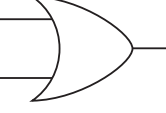
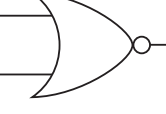



### HOW YOU USE IT

Logic gates are digital devices and their inputs and outputs are always represented as 0 or 1. The input or output is 1 when the voltage on it is high or 0 when the voltage is low (approx. 0 V)

The action of a logic gate is shown by a **Truth Table** in which outputs for particular patterns of inputs are defined.

### Logic gates and their truth tables

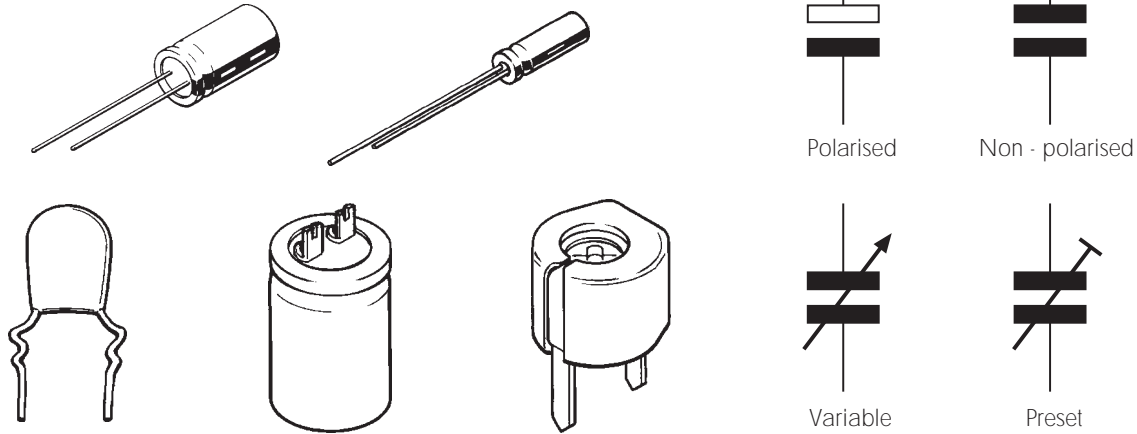
Logic gate	Symbol	Truth table			IC number	
		Inputs A	B	Output X	TTL	CMOS
<b>NOT</b> (Inverter)		0		1	7404	4049B
		1		0		
<b>AND</b>		0	0	0	7408	4081
		0	1	0		
		1	0	0		
		1	1	1		
<b>NAND</b>		0	0	1	7400	4011B
		0	1	1		
		1	0	1		
		1	1	0		
<b>OR</b>		0	0	0	7432	4071B
		0	1	1		
		1	0	1		
		1	1	1		
<b>NOR</b>		0	0	1	7402	4001B
		0	1	0		
		1	0	0		
		1	1	0		
<b>XOR</b> (Exclusive OR)		0	0	0	7484	4070B
		0	1	1		
		1	0	1		
		1	1	0		

### NOTES

- All the integrated circuits in the table contain four gates, each with two inputs, except for the 7404 4099B which have six gates each with a single input
- A small circle on the output of a gate symbol shows an inversion

# TEP DATA SHEET 7 - CAPACITORS

## WHAT IT LOOKS LIKE



## WHAT IT'S USED FOR

- To tune radios
- To smooth the output from a power supply
- To separate d.c from a.c.
- To control the frequency of an oscillating circuit
- To control the delay in a timing circuit

A capacitor stores electrical energy (charge) in a circuit. The amount of charge it can store is given by the value of capacitance, stated in Farads (F), and the applied voltage, V.

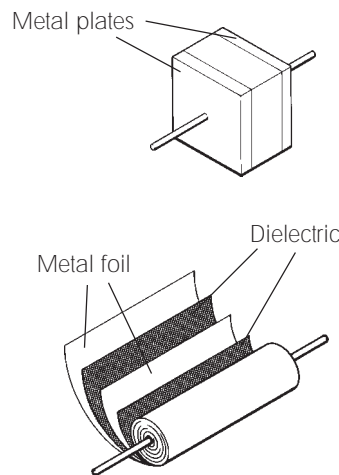
$$Q \text{ (charge)} = CV$$

## WHAT IT'S MADE OF

Two metal plates separated by an insulating material called a dielectric.

**Fixed value capacitors** are of 2 types - polarised and non-polarised. Polarised or **electrolytic** capacitors use aluminium and tantalum, **non-polarised** capacitors use Polyester, mica or ceramic for the dielectric material .

**Variable capacitors** use either fixed and moving metal plates separated by a dielectric of air or sheets of metal foil and mica which can be compressed.



## HOW IT WORKS

A capacitor either blocks the flow of **direct current (d.c.)** or restricts the flow of **alternating current (a.c.)**.

In the case of d.c. once the capacitor is full of charge, the flow of charge ( current) stops. With a.c. the capacitor is continually charged and discharged. Its resistance to current flow depends on the size of the capacitor and the rate at which the current changes direction (frequency). To draw a comparison with the flow of water - if you try to empty a tank of water with a bucket while the tank is being filled with water from a tap, your success depends on the size of the bucket and your rate of working.

A 1 Farad capacitor stores a charge (Q) of 1 coulomb (ampere-second) when the pd (V) across it is 1 volt:

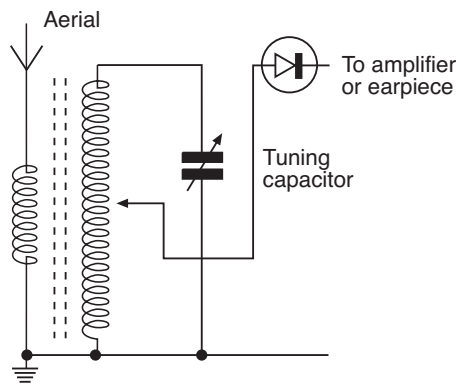
$$\text{So the Capacity } C = Q/V$$

The resistance of a capacitor to a.c. is called its reactance (Xc) and is calculated using the formula:

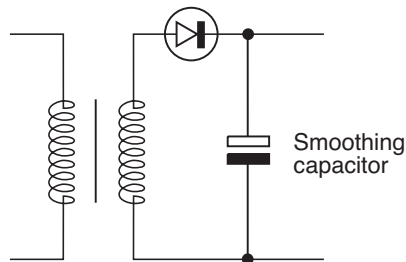
$$\text{Reactance } X_c = 1 / 2\pi fC \quad (f = \text{frequency})$$

