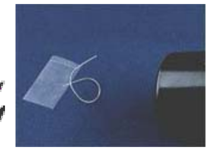

Memory Metal Activity Guide

Quick Reference Activity Guide

Activity Materials

NiTi wire samples (low-temperature martensite phase approximately 3” long x 0.03” diameter).
Source of heat (hot water or a hair dryer).

Optional: Overhead projector with tape and hair dryer or clear dish of hot water

Starting Points

“Smart” materials have the capability to sense changes in their environment and respond to the changes in a preprogrammed way. This demonstration can serve as an example of smart materials, with a discussion focussing on potential uses.

Does the arrangement of atoms in a material affect its properties? NiTi has two different solid structures that interchange near room temperature. These two phases of NiTi have the same chemical composition and the demonstration could focus on their different physical properties.

During the phase change the atoms move very slightly in an atomic ballet. The demonstration could emphasize the incredible number of atoms in the sample if very small atom shifts cause such a large macroscopic change.

The superelastic properties of NiTi are a demonstration of Le Chatelier’s principle of chemical equilibrium since the material responds to pressure and temperature by changing to partially counteract the applied stress.

A student with braces provides the perfect opportunity – ask the student, “Do you know that you have memory metal in your mouth?” Most dental arch wires that are attached to the braces are made from NiTi memory metal. These used to be made of stainless steel, but the memory metal makes the process of moving teeth less painful and requires fewer visits to the orthodontist.

Demonstration Procedures

Show the linear shape of a sample of NiTi wire. Ask someone to coil the wire around his or her finger. Holding one end of the coiled wire, apply heat by dipping in hot water or holding one end in a stream of hot air. As the wire is heated, it transforms into the high-temperature austenite phase and straightens back into the linear shape it had been “trained” to remember.

Optional: This demonstration can also be done using an overhead projector. Use a clear dish of hot water or tape the bent wire to the overhead projector and use a hair dryer to return the wire to its original shape.

Fact Sheet

Memory metal is sometimes called Nitinol, which is short for **ni**ckel **ti**tanium **N**aval **O**rdnance **L**aboratory and which acknowledges the site of its discovery in 1965.

There are actually numerous metal alloys that can display shape memory properties, however, NiTi alloys have been the most commercially successful because of their ability to display large reversible strains and undergo transformations at temperatures near room temperature.

Shape Memory: The ability of certain alloys to return to a predetermined shape upon heating via a phase transformation.

Superelasticity: The springy, "rubber-like" behavior present in NiTi shape memory alloys at higher temperatures relative to the particular alloy's transformation temperature. The superelasticity arises from the formation and reversion of stress-induced martensite.

Phase Transformation: The change from one alloy phase to another with a change in temperature, pressure, stress, chemistry, and/or time.

Austenite: The stronger, higher temperature phase present in NiTi.
Martensite: The more deformable, lower temperature phase present in NiTi.

Nickel titanium (NiTi) is a shape memory alloy used in a wide variety of biomedical, aerospace, automotive and other applications. The most common use of NiTi that people are familiar with is the dental arch wire used in orthodontic braces. NiTi is also used to make high integrity couplings and connectors for defense, aerospace, and electronic applications where space savings and reliability are of key importance.

Applications are based on memory metal's thermal shape memory, flexibility and kink resistance permitting significant bending without permanent deformation, constancy of stress over a wide range of strain, and biocompatibility.

Commercial products include actuators, eyeglass frames, cell phone antennas, brassiere wire, orthodontic archwires, stents, medical guidewires, and surgical staples.

References

A. B. Ellis, M. J. Geselbracht, B. J. Johnson, G. C. Lisensky, and W. R. Robinson, *Teaching General Chemistry: A Materials Science Companion*, ACS Books, 1993, Chapter 9.

For movies see these pages in the Cineplex:
http://mrsec.wisc.edu/edetc/cineplex/sound/index.html
http://mrsec.wisc.edu/edetc/cineplex/mystery/index.html
http://mrsec.wisc.edu/edetc/cineplex/NiTi/index.html

Shape Memory Application, Inc.
http://www.sma-inc.com/

Authors: George Lisensky, Cindy Widstrand, Amy Payne, Wendy Crone, Janet Kennedy, Mike Condren, Ken Lux, and Arthur Ellis

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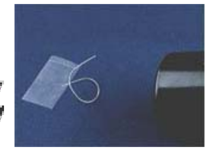

Background and Supporting Information

NiTi materials display an astonishing, counterintuitive property: they can be distorted into a variety of shapes while in their low-temperature phase at room temperature, then, upon gentle warming into the high-temperature phase, the samples will return to their original shape. Cooling the sample from its high-temperature phase into its low-temperature phase will not generally cause an observable change in its shape.

The different structures of austenite and martensite result in considerably different mechanical properties for the two phases. The austenite structure is relatively rigid and hard. In contrast, the ability to re-orient variants of the martensite phase imparts mechanical flexibility and makes the low-temperature phase a little softer than the high-temperature phase.

Applying mechanical pressure to NiTi in the lower density austenite form can cause the transformation to higher density martensite. When the stress is removed, the martensite phase will transform back to the austenite phase and the NiTi will return to its original shape. This mechanical property is sometimes known as superelasticity.

The regular structure of the austenite leads to a ringing sound when a sample is dropped or struck: a sound wave launched in the material travels relatively unimpeded through it. In the martensite phase, the boundaries between regions with different orientations (the variants) appear to act as baffles for vibrations, resulting in a more muffled-sounding thud when martensitic samples are dropped

To give the NiTi a new shape to remember requires substantial energy, provided, for example, by heating the NiTi in a candle flame to about 500 °C, while it is physically held in the desired shape. During the annealing (heating) process, the atoms surrounding the defects gain enough energy to relax into lower energy configurations, and this new configuration of defects effectively pins the austenite into its new shape. The gentle heating used in the shape-memory demonstration to return to the austenite phase from the martensite phase does not provide enough energy to allow the defects to readjust.

