Data Table

Trial	Mass (kg)	Δx (m)	T (°C)	ΔT (°C)	Mg (N)	PE_s (J)	PE_g (J)	Q
1								
2								
3								
4								
5								
6								
7								
AVE								

TEACHERS GUIDE

NITINOL SPRING
ITEM # 1001-18-S

ENERGY - HEAT

Nitinol (pronounced “night-in-all”) is an alloy metal that stands for Nickel (Ni), Titanium (Ti), and the “NOL” stands for the Naval Ordnance Laboratory where it was discovered. Bend it, then drop it into hot water and watch it return to its original shape! This crystalline metal changes phase around 45°C / 113°F. You can also retrain the wire by annealing it. First bend it into the desired shape, heat it to a dull red glow along the entire length, then cool it by immersing in water. After cooling, the wire can be deformed but will instantly return to its newly trained shape by dunking it into hot water!
Spring Coil inner diameter: 20mm, pitch: 1mm (spacing between loops), approx height of coiled spring 0.5”, length of wire: 18”, thickness: 0.75mm, standard transition temperature: very hot tap water or 45°C/113°F.

Materials

- one trained Nitinol spring
- four slotted masses
- one 50g hanging mass
- metric ruler
- s-hook
- 6 volt battery or low-amperage 6 volt power supply
- two leads with alligator clips
- thermocouple
- thermocouple reader
- spring scale
- ring stand
- battery clips
- two D batteries
- circuit light bulb
- small matchbox toy car

Goals & Objectives

See page 7 for applicable Next Generation Science Standards and AP Physics Standards

History

Scientists have known about and experimented with shape memory alloys (SMAs) since 1932, but it wasn't until 1962 that William Beuhler and his team, working at the US Naval labs, discovered the SMA effect in an alloy of nickel and titanium. This new material was relatively inexpensive and much safer (non-toxic) than previous SMA's. The team named their new alloy Nitinol (pronounced *night-in-all*).

The name represents the alloy's elemental components and place of origin. The "Ni" and "Ti" are the atomic symbols for nickel and titanium. The "NOL" stands for the Naval Ordnance Laboratory where it was discovered. The mixture of nickel to titanium in nitinol is about equal, but the smallest change in the ratio of the two compounds has a dramatic effect on the transition temperature of the resulting alloy. For instance, a 1% difference in the ratio varies the transition temperature from -100° to +100°C.

Every company manufacturing nitinol products today must hold the ratio of the components to a precise level to insure a stable and repeatable transition temperature.

Next Generation Science Standards

Students who demonstrate understanding can:

4-PS3-1. Use evidence to construct an explanation relating the speed of an object to the energy of that object.

4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy

HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Standards Key

K = Kindergarten
3 = Third Grade
(numbered by grade)
MS = Middle School
HS = High School
PS = Physical Science
LS = Life Science
ES = Earth Science

!

AP Physics 1 Standards

Essential Knowledge 1.C.1:
Inertial mass is the property of an object or a system that determines how motion changes when it interacts with other objects or systems.

Learning Objective 1.C.1.1.:
The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration.

Essential Knowledge 1.C.2:
Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields.

ACTIVITIES ALL AGES

1. Test the force the SMA spring can make. Stretch out the spring and hang from the s-hook. Attach the alligator clips. When the spring starts to resume its memory shape (contract), pull it down with a spring scale. Using just enough force to stop the spring from contracting.

2. Use D battery holders to connect in series two D batteries. This should be a 3v source. Four will be 6v and six will be 9v. Does the higher voltage make the spring contract faster? Using the vocabulary (kinetic energy, potential energy, electricity, velocity, and forces), explain your observations and make a conclusion. How could you test your conclusion to see if it is accurate?

3. Use the Nitinol spring as a part of a circuit with a small light bulb. Try the same circuit without the Nitinol wire. Is the light bulb dimmer? Why?

4. Design an experiment to pull the toy car with the spring. Imagine it is stuck off road. Calculate the work the spring can do to the car. W = Fd or W = PE (final) – PE(initial)

DISCUSSION

Additional Discussion and Real Life Applications

1. Nitinol is called an MRI compatible alloy. How can metals affect medical imaging?

2. There are many applications for Nitinol wire in the field of robotics. Research and present examples.

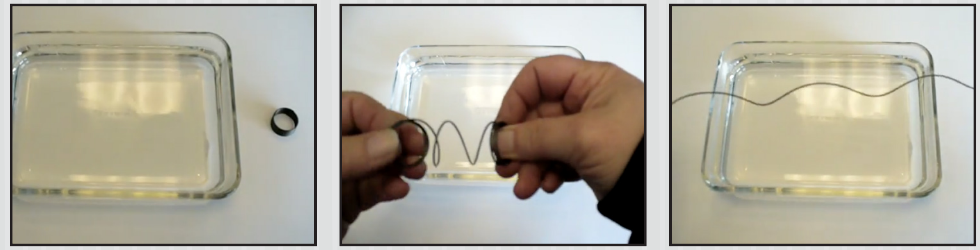
3. Be sure to discuss results from the Hooke's law and SMA labs with your students.

