Teacher guide

This activity is aimed at higher tier students. It requires them to perform calculations with the following formulae:

- power = voltage x current
- energy = power x time
- work = force x distance
- efficiency = $\frac{\text{useful energy output}}{\text{energy input}}$

They are introduced to Nitinol wire, a shape memory alloy which can transform electrical energy into mechanical work, albeit with an efficiency of less than 1%. The extension activity requires students to perform an extra experiment to test a theory about the low efficiency. All told, the activity lasts an hour.

Safety notes

The Nitinol wire will get hot (possibly up to 100 ºC), so students need to be warned about burning themselves. A risk assessment must be carried out before any practical work is undertaken.

Suggested approach

Demonstrate a small 3 V electric motor doing some work - perhaps lifting up a small weight on a piece of thread wrapped around its shaft. Then demonstrate the arrangement of Nitinol wire that they will be using later on in the lesson. By questioning, clarify the important energy transfers and transformations involved and how to calculate them:

- electrical power = voltage x current
- electrical energy input = power x time
- useful work out = force x distance

It may help to write these on the board, in this order, as you go along.

Finally, introduce efficiency as a way of calculating how wasteful any sort of motor is:

- efficiency = $\frac{\text{useful energy output}}{\text{energy input}}$

Students can work in pairs. The initial tasks on the worksheet ensure that students know how to process the results of their experiment before they start. While they are busy on this, issue them with their loops of Nitinol wire, already fastened to 4 mm leads by a connector block, in numbered plastic bags. This is so that you can collect them all in easily at the end of the lesson, without any tangling - Nitinol wire is not cheap!

The initial tasks also provide a useful way to discuss rounding numerical answers and significant figures.

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Answers to the exercises

When the switch is closed, the ammeter and voltmeter read 0.38 A and 5.5 V respectively.

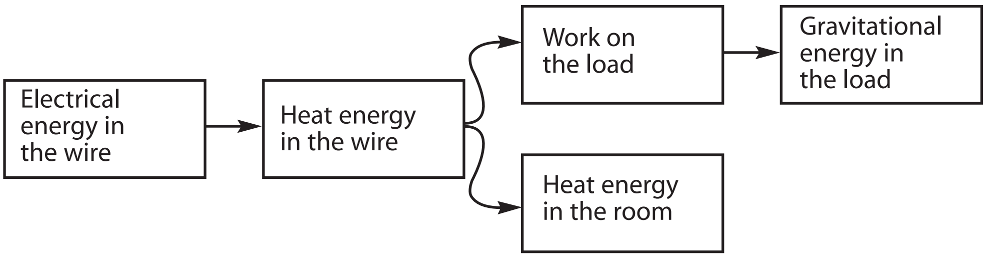
*The electrical power delivered to the muscle wire is **5.5** x **0.38** = **2.1 W**.*

*The switch is closed for 5.2 s, so the total electrical energy delivered to the wire is **2.1** x **5.2** = **11 J**.*

*During that time the 4.0 N load rises by 3.2 cm. The useful work done on the load by the wire is therefore **4.0** x **0.032** = **0.13 J***

The efficiency is therefore $\frac{0.13}{11}$ = **0.012** or **1.2 %**

Students should find that the efficiency increases and then decreases with increasing load.



The low efficiency is an obvious disadvantage. The best two advantages are probably the lightness and the lack of moving parts, but it does depend on the context. In the freezing cold of Space, where electricity is easily available through PV panels, lots of waste heat can be useful for keeping vital electronic systems warm, the wire's lack of weight and low maintenance could provide unassailable advantages for an unmanned spacecraft.

Less current increases the heating time quite considerably, supporting Melanie's theory. Don't attempt to run muscle wire off 7.5 V, or you run the risk of overheating it and damaging its shape-memory properties.

As part of the plenary, you could use questioning to find out what students thought were the advantages and disadvantages of Nitinol. It has been used by robot builders for some years, so you could ask students to search the Internet for more information as a useful homework.

Technician guide

Each pair of students will need:

- stand
- two bosses and one clamp
- 30 cm loop of Nitinol wire in a numbered plastic bag
- two string loops
- 50 cm wooden bar
- 150 mm steel nail
- 6 V battery
- push switch
- ammeter (0 - 1 A)
- voltmeter (0 - 10 V)
- five 4 mm leads
- six 100 g slotted masses

- 50 cm ruler
- stopwatch

The wooden bar needs a hole at its centre large enough to accommodate the 150 mm nail freely and a smaller hole 5 cm to one side to take the string loop from the Nitinol wire.

