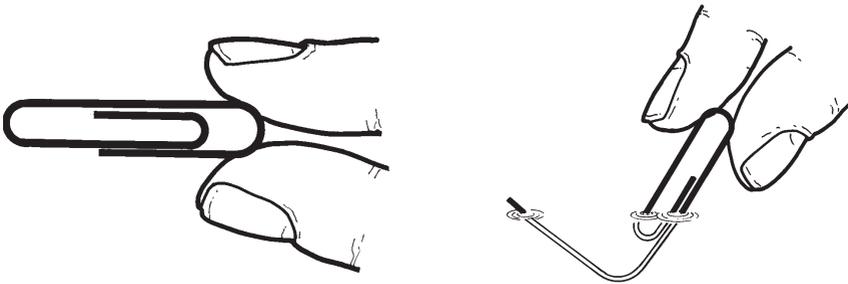# SMART WIRE

Shape Memory Alloy (SMA)

SMA is a smart material which, as its name suggests, has a memory. The most common SMA is an alloy (mixture of metals) of nickel and titanium - called **nitinol**. By means of special heat treatment, a piece of SMA can be made to 'remember' a shape. For example, a length of wire can be made to remember that it should be straight at temperatures above 70°C. If you bend this wire at normal room temperature into the shape of a paper clip, it stays bent and will continue acting as a paper clip. However, if you place it in a glass of water whose temperature is above 70°C, it immediately straightens out! When cool, it remains straight until it is bent again.

This cycle of bending and then straightening when heated can be continued millions of times. The temperature at which SMA 'remembers' its original form is called the transition temperature and when this point is reached, it changes shape.

SMA has a relatively high electrical resistance and can be heated to its transition temperature by passing an electrical current through it.

SMART WIRE

A common form of SMA is wire available in different diameters. This ranges, for example, from 5 mm diameter down to 50 microns (1 micron = 1/1000 millimetre). The SMA wire sample provided with this book is Nitol with a diameter of 100 microns. It is heat treated to 'remember' that it has a shorter length when heated above its transition temperature (70°-80°C) than below it. (See study File 2)

If the sample length of wire is held between two points it has a length of approximately 10 cm. When heated to between 70° and 80°C, it shortens by about 5% or 1/20 and exerts a useful pulling force. (The wire becomes shorter and it gets slightly fatter.) When the wire cools down, it relaxes to its longer length of 10 cm.
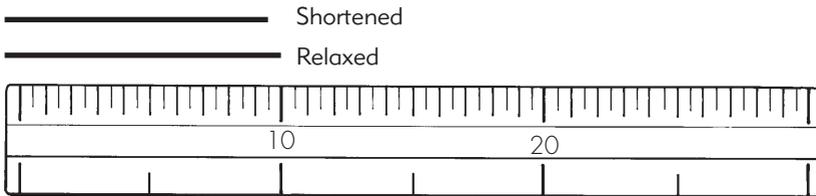
The 5% change in length is constant for any length or diameter of SMA wire. This results in quite small movements for shorter lengths of wire. However, the movement can be increased by increasing the length of wire. To work out the amount of movement for a given piece of wire, you simply multiply its length by 5%.

For example, for a wire 150 mm in length, the shortening is:

150/1 × 1/20 = 150/20 = 7.5 mm

The 5% shortening of SMA can also be turned into a much larger movement using simple lever systems.

SMA wire has to be stretched or biased to return to its longer length. The force required to do this is much smaller than the pulling force that the wire exerts when it shortens. There are two main ways of biasing:
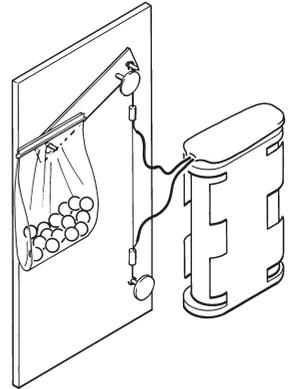
• Using a weight
• Using a spring
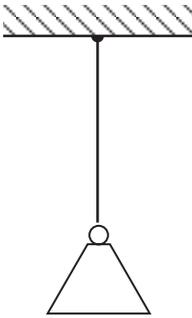
Using a weight
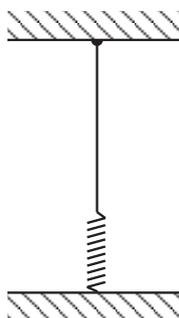
Using a spring

Because SMA has a relatively high electrical resistance, it can be heated to its transition temperature simply by passing current through it. This opens up many possibilities for providing mechanical actuation (movement) without any moving parts other than those the SMA is attached to! Also, for smaller diameter wires, the currents needed are quite small and can be provided from smaller batteries.

In a practical design using SMA wire, you need to know what force to use to bias it, and what force it will exert when it shortens. If you are heating it with electric current, you also need to know how much current to pass without overheating and damaging it.

+V

Shape memory alloy wire symbol used for this book.

-V
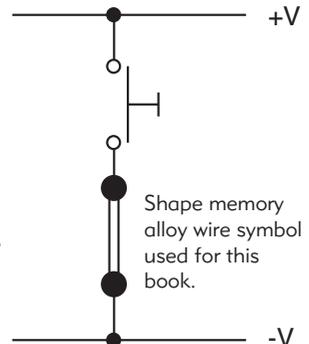
All these figures (for 100 micron wire) are provided in the table below:

Bias force	0.3 N
Pulling force	1.5 N
Resistance	150 ohms per metre
Max. current	180 milliamps
Max. power	5 Watts per metre
Shortening time	0.1 second
Relaxation time	1.0 second
Recommended extension	5%
Minimum bend radius	5 mm
Effective transition temperature	70°Centigrade
Pulling starts at	68°C.
Pulling finishes at	78°C.
Relaxation starts at	52°C.
Relaxation finishes at	42°C.