4. What other shape memory alloys are available?

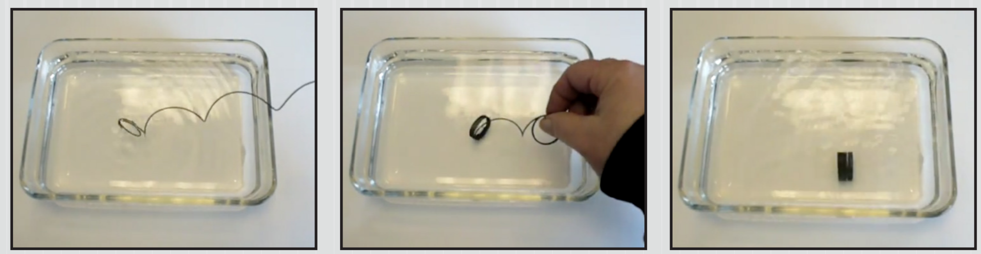
5. How does the ratio of the Ni – Ti affect the alloy?

How it works

Nitinol is an alloy that will remember whatever shape you select. Whenever you heat it to a certain temperature (called the transition temperature), the Nitinol Spring will automatically go back to the remembered shape.



When a trained Nitinol Spring is bent out of shape, and then released into hot water, it turns back to its original shape



GLOSSARY

- circuit
- electrical potential energy
- energy
- Hooke's law
- kinetic energy
- resistance
- spring force constant
- thermocouple
- work

ACTIVITIES ADVANCED

1 Determine the relationship between Force and Distance (x) for a nonlinear spring made of Nitinol (shape memory alloy), and the different Force Constants (k) of the SMA spring and compare it to data from a traditional non-SMA spring. Attach the spring to a ring stand or frame with the s-hook.

2 Record the "rest" position of the spring (let xo = 0.0 cm).

3 Add a 50g mass to extend the spring beyond its rest position (xo)

4 Attach one lead to the top loop of the spring and then to the positive node of a 6V battery.

5 Attach a second lead to the bottom loop of the spring. Do not attach it to the negative node of the 6V battery yet.

6 Attach the ends of the thermocouple to the center loop of your elongated spring and record the displacement (Δx), and the initial temperature T0.

7 When you have finished recording the initial data and your partner is ready to proceed, attach the second lead to the negative node of the 6V battery.

8 As your spring heats up, the mass will rise. You will record the position of the mass and the temperature when each of the following occurs:

a The mass begins to rise at a smooth rate of acceleration.

b The mass begins to decelerate.

c The mass stops.

9 As soon as the mass stops (do not let the temperature exceed 38°C) detach the lead at the battery's negative node and record the following positions and temperatures:

a The mass begins to fall at a smooth rate of acceleration.

b The mass begins to decelerate.

c The mass stops.

10 Take the load off the spring and reheat it (using the battery and alligator clips) until it is fully compressed.

11 Repeat #1-10 for 6 more masses; do not let the mass exceed 150g.

12 For each spring, plot a graph of Force (N) vs. distance (Δx).

Let g = 10 m/s2 when converting the masses to Newtons using F = mg.

Determine the slope (k) of the curve at 6 positions using the graphing calculator function for derivatives and write them in your data table.

What are the units and what does the slope represent?

Calculate the elastic potential energy in Joules for your spring at the various Δx's that you found the k's for.

Plot this energy on a graph by using PEs = 1/2kx2 for the vertical and Δx for the horizontal.

Calculate the gravitational potential energy of the spring mass system for the positions recorded in #2.

Using the Law of Conservation of Energy, determine the energy lost to the environment by finding the heat energy added to the spring by the battery. Use the formula for heat energy (Q = mcDT) and subtract the sum of the elastic and gravitational potential energy for two of your Δx's.

Calculate the efficiency of the Nitinol Spring using:

$$eff = \frac{|Q - PE_T|}{Q} \times 100\%$$

Compare your force constant for the SMA spring to the spring from the Hooke's Law lab and draw a conclusion about the magnitude of the force constant k and the "stretchability" of an SMA spring.

Using what you have learned about SMA's and their pseudoelastic behavior, how much more work can SMAs do compared to linear springs?

Compare the results from the efficiency of the linear spring to the SMA spring.

ADVANCED ACTIVITIES

Data Table Find a larger, reproducible version of this table on Page 8

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