Memory Metal: Using Shape Memory Metals in Simple Machines

Student Materials

Investigation 1
Exploring Memory Metals

You will have a chance to investigate the piece of wire that has been provided by your instructor. This wire is part of a general group of metals called "memory metals" or "smart metals". This particular metal is called Nitinol. It is a metal **alloy**. An alloy is a combination of two or more metals. Nitinol contains roughly equal numbers of nickel and titanium atoms.

Please use extreme caution when using hot water in the procedures below. Wear safety goggles when working with the hot water.

1. Your teacher will give you a piece of memory metal. Make coils in the wire by wrapping it around your pencil several times. Is the wire easy or difficult to bend?

2. Place the wire into a beaker of hot water. What happened?

3. Use two tongs to try to bend the wire while it is in the hot water. What happens? Take the wire out of the hot water using the tongs. How is the wire different than it was when it was at room temperature?

4. Set the metal on a table and watch what happens as the metal cools. Try to bend it as it cools. What happens?

5. What questions came to mind as you performed this experiment? What questions do you have about the things you have just observed? What else would you like to know about memory metals?

6. Why do you think these wires fall into a category called "smart materials" or "memory metals"?

7. What do you think might be happening when the metal is heated up and cooled down? What do you think might be happening to the atoms inside the metal?

8. Have you ever seen memory metals used before? Can you think of ways engineers might use these memory metals to solve problems.

Investigation 2
Form and Function

In Investigation 1, you had the opportunity to observe how Nitinol behaves when heated and cooled. Scientists studying Nitinol have determined that there are two different phases of Nitinol, one is a high temperature phase and the other is a low temperature phase. In this investigation, you will use your observation skills to match the structures presented below with the phase at which that structure is found.

The structures below each show two **unit cells**. A unit cell is a small portion of a material's atomic structure. This unit cell can be repeated in all directions to show the full structure of the material. One analogy is to use 27 sugar cubes to build one larger cube. Another oversimplified analogy is a cob of corn. Each individual kernel of corn represents one unit cell of the structure. The basic kernel shape is repeated over and over again in regular patterns to form the entire cob of corn.

The diagram below shows the martensite and austenite phases of Nitinol. One of the phases is the high temperature phase and the other is the low temperature phase. You'll have to figure out which one is which.

Martensite

b a

γ

c

Austenite

a, b, and c are not equal,
γ is about 96°

CsCl Structure (cubic)
a = b = c
α = β = γ = 90°

<u>Key</u>

Nickel

Titanium

1. As assigned by your teacher, build simple models of austenite and martensite. Use these model and/ or the diagrams above to answer the following questions.

2. Compare the models of austenite and martensite. How are their basic structures different?

3. Test the strength and flexibility of the martensite and austenite phase models. Which one is stronger? Which one is more flexible?

4. From what you have learned about these structures and by testing the strength of your models, which do you think would be the more flexible low temperature phase of the wire in Investigation 1? Explain.

Investigation 3
Properties of Martensite and Austenite

Part I: Review

1. In the last investigation, we matched each phase of NiTi with its structure. Martensite is found in which temperature phase, high temperature or low temperature?__________ . Austenite is found in which temperature phase, high temperature or low temperature? __________

2. What we learned in Investigation 2 can be summarized by the following equations:

   Equation 1: martensite + energy = austenite

   Equation 2: austenite – energy = martensite

In your own words, restate what each equation means.

Equation 1:

Equation 2:

3. As you have already learned, Nitinol is a mixture of nickel and titanium. By slightly changing the amount of nickel that is mixed with the titanium, material scientists can change the temperatures at which Nitinol changes from martensite to austenite. Depending on the mixture, Nitinol can be in the martensite phase at room temperature or in the austenite phase at room temperature.
4. You will be given two samples of Nitinol. One is in the austenite phase, the other in the martensite phase. One is called Sample A and the other Sample B. Try to bend each sample. Which sample is the martensite phase? __________________How can you tell?