## HOW YOU USE IT

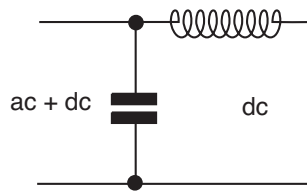
### In radio tuning circuits



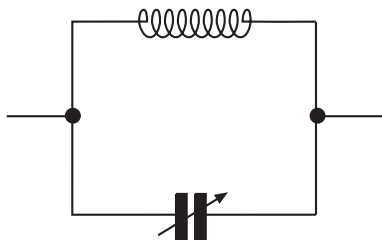
### To smooth a power supply output



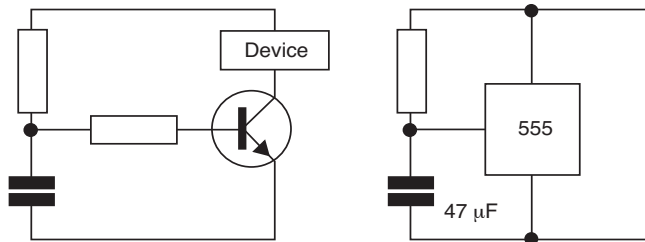
**To separate a.c. and d.c.**



**In oscillator circuits to control the frequency**



**In timing circuits**

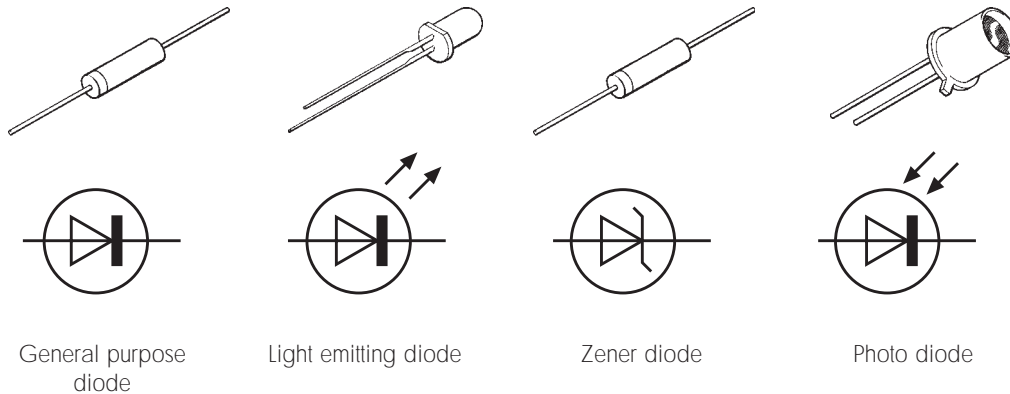


**NOTES**

Polarised capacitors are marked with + and - on the body and must be connected the right way round in a circuit

# TEP DATA SHEET 8 - DIODES

## WHAT IT LOOKS LIKE

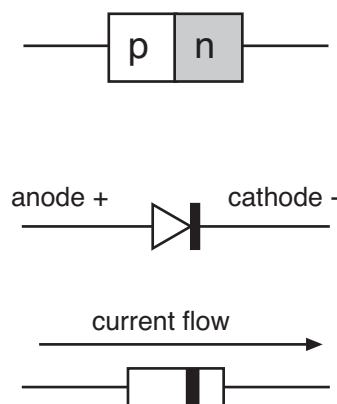


## WHAT IT'S USED FOR

- (1) • to prevent damage to a circuit  
• to convert a.c. to d.c.
- (2) as an indicator lamp
- (3) to stabilise voltage levels
- (4) as a high speed light sensor.

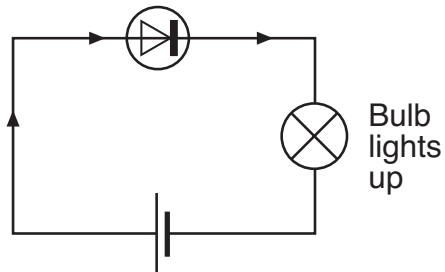
## WHAT IT'S MADE OF

A small piece of p-type silicon joined to a small piece of n-type silicon creating a p-n junction. Wires connected to each piece make two leads called the anode and cathode. The cathode is indicated by a band on the diode body.



### HOW IT WORKS

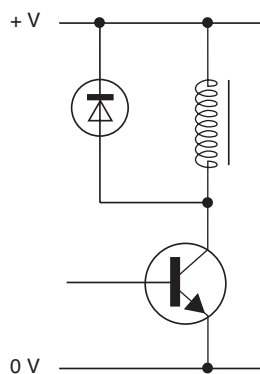
The diode only conducts electricity when it is forward biased. This means when the p-type silicon is connected towards the positive terminal of a power supply.



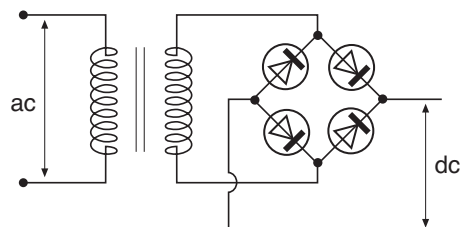
The photodiode conducts when light falls on it, whilst the LED emits light when it conducts.