EXPLANATION OF THE TABLE

The table tells us that at normal room temperature the wire needs to be stretched with a bias force of 0.3 newtons - which is roughly equivalent to hanging a weight of approximately 30 grams on the end. When heated to the transition temperature of between 70° to 80°C, the wire shortens about 5% in length and will exert a pulling force of 1.5 newtons - roughly equivalent to lifting a weight of 150 grams.

The speed at which the wire shortens when it reaches the transition temperature is about 0.1 seconds. It takes longer to relax or stretch back to its longer length - about 1 second. The table also tells us that when heated, the wire actually starts changing length at 68°C and finishes at 78°C. When it cools, however, the stretching or relaxation does not take place until it has reached 52°C. (The difference between the higher transition temperature and the relaxation temperature is called hysteresis (see Study File 2).

The figures given in the table are the recommended ones for 100 micron nitol; if they are exceeded, the useful life of the wire will be reduced.

The supply needed to heat the wire can be determined 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 150Ω per metre.
Divide by 100 = 1.5Ω per cm.
10 cm of wire = 1.5Ω × 10 = 15Ω.

Step 2
The maximum current is 180 mA or 0.18 A.
(1 milliamp = 1/1000 Amp.)

Step 3
V = I × R. Substituting the figures above gives:
V = 0.18 A. × 15Ω = 2.7 volts.

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

To check that the power rating (the rate of doing work) is not exceeded, we can use the power equation W = I × V.

If we substitute the above figures W = 0.18 × 2.7 = 0.49 Watts for a 10 cm length of wire and 10 × 0.49 = 4.9 for a metre length. This is the maximum figure given in the table.
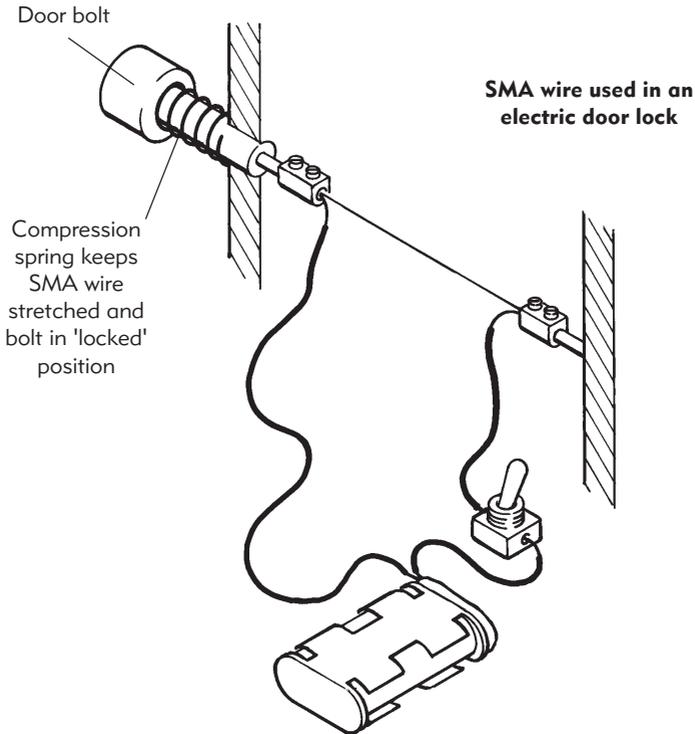
What voltage would be needed to supply a 15 cm length of 100 micron SMA wire?

How many times per minute could a length of 100 micron SMA wire go through a complete shortening and relaxation cycle?

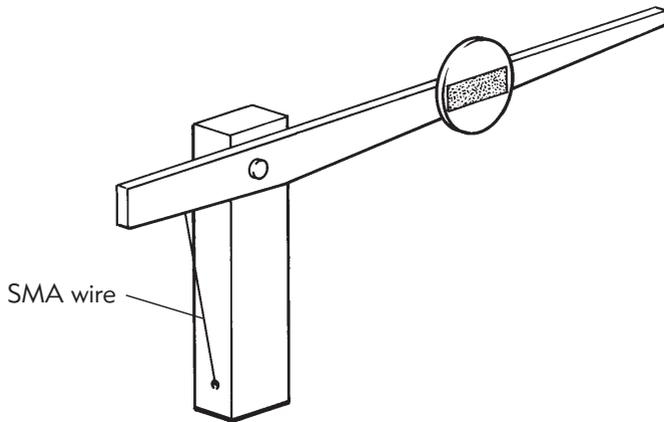## Practical Applications of SMA Wire

Linear actuation

SMA wire is most easily used to provide linear or straight line movement. The example shown uses SMA wire to pull a bolt in a simple lock. In this application very little linear movement is needed. If its length can be accommodated, SMA wire can often be used in place of a more expensive solenoid. A free-standing actuator can be made by containing the wire in a plastic tube.

Door bolt

SMA wire used in an electric door lock

Compression spring keeps SMA wire stretched and bolt in 'locked' position

Angular actuation

In many practical applications of SMA wire, a mechanical system is used to amplify movement. The barrier prototype model illustrated uses the lever principle to move and lift up the arm. The same principle can be used to provide the movements of a robot arm.

SMA wire