5. Try scratching the samples with one another. Which sample is scratched by the other? _____________________

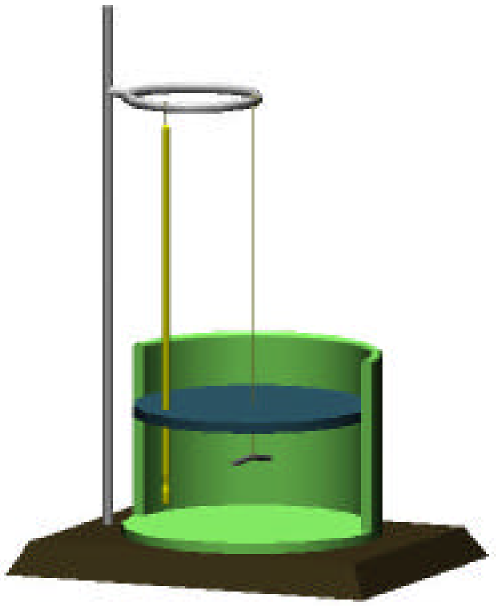
Part II: Moving from Austenite to Martensite

6. Place the austenite sample in the liquid nitrogen or dry ice/ acetone bath. What happens? Why?

7. After bending the cold sample, how do you return it to its original shape?

Part III: Transition Temperature

As you found out in Investigation 1, a martensite sample can be returned to it original shape by heating it with hot water. By changing how much nickel is in the NiTi, material scientist can change how warm the martensite has to be before it returns to the austenite phase. This is called the **transition temperature**. This is the temperature at which the wire changes from austenite to martensite and vice versa.



8. Bend the martensite sample. Set up your equipment as shown above (beaker is cut open to show placement of the Nitinol and thermometer). It is very important that the neither the thermometer nor the memory metal sample touch the bottom of the beaker or hot pot since the temperature of the heat element or the beaker will not be the same as the temperature of the water. Tie a string to the martensite rod so it can be suspended in the hot water. Slowly heat up the water in the beaker. As the water is heated, you will probably notice that the wire begins to straighten out. Carefully observe the wire. When it has become completely rigid and has returned to its original shape, record the temperature. This is the transition temperature. At what temperature does the sample fully transform into austenite? ________________

Part IV: Analysis

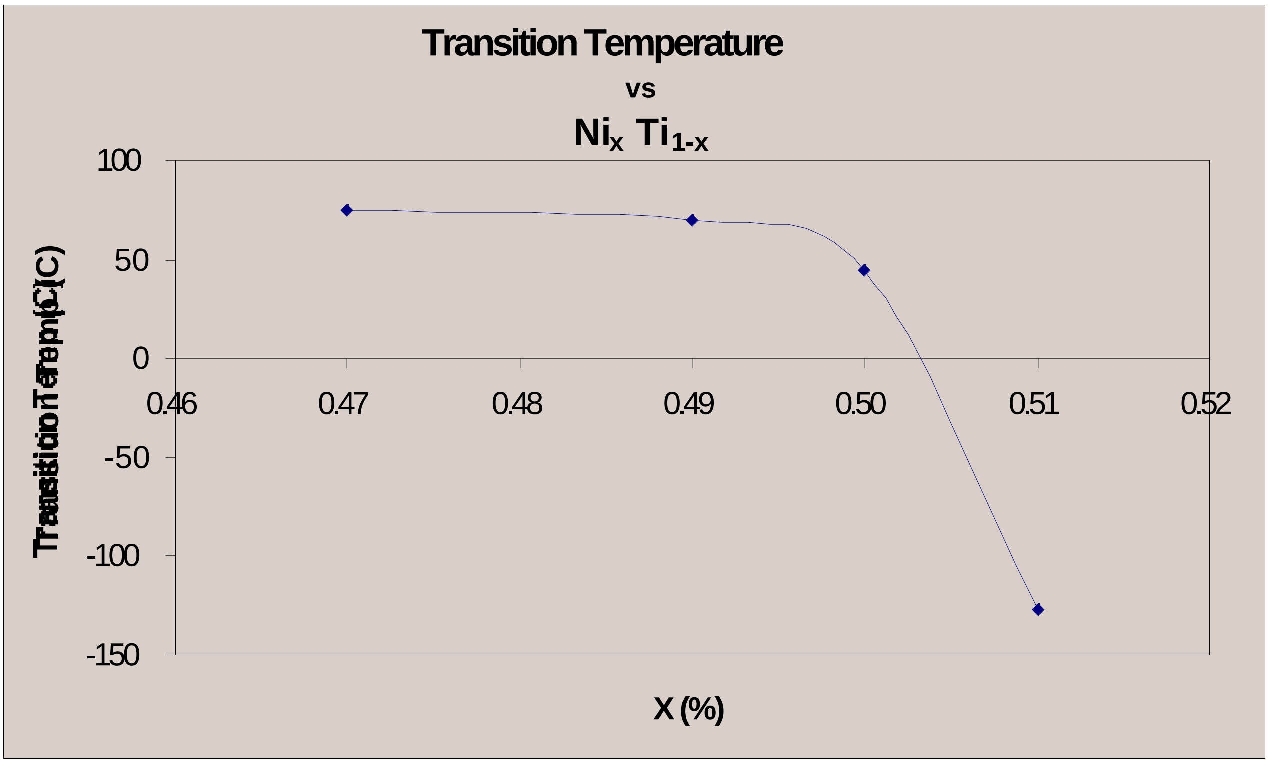
9. Obtain the transition temperatures of all the other students in the class. Average the data. What is the average transition temperature? ________________