### HOW YOU USE IT

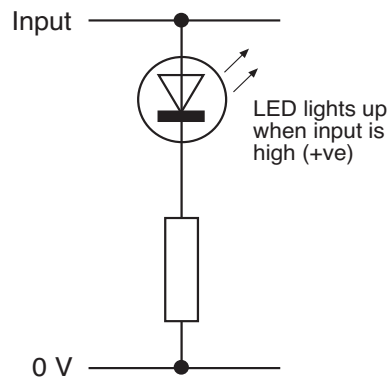
#### As a protective device



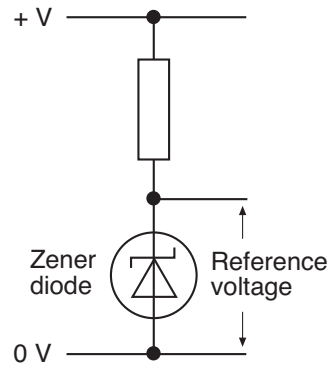
#### To convert ac to dc



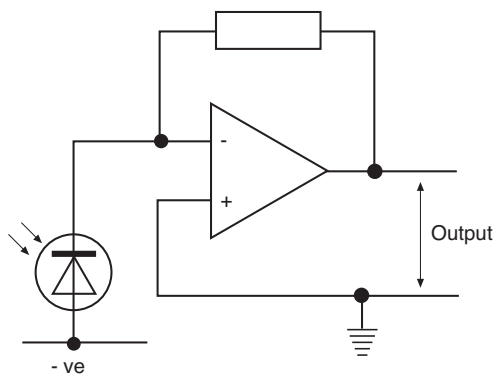
**As an indicator**



**To stabilise voltage levels**



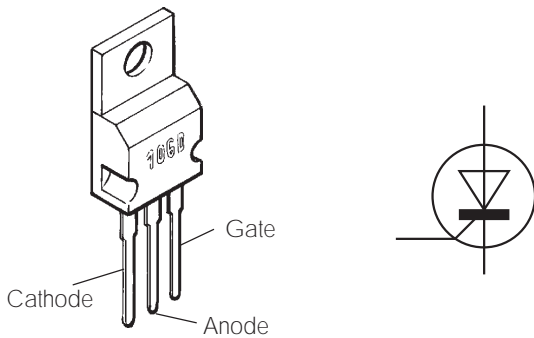
**As a light sensor**



# TEP DATA SHEET 9- THE THYRISTOR

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## WHAT IT LOOKS LIKE



## WHAT IT'S USED FOR

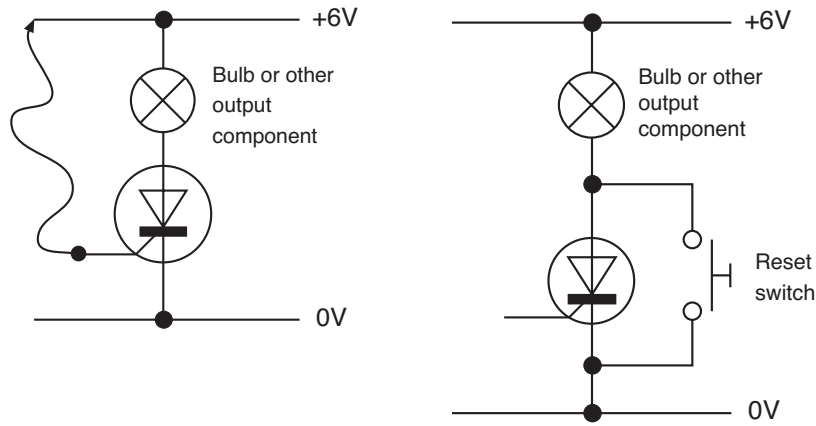
To supply large currents or switch large-current devices on or off. In particular, it is used where an electronic "latching" action is needed. When triggered with a small gate current, it remains switched on until the power supply is interrupted. Thyristors are widely used in burglar alarm systems where a momentary switch action results in a continuous alarm sound.

## WHAT IT'S MADE OF

P-type or n-type semiconductor material with two metal contacts called the anode A and cathode C - one at each end. A third contact, gate G connects to the side.

## HOW IT WORKS

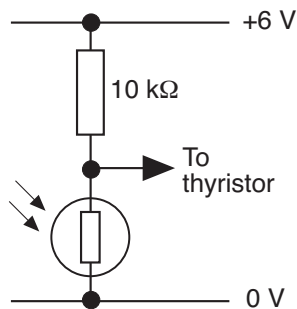
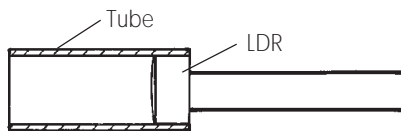
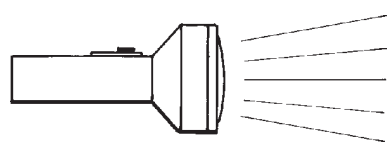
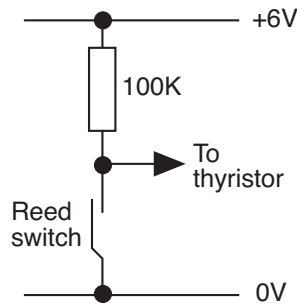
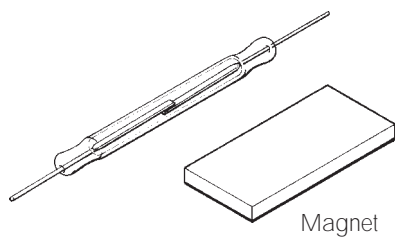
The voltage at the gate controls the flow of current between the anode and cathode. When a positive voltage of approximately 2 volts is applied to the gate, a large current will flow anode to cathode and remain flowing even though the voltage at the gate is removed. A momentary voltage at the gate will be sufficient to trigger the thyristor into conduction.



The thyristor can be turned off either by interrupting the power supply - e.g. a switch in the +ve power supply rail - or by momentarily bypassing the thyristor anode to cathode with a switch.

NOTES

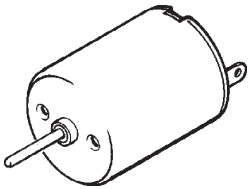
Method of triggering a thyristor



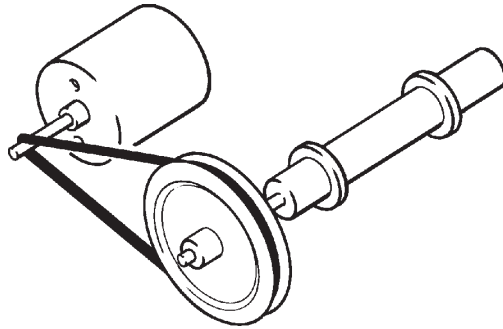
# TEP DATA SHEET 10 - MINIATURE DC ELECTRIC MOTOR

