

TEACHER INSTRUCTIONS

Shape Memory Alloys

Objective: To learn how the motion of atoms under added heat can change the shape of metals.

Background Information: Nitinol is a nickel titanium alloy (~50% Ni, ~50% Ti) which has two phases or crystalline structures, a high temperature (austenite) and a low temperature (martensite), shown in Figure 1. The low temperature phase is weaker, allowing the material to be bent and pulled out of shape. When deformed at a low temperature and then heated, nitinol will return to the shape established when in the high temperature, stronger phase. By heating the material, the atoms are given enough energy to rearrange themselves back to their high temperature phase. The composition of the wire can be varied slightly to change the transformation temperature. This ability to remember and revert to the original shape gives this material the name “shape memory.”

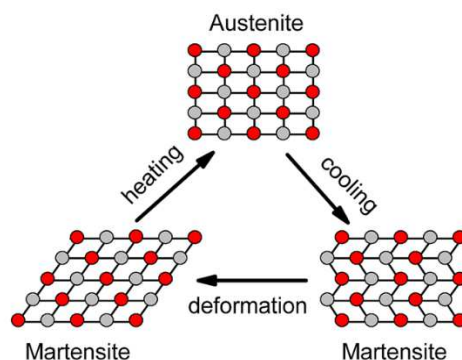


Figure 1. When deformed at a low temperature and then heated, nitinol will return to the shape established at the high temperature as the atoms rearrange themselves back to their high temperature positions.

In this demo, a nano-scale change is impacting the macro-scale. When heated, nitinol wire that has shape memory properties will return to its original shape due to changes that are happening on the nano-scale. See the Introductory Presentation for a top view of the atomic arrangements during this transition. In comparison, a piece of normal steel wire (whose composition is generally iron and carbon) will be unaffected by the addition of heat and maintain its deformed shape. Nitinol is an ordered intermetallic compound. This means that the atoms have very specific locations in the crystal structure. Nitinol is a popular choice for a variety of applications: as a material in temperature control systems, retractable antennas in cell phones, springs in orthodontic braces, and for eyeglass frames. See the introductory PowerPoint presentation on the flash drive in the kit for examples of real-world applications of shape memory alloys.

Demo Description: During this demo, students will see how a shape memory alloy can return to its original shape when heat is applied.

Keywords:

- phase – the region of a material that is chemically uniform, physically distinct, and usually mechanically separable.
- phase change – a change from one phase to another (often caused by a change in temperature).
- thermal shape memory – the ability of a material to return to its original, cold-forged shape when heated.
- alloy – a metal containing two or more elements.
- nanoscale – features smaller than 1/10 of a micrometer.
- macroscale – features measurable and observable with the naked eye.
- crystal structure – unique and orderly arrangement of atoms or molecules in a crystalline material.

Materials List:

Items provided in the kit:

- 6 inches of nitinol wire
- 6 inches of steel wire
- glass beaker

Items to be provided by the teacher/school:

- hotplate
- needle nose pliers
- water

Safety Precautions: Safety glasses should be worn in case of water splashing. The beaker and hot plate can get very hot. Use the beaker tongs to handle the beaker during the demo to avoid accidental burns. After the demo, be careful not to touch the wire, water, beaker or hot plate until they have completely cooled!

Instructions:

1. Fill the beaker with water.
2. Place the beaker on the hot plate and turn to the high temperature setting. The water should be heated to just below boiling.
3. Bend the nitinol wire to a desired shape.
4. Place the nitinol wire in the hot water.
5. The nitinol wire should immediately return to its original shape.
6. Remove the nitinol wire from the beaker using the pliers and show it to the students.

7. Repeat steps 3 - 6, trying different shapes and amounts of deformation.
8. Repeat steps 3 - 6 with the steel wire.

Demo Delivery Hints: Try coiling the wire into a tight spring and tossing it into the water. If done correctly, the nitinol wire will “jump” out of the beaker. Students can be asked to bend the wire or place it in the water for a more interactive demonstration.

Troubleshooting: Do not make sharp corners in the nitinol wire or tie it into knots. The wire is limited on how much deformation it can recover from.

Cleanup/Replacement Parts: Turn off the hot plate and allow it, the beaker, and the water to cool down. Pour out the water. Do not return the supplies to the kit until they are cool to the touch.

TEACHER DISCUSSION QUESTIONS

Shape Memory Alloy

Discussion Questions to Ask Before the Demo

1. Can nano-scale changes impact the macro-scale?

Discussion: Yes, this demo shows how the movement of atoms just a very small distance can cause the macroscale shape of the metal to change.

2. What do you expect to happen when the nitinol wire is placed in the water?

Discussion: Encourage the students to discuss what they think. Do they think the wire will stay the same, expand, or return to its original shape?

3. What is a phase?

Discussion: A simple definition is a region of material that is physically distinct, and has its own state (solid, liquid or gas), own arrangement of atoms (crystal structure), and composition.

Discussion Questions to Ask During the Demo

1. Once the nitinol wire is placed in the water, what do you see?

Discussion: The nitinol wire should start straightening out. Depending on what shape you bent the wire in (such as a spring-like shape), the wire may tend to “jump” or “pop” out of the water.

2. Why did the nitinol wire change?

Discussion: The atoms are rearranging themselves back to the positions for the high temperature phase.

3. Does the same thing happen with the normal steel wire?

Discussion: The steel wire should remain in the same shape as it was bent. No change or reactions occur, therefore the wire does not return to its original shape.

Discussion Questions to Ask After the Demo

1. Why does the nitinol wire change shape, but not the steel wire?

Discussion: The nitinol wire has two distinct, ordered phases. The high temperature phase is called austenite and the low temperature phase, martensite. During this demo, the atoms in the nitinol wire are undergoing a phase transformation between the low temperature martensite and the high temperature austenite. The steel wire remains the same, regardless of temperature, as it does not undergo any phase transitions and is not an ordered intermetallic.

2. What uses can you think of for materials that have this special behavior?

Discussion: Nitinol is a popular choice for a variety of applications: as a material in temperature control systems, retractable antennas in cell phones, springs in orthodontic braces, and for eyeglass frames! It was even used in the Mars Rover as part of a sensor used to close delicate ports and prevent damage.

STUDENT QUESTION HANDOUT

Shape Memory Alloy

1. Define the following keywords:

phase:

phase change:

thermal shape memory:

alloy:

nanoscale:

macroscale:

crystal structure:

2. What is happening to the atoms as the nitinol wire heats up?

3. What is the difference between the nitinol wire and the steel wire?