10. Use the graph on the next page and determine what percentage of nickel the wire sample contains using the average transition temperature data above. What percentage of the sample is nickel? _____________________

11. If you wanted to use Nitinol that become soft and flexible when placed in an ice bath (0 C), about what percentage of nickel might you use? Select one.

a. 49.5% b.50.0% c. 50.5% d. 51.0%

12. Flexible, "unbreakable" eyeglass frames are made with Nitinol memory metal in the austenite phase at room temperature. If the frames are made with 50.5% nickel, what might happen to eyeglass frames worn in Antarctica on a very cold day (about – 60 C)? Explain.



Investigation 4
Acoustic Properties of Nitinol

1. Compare the two Nitinol rods you have been given. Determine which of the rods is in the martensite phase. How can you tell it is in the martensite phase?

2. Drop each of the Nitinol rods onto the table from a height of one meter above the tabletop. . The rod should be held parallel to the tabletop as it is dropped. Note the nature of the sound that the rod produces. Would you categorize the sound of the martensite as a "thud" or a ring? How would you categorize the sound of the austenite?

3. Using tongs, drop the martensite rod in a beaker of boiling or near boiling. Remove it from the water with tongs. As in step 2, drop the rod onto the tabletop from a height of one meter (the rod should be held parallel to the counter as it is dropped). Note the nature of the sound that the rod produces (thud, ring, or an intermediate sound). Quickly pick it up with your fingers (it will cool off rapidly) and drop it again, making sure to note the nature of the sound. Continue to pick up and drop the rod until there is no more change in sound (about 2-3 times).

4. Describe the changes in sound produced as the rod cooled.

5. Knowing what you do about atomic structure of martensite and austenite, how might you explain the different sounds they make when dropped? How do you account for the change in sound as the rod moves from the martensite to austenite phase?

Investigation 5
Changing the Shape of a Memory Metal Rod

So far in our investigations we have been changing NiTi rods from one phase to another using hot water or liquid nitrogen. We have found that heating the rods returns them to their rigid austenite phase. The rods we have used thus far straightened as they returned to the austenite phase.

You may have wondered if it is possible to change the shape of the Nitinol rod so that it returns to a different shape when heated. You may have also wondered how the rod's original shape is always "remembered." This ability to "remember" its original shape is caused by small gaps or defects. All the atoms in the metal are not perfectly arranged.

Consider the cob of corn we used to understand what a unit cell is. For the most part, the kernels of corn repeat over and over again in regular ways to form a full cob. Usually there are straight rows from one end of the cob to the other. However, some kernels of corn do not neatly fit into the rows and may even form small, distorted rows. There may even be gaps between rows in some places. We could call these areas of "misplaced" kernels and the gaps between rows **defects**. In a very similar way, "misplaced" atoms and gaps form defects in the NiTi. This unique set of defects and atom arrangements give the Nitinol its "remembered" shape, the shape to which it returns when heated. Your teacher might also show you another analogy using BB boards that demonstrates this same concept.

To give the metal a new shape it is necessary to create a new set of defects that will in turn force the metal to return to this new shape upon mild heating through the martensite-to-austenite phase change. This new set of defects can only be obtained by heating the metal sample to approximately 500^{o}C while it is secured in the new shape. This large amount of thermal energy excites the atoms. As the metal cools, atoms settle into lower energy positions specific to the new shape, thus creating a new set of defects.