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## WHAT IT LOOKS LIKE



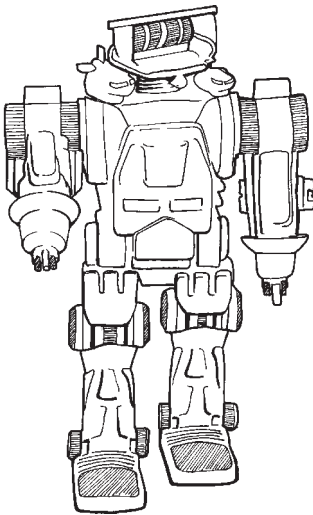
Small  
electric  
motor



Circuit  
symbol for  
motor

## WHAT IT'S USED FOR

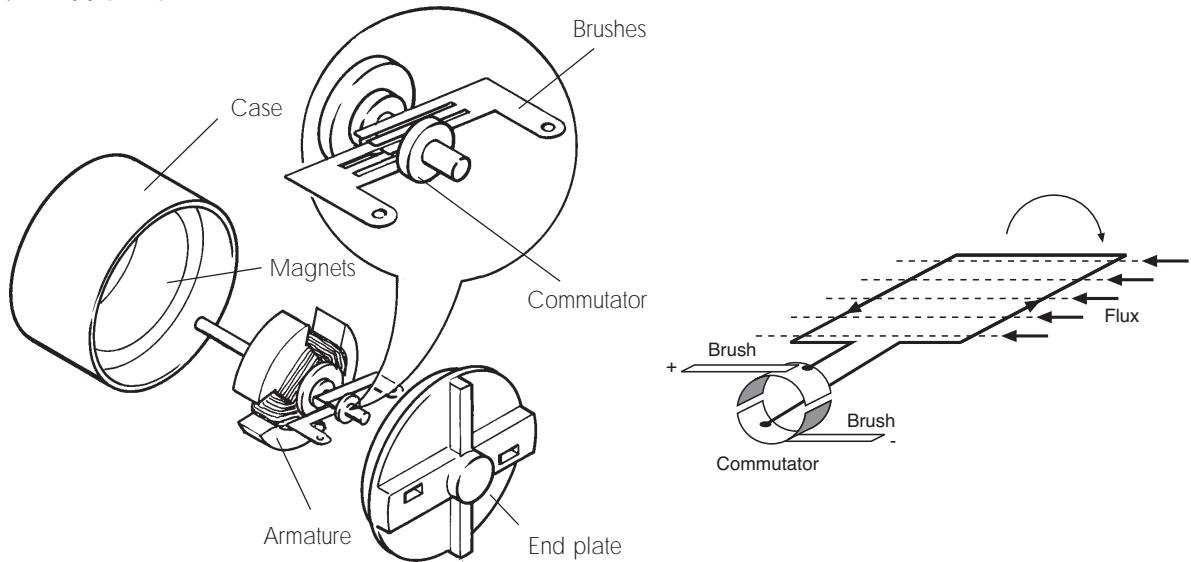
Small DC (direct current) electric motors are used to convert electrical energy into the mechanical energy of movement. They are used most often in battery powered products such as toys, cassette recorders, cordless drills, hand-held sewing machines etc.



### WHAT IT'S MADE FROM

A miniature DC motor is made up from several materials including steel (the case), sintered ferrite compound (the magnets), copper wire (the armature windings, brass/bronze (the bearings), nylon (insulators - and sometimes the back of the case)

### HOW IT WORKS



Electric current passes to the armature coils through brushes resting on a commutator. This causes the armature pole pieces to become magnetic. The magnetic field of the armature poles opposes the magnetic field of the two permanent magnets and the armature is forced to turn. As it does so, the commutator reverses the flow of current to the armature which keeps turning. Typical characteristics for a miniature DC motor are given below:

NOMINAL	NO LOAD		AT MAXIMUM EFFICIENCY					Stall Torque g-cm
	Constant Volts	Speed rpm	Current A	Speed rpm	Current A	Torque g-cm	Output W	
3.0	1800	0.022	1430	0.085	8.4	0.123	48.3	41
6.0	3700	0.028	3060	0.134	14.5	0.455	56.4	84

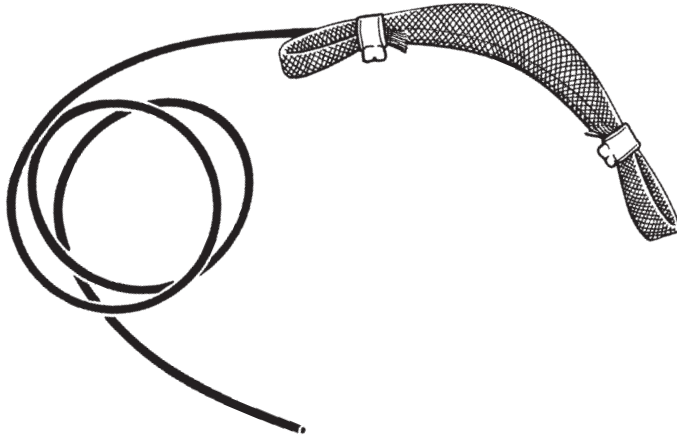
### NOTES

Miniature electric motors are becoming smaller **and** at the same time more powerful! This is because incredibly powerful permanent magnets have been developed using rare earth materials. Motors using these magnets have a very high power to weight ratio (they are very powerful for a small weight). They have now made it possible, for example, to power model aircraft, including helicopters, with electric motors.

# TEP DATA SHEET 11 - SHADOW AIR MUSCLE

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## WHAT IT LOOKS LIKE



## WHAT IT'S USED FOR

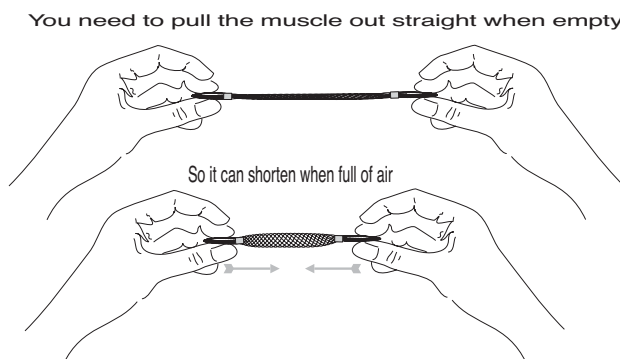
To provide controlled linear (straight line) movement. It can also provide rotary movement if connected, for example to a pivoted lever. Air muscles are used to actuate (move) puppets and other models and props in film and video productions. They are also being used under computer control to power robots.