Nitinol wire (as 'smart wire', a shape memory alloy) is available from Middlesex University Teaching Resources at

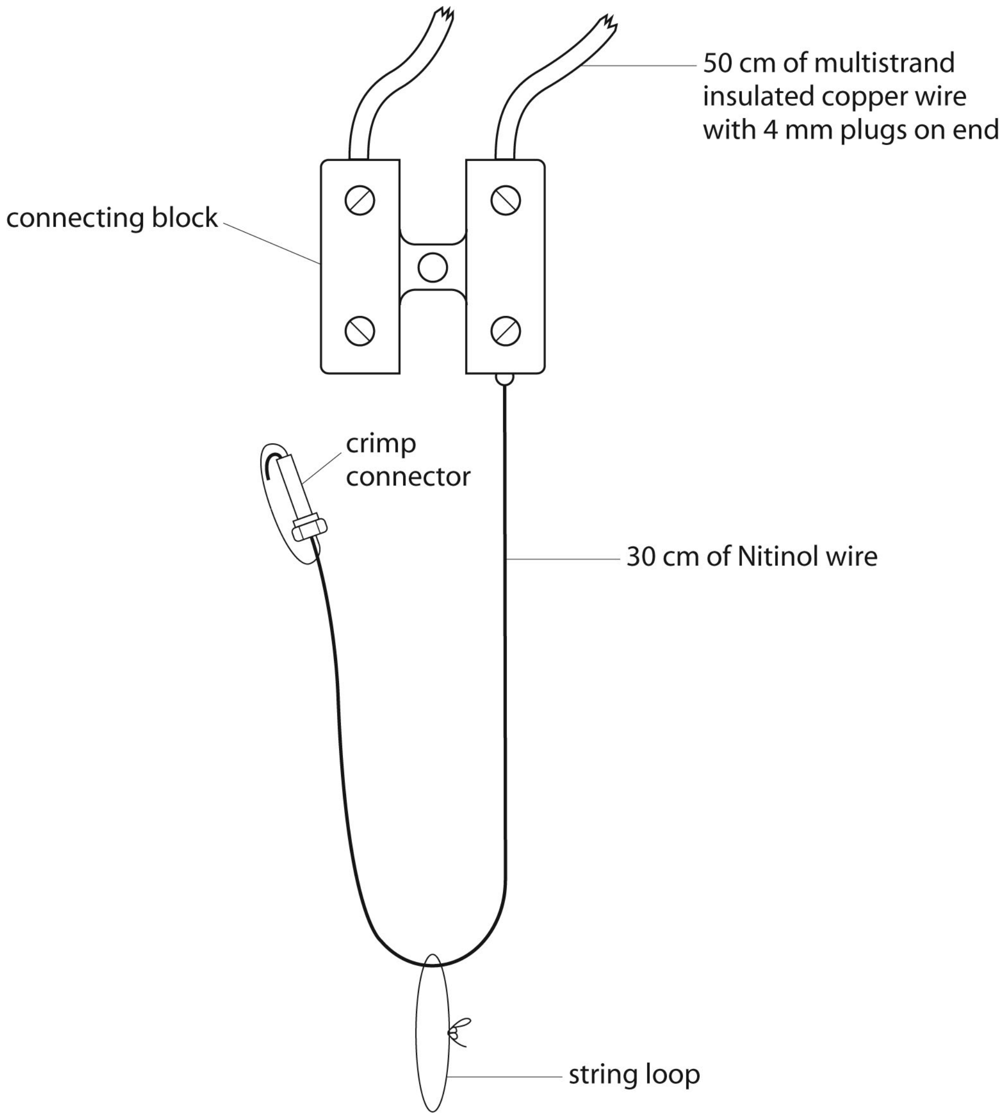
www.mutr.co.uk/prodDetail.aspx?prodID=179

You will need crimping fasteners as interfaces between the wire and the connecting block

www.mutr.co.uk/prodDetail.aspx?prodID=181

Loop the wire a couple of times through the fastener before crimping it. It can then be screwed into the connecting block as shown. Issuing each loop assembly in its own plastic bag stops tangling (see diagram, below).

Nitinol is an alloy of titanium and nickel which undergoes a phase change from a low density cubic structure to a high density close-packed structure at 70 ºC, shrinking by a few percent in the process. When heated to that temperature, its shape reverts to the original unstretched one, providing it hasn't been stretched too far.



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