1. Using two tongs, grasp the wire at its ends (CAUTION, the ends may be sharp!), and hold the middle of the wire over the flame. When the middle of wire becomes red hot, bend it into a V-shape using the tongs and place the middle of the V into the center of a candle flame.

2. Cool the wire by blowing on the wire, straighten out the wire, place in a cup or beaker, and cover with hot water. What happens?

3. In a similar fashion, return the wire to its original shape.

4. Why can't you use hot water to retrain the wire to "remember" a new shape?

Investigation 6
Heating Memory Metals

In the previous investigations we used hot water to change memory metal samples from the martensite to the austenite phase. If we want to use memory metals for practical applications, it is useful to find other ways of heating the memory metal.

1. What might be some other ways to heat the memory to its transition temperature? Brainstorm possibilities and list them below.

2. Design an experiment to test one of these possible ways of heating the wire. Describe your procedure below. Draw a diagram to show how you will test this heating method.

3. What materials will you need?

4. Carry out your experiment. Did your original idea work? Did you make any modification to the original design to make it work. Be ready to demonstrate your experiment and share the results with the rest of the class.

Investigation 7
Practical Applications

As you have learned in previous investigations, Nitinol can be retrained in different shapes and can be made to transition between phases at different temperatures depending on its composition. Because of these unique qualities, it has a wide range of uses in industry, health, art, and home use. It can be made into sheets of Nitinol, Nitinol tubes, or very thin wires. Since Nitinol has the capability of remembering its shape, this "smart" material can sense changes in its environment. It can respond to temperature changes in a pre-programmed way. This new high-tech solid can consequently be used in a variety of artistic, medical, and engineering applications.

As assigned by your teacher, brainstorm and identify real life problems that could be solved using memory metal or toys that could incorporate memory metals. When brainstorming is complete, choose one problem to solve or an idea for a memory metal toy. On posterboard, draft a diagram of the design for your solution to this problem or draft a design for a toy that uses this material. Clearly label the parts of the diagram. On the poster, write a paragraph describing how the device or toy might work. Be prepared to share your idea with other students.

Possible Problems to Be Solved

Possible Memory Metal Toys

Toy or problem I have chosen:

Design Draft:

Investigation 8
Motorless Motion

For engineers, one the most exciting aspects of memory metal is that it is capable of providing motion with out the use of a motor. Memory metal can easily be caused to contract by running an electric current through it. As the current passes through the wire, the wire heats up and moves from the martensite to austenite phases. When the current is removed, the metal cools and returns to its original phase. Use of a current to heat the wire can provide a simple way to regulate the movement of the wire.

You will be provided plans for building a catapult and a paper airplane launcher using a lynch pin that is pulled by a memory metal attached to a simple circuit. With the materials provided, build one of the two devices.

Memory Metal Assessment

Matching

Match the word with the best definition.

____ 1. Austenite	a. a pattern than can be shifted repeatedly to create the entire structure of atoms in crystal
____ 2. martensite	b. a solid solution composed of two or more metals
____ 3. transition temperature	c. alloy containing nearly equal amounts of nickel and titanium
____ 4. Nitinol	d. a physical state of matter
	e. a substance that can respond to stimuli in its environment
____ 5. alloy	
____ 6. smart material	g. high temperature phase
____ 7. unit cell	h. low temperature phase
____ 8. phase	i. the temperature at which a phase transformation occurs

Multiple Choice

Choose the best answer.

_______ 9. Austenite exhibits which characteristic?

a. contains more nickel than martensite
b. is more rigid than martensite
c. is more flexible than martensite
d. both a and c

_______ 10. At room temperature Nitinol can exist in either of two structures, which are dependent upon

a. the mass of the sample.
b. the exact ratio of Ni to Ti.
c. the length of the sample.
d. the diameter of the rod.

________ 11. In some phase changes like that of ice and water, there is a noticeable change; however, there is no visible phase change between austenite and martensite because

a. it only occurs at the atomic level.
b. only two atoms exchange places.
c. the structures are the same
d. the temperature is too high
e. no phase change occurs.

12. Describe why heating a memory metal sample to over 500 C causes it to take on a new “remembered” shape.