## WHAT IT'S MADE OF

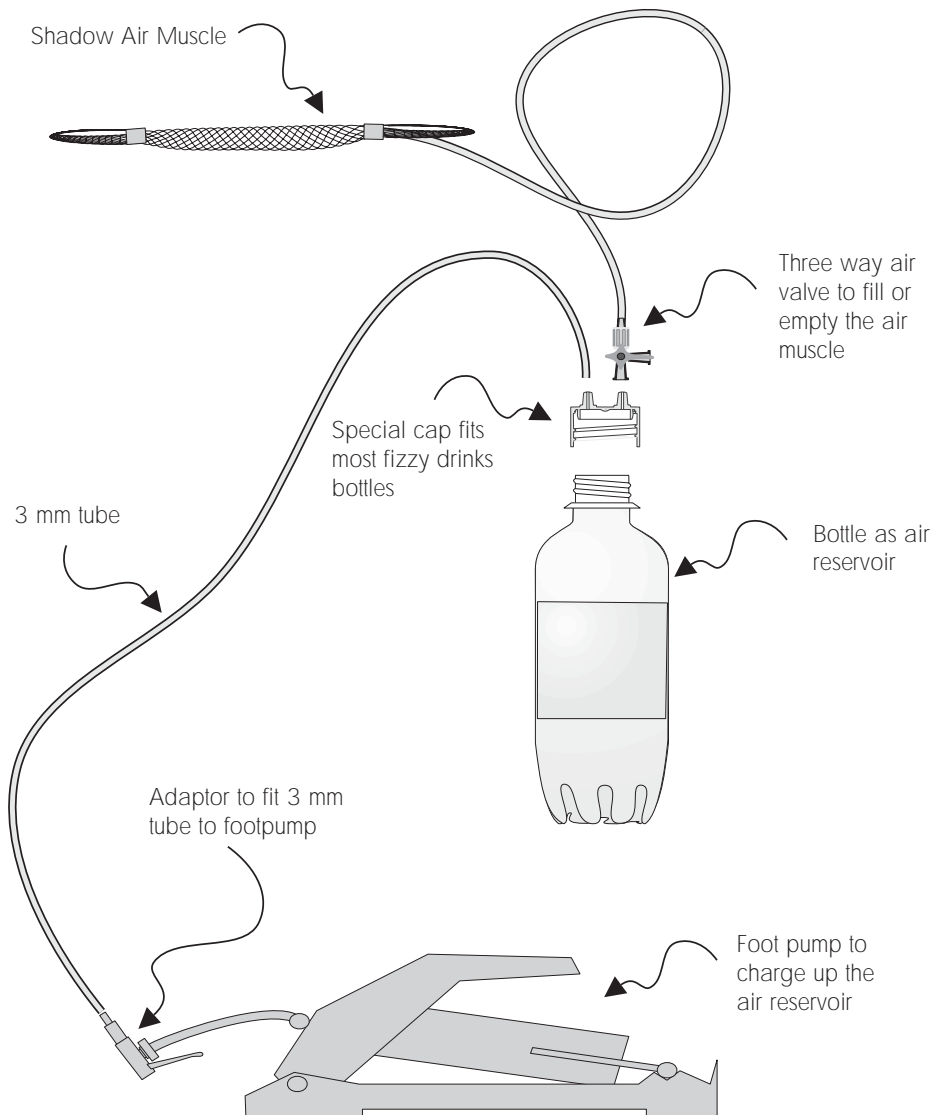
An muscle consists of a rubber tube surrounded by a polyester mesh or braid. A nylon air line is brought into the rubber tube at one end and the outer braid is crimped over the rubber at both ends to form a seal.

## HOW IT WORKS

When compressed air is fed into the muscle, the tube expands outwards which causes the woven braid to pull the two ends of the muscle together with considerable force. The force depends on the air pressure supplied. Typically this will be 2 to 3 bar.

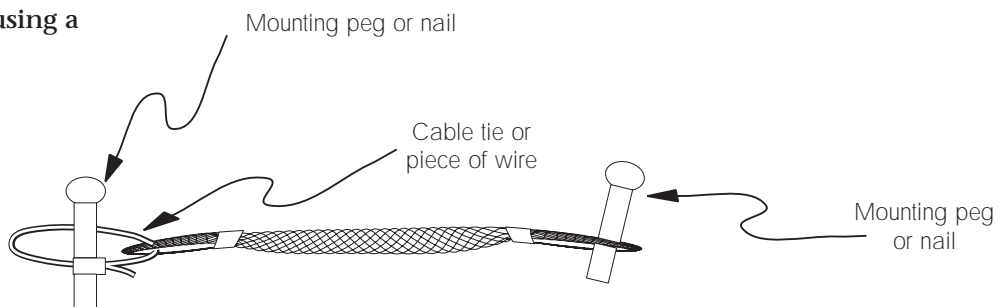


Air muscles can be energised from a fizzy drinks bottle using the 'low tech' air muscle kit. Alternatively, a number of air muscles can be operated from a standard air supply controlled by a computer via solenoid valves.



**NOTES**

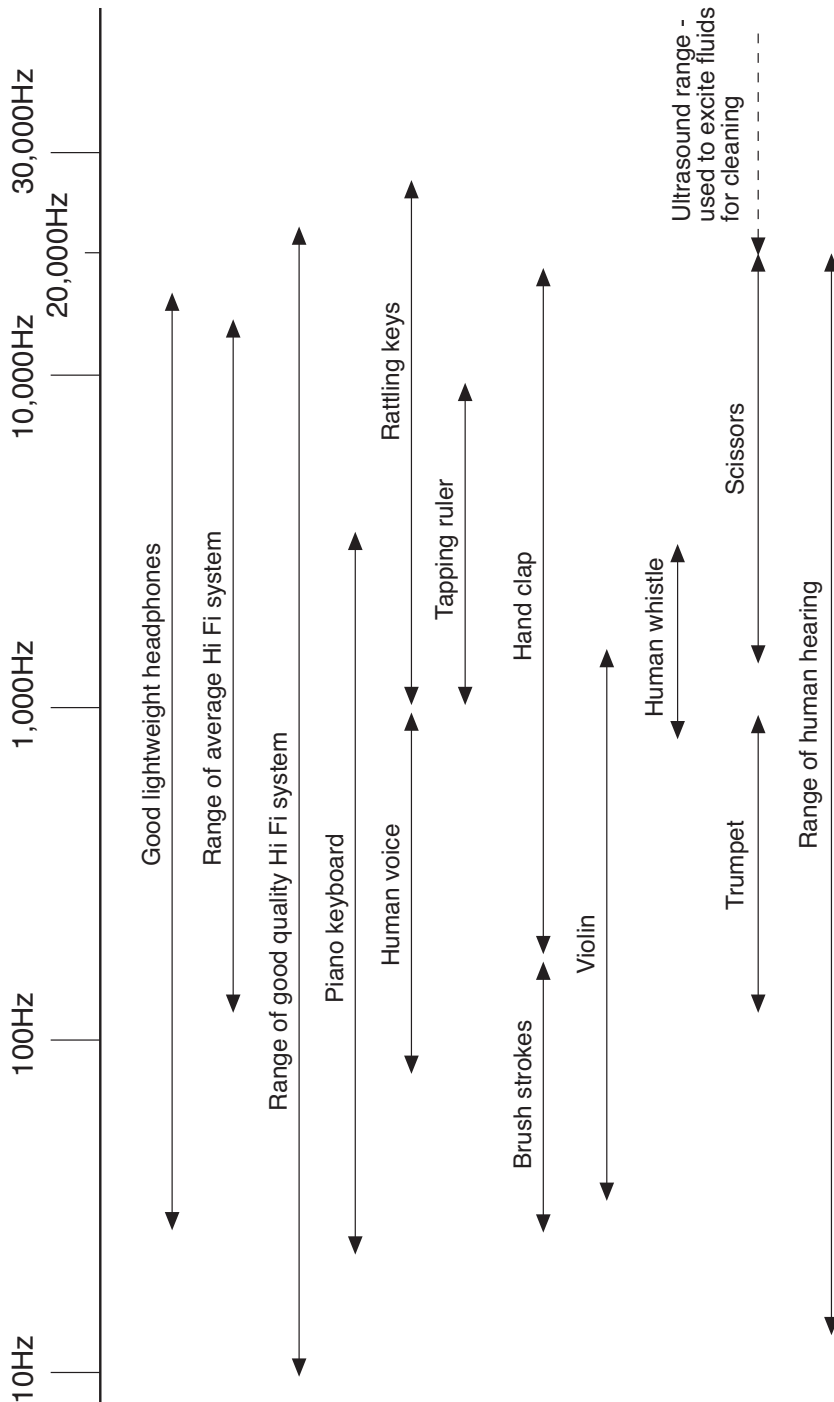
An air muscle can be mounted and tensioned using a cable tie.



# TEP DATA SHEET 12 - THE AUDIO FREQUENCY SPECTRUM

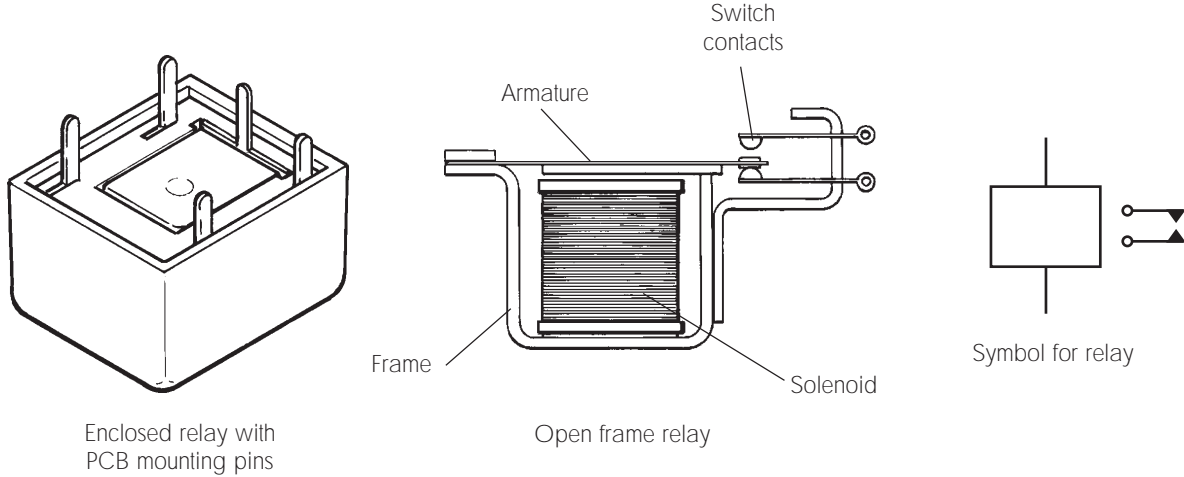
Mechanical vibration in solids, fluids and gases produces what we perceive as sound.

Speed of sound in air (27°C): 347 m/sec at 101.3 kN/m<sup>2</sup>.



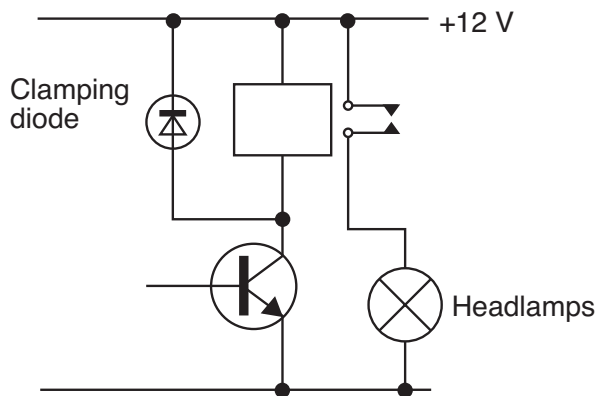
# TEP DATA SHEET 13 - THE RELAY

## WHAT IT LOOKS LIKE



## WHAT IT'S USED FOR

To switch large current devices on or off by means of a much smaller current. Relays are used, for example, where a small control switch cannot pass a high current; e.g. a small switch on the steering column of a car turns on the headlights indirectly through a relay. Relays are also useful when complete separation between a small control current and the load current is needed. Relays are used, for example, to separate mains supplies from electronic control circuits.



## WHAT IT'S MADE UP FROM

A relay comprises three main parts: coil, armature and switch(es). The coil is insulated copper wire wound around a steel core. The armature is a steel plate connected mechanically to the relay switch(es). Each switch comprises two or more thin strips of beryllium copper (or equivalent spring material) each having a switch contact at the end. The contacts are plated to reduce damage through arcing.

## HOW IT WORKS

A small control current is passed through the relay coil to *energise* it. When this happens, the coil becomes magnetic and attracts the armature which opens or closes the relay switch(es).

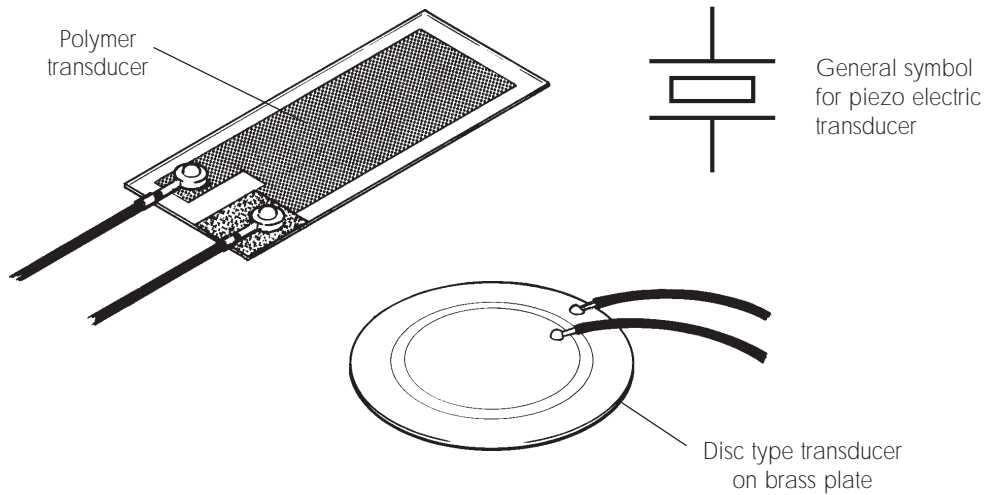
## NOTES

Relays are normally marked with their coil resistance (e.g. 120 ohms) and the operating current limits of the switch(es). Where a relay is connected as the output of an electronic circuit, a clamping diode is normally added to eliminate high voltage 'spikes' caused when the magnetic field collapses around the coil, since such spikes can damage electronic circuit components.

# TEP DATA SHEET 14 - PIEZO-ELECTRIC TRANSDUCERS

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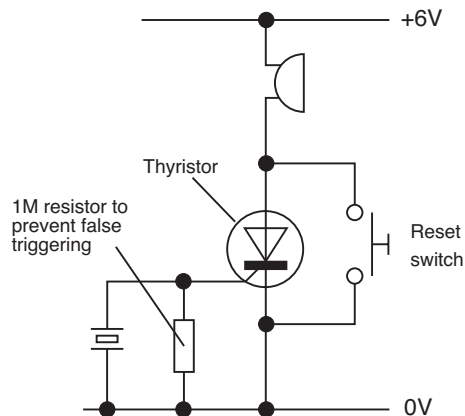
## WHAT THEY LOOK LIKE



## WHAT THEY ARE USED FOR

Piezo-electric transducers produce movement in response to applied voltage. They produce voltage in response to applied pressure. Piezo transducers are the 'loudspeaker' in musical greetings cards; they produce sound from an electrical signal. Strips of piezo-electric material can be laminated together to produce useful movement when a voltage is applied; these are called *bi-morphs*.

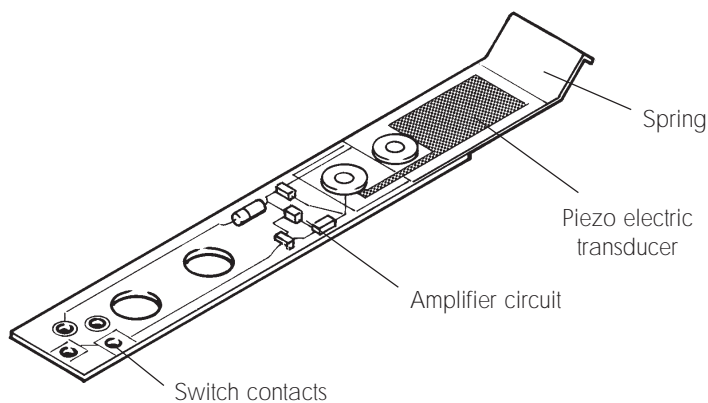
Piezo transducers are used as sensors in a wide variety of applications - including burglar alarms. A simple alarm circuit is shown. The transducer produces a voltage in response to a movement or loud sound which causes the thyristor to turn on a sounder.



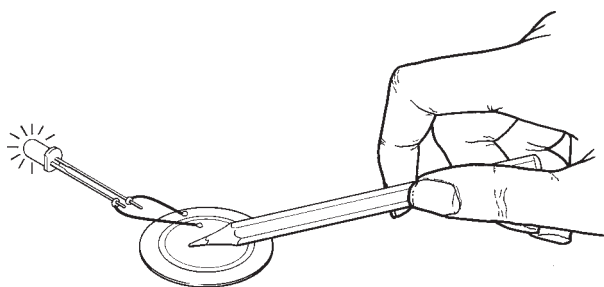
Piezo electric polymers are used increasingly as sensors. In several applications - including pinball machines - piezo electric polymer is used in special switches. The polymer is bonded to a metal spring and connected to a small amplifying circuit. When the metal spring is touched lightly, the polymer produces a small voltage which is amplified to give a signal.

### WHAT THEY ARE MADE OF

Piezo electric transducers can be made from minerals, ceramics or polymers. Naturally occurring minerals such as quartz exhibit the piezo electric effect. Many polymers also exhibit piezo electric behaviour but some are better than others in this respect. The piezo-electric film is cut up into various sizes and coated either side with a metallic film attached to wire connectors.



### HOW IT WORKS



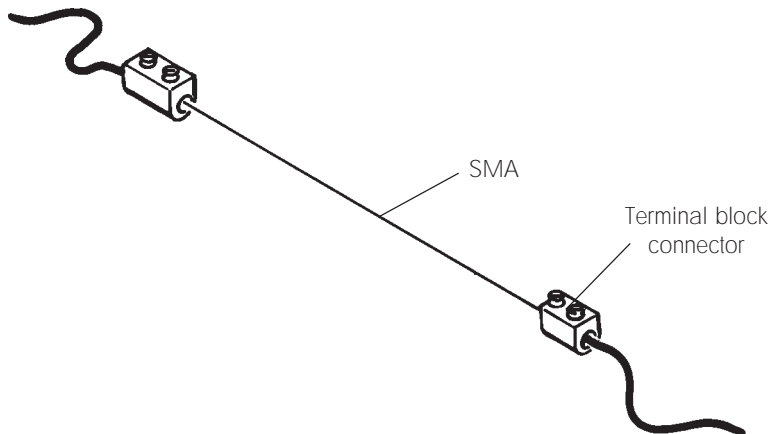
A transducer is something that converts energy from one form to another. Piezo electric transducers (sometimes shortened to 'piezo-transducer') convert mechanical energy into electrical energy and vice versa. When a piezo electric material is deformed - e.g. by tapping with a pencil - a voltage appears across it. On the other hand, if a voltage is applied to the material, it deforms and produces a sound.

The voltage only appears during deformation and mechanical movement only occurs during a change in applied voltage.

# TEP DATA SHEET 15 - SHAPE MEMORY ALLOY (SMA)

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## WHAT IT LOOKS LIKE



## WHAT IT'S USED FOR

Shape memory alloy is a relatively new material and new ideas for practical applications are being thought of each day! It can be used for mechanical actuation (movement) in robotic devices, valves, door locks etc. - without involving a lot of moving parts. It is also finding applications in the medical field where wire structures can be made to change shape within the body.

SMA can be made in any shape or section. It is commonly available in the form of wire of different diameters - e.g., 50 microns, 100 microns, 150 microns. (1 micron = 1/1000 millimetre).

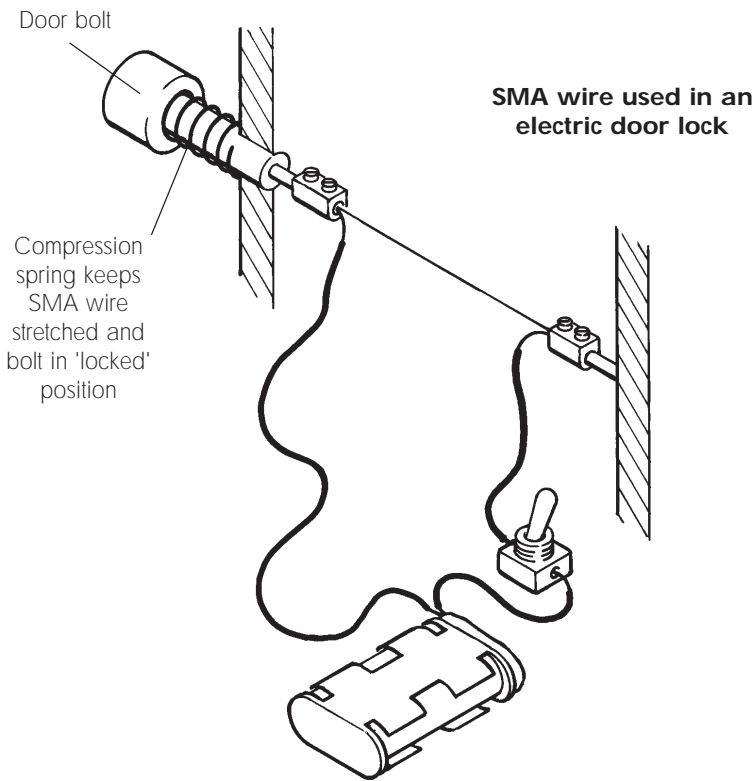
## WHAT IT'S MADE OF

A number of alloys exhibit shape memory properties. The most common alloy is nickel and titanium- called *Nitinol* for short. Nitinol is one of a growing number of 'smart' materials - so called because they can respond 'intelligently' to different conditions.

## HOW IT WORKS

Shape memory alloy can be made to 'remember' a shape by means of heat treatment and will always try to return to this shape if heated to the correct temperature. For example, a length of wire is made to 'remember' that it is straight; it is then bent into a different shape at room temperature. It retains this new shape at room temperature but as soon as it is heated - say - in a glass of warm water it goes straight again ! The point at which SMA returns to its 'remembered' condition is called the *transition* temperature.

SMA wire can be made to remember its length. If stretched between two points at room temperature, it 'relaxes' to a longer length. If it is then heated, it remembers its original length and shortens by about 5% - with a useful pulling force. When it cools down, it relaxes again. This cycle can be repeated endlessly.



SMA wire has electrical resistance and so can be heated up by passing current through it. The diagram shows a simple means of moving a cupboard locking bolt with SMA wire. The wire shortens when current flows to pull the bolt back and when the current is switched off the wire is stretched again by the bolt return spring. This method of linear actuation (movement) requires no moving parts other than the bolt.

The following table gives information for 100 micron Nitinol wire:

Properties of Muscle Wires	Flexinol 100	
Bias force	0.3 N	(Equivalent to a mass of approx. 30 grams)
Pulling force	1.5 N	(Equivalent to a mass of approx. 150 grams)
Resistance	150 $\Omega$ per metre	
Max current	180 milliamps	
Max. power	5 Watts per metre	
Shortening time	0.1 sec	
Relaxation time	1 sec	
Recommended extension	5%	
Minimum bend radius	5 mm	
Transition temperature	70°C	
Pulling starts at	68°C	
Pulling finishes at	78°C	
Relaxation starts at	52°C	
Relaxation finishes at	42°C	

It is easy to calculate the current needed to heat the wire by using Ohm's Law. This states the relationship between voltage (V), current (I) and resistance (R). Ohm's Law states that:

$$V = I \times R$$

$$I = V/R$$

$$R = V/I$$

The table gives us the resistance of the wire and also states the maximum current. Using Ohm's Law we can therefore work out the voltage needed. For example, what is the voltage needed to pass the maximum safe current through the 10 cm length of 100 micron sample wire provided with this book?

#### Step 1

The resistance of the wire is 150  $\Omega$  per metre.

Divide by 100 = 1.5  $\Omega$  per cm.

10 cm of wire = 1.5  $\Omega$   $\times$  10 = 15  $\Omega$ .

#### Step 2

The maximum current is 180 mA or 0.18 A.

(1 milliamp = 1/1000 amp)

#### Step 3

$V = I \times R$ . Substituting the figures above gives:

$V = 0.18 \times 15 \Omega = 2.7$  volts.

A 3 V battery (2 AA cells in series) can be used to power this length of wire because as current is drawn, its voltage will reduce slightly.