In addition to the basic demonstration of a wire regaining its original shape upon heating, several additional experiments are described below.

Extension 1: Wire Retraining

Activity Materials: Candle and matches

Grasp the two ends of the wire, and place the middle of the wire in the center of the candle flame. Try to bend the wire into a V-shape. It will yield as it becomes hot, at which point it should be removed immediately from the flame. After the wire has cooled for a few seconds, repeat the original demonstration, but this time the wire will now return to the V-shape, not the linear shape.

Extension 2: Acoustic Properties of Rods

Activity Materials: Liquid nitrogen, Styrofoam cup, tongs, gloves, and NiTi rods (0.10" diameter) with slightly different Ni:Ti atomic ratios so you have both the low-temperature (martensitic rods) and high-temperature phase (austenitic rods) at room temperature.

CAUTION: Liquid nitrogen is extremely cold. Do not allow it to come into contact with skin or clothing, as severe frostbite may result.

Simply dropping them reveals the characteristic acoustic signatures of the two phases of NiTi. The high-temperature austenite rods will ring like a bell, and the low-temperature martensite samples will yield a dull thud! Cool the high temperature phase in liquid nitrogen and then repeatedly drop the sample on a hard surface as it warms back to room temperature.

Extension 3: Mechanical Properties of Rods

Activity Materials: Liquid nitrogen, Styrofoam cup, tongs, gloves, and NiTi rods (0.10" diameter) with slightly different Ni:Ti atomic ratios so you have both the low-temperature (martensitic rods) and high-temperature phase (austenitic rods) at room temperature.

CAUTION: Liquid nitrogen is extremely cold. Do not allow it to come into contact with skin or clothing, as severe frostbite may result.

Try to bend rods that are in the two different phases at room temperature. A rod that is in the high-temperature austenite phase at room temperature will be extremely difficult to bend into a V-shape. In contrast, a rod that is in the low-temperature martensite phase at room temperature is comparatively flexible. Of course, the bent rod can be placed in very hot water or in front of a heat gun to restore its linear shape.

Cool a high temperature austenite phase inflexible rod in liquid nitrogen in a Styrofoam cup. CAUTION: Liquid nitrogen is extremely cold. Do not allow it to come into contact with skin or clothing, as severe frostbite may result.

Use tongs to remove the rod from the liquid nitrogen. While wearing gloves, bend it into a V-shape. As the rod warms back to room temperature, it will return to a linear shape. (The bent rod can be placed on an overhead projector to show its return to linearity to an audience.)

Alternatively, immerse a rod that is in the martensite phase at room temperature in very hot water. It will become inflexible when hot and flexible as it cools back into the martensite phase.

Try to scratch a rod in the martensite phase with one in the austenite phase. The end of an austenitic rod will scratch the martensite, but a martensitic rod will not scratch the surface of the austenite. This activity demonstrates the hardness of the austenite compared to the martensite.

Extension 4: Glasses

Activity Materials: Liquid nitrogen, Styrofoam cup, and NiTi eyeglass frames

CAUTION: Liquid nitrogen is extremely cold. Do not allow it to come into contact with skin or clothing, as severe frostbite may result.

Lay the eyeglass frames on the overhead projector to show the initial shape.

Show that the when the frames are bent they snap back into their original shape. (This means that the metal is in the high temperature austenite phase. How could you show that this is true?)

Cool the center of one sidearm piece of the glasses in liquid nitrogen in a Styrofoam cup and bend to deform the glasses. Repeat with the other temple and then with the nose bridge. Try not to cool the area around the lenses.

Lay the bent frames on the bench top or on an overhead projector. Observe as the eyeglasses return to room temperature and return to their original shape.

By the end of the 2nd grade, students should know that*

- Objects can be described in terms of the materials they are made of (clay, cloth, paper, etc.) and their physical properties (color, size, shape, weight, texture, flexibility, etc.).
- Things can be done to materials to change some of their properties, but not all materials respond the same way to what is done to them.

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* (Taken from "Benchmarks for Science Literacy," Project 2061, American Association for the Advancement of Science, 1993.)

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By the end of the 5th grade, students should know that

- Heating and cooling cause changes in the properties of materials. Many kinds of changes occur faster under hotter conditions.
- Materials may be composed of parts that are too small to be seen without magnification.

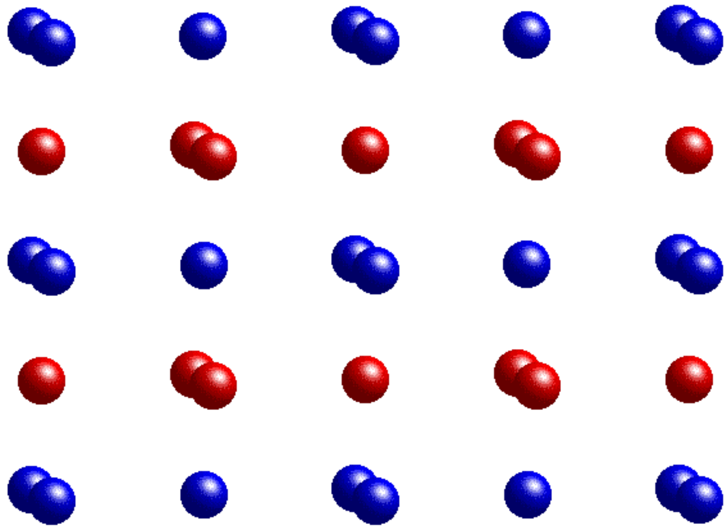
By the end of the 8th grade, students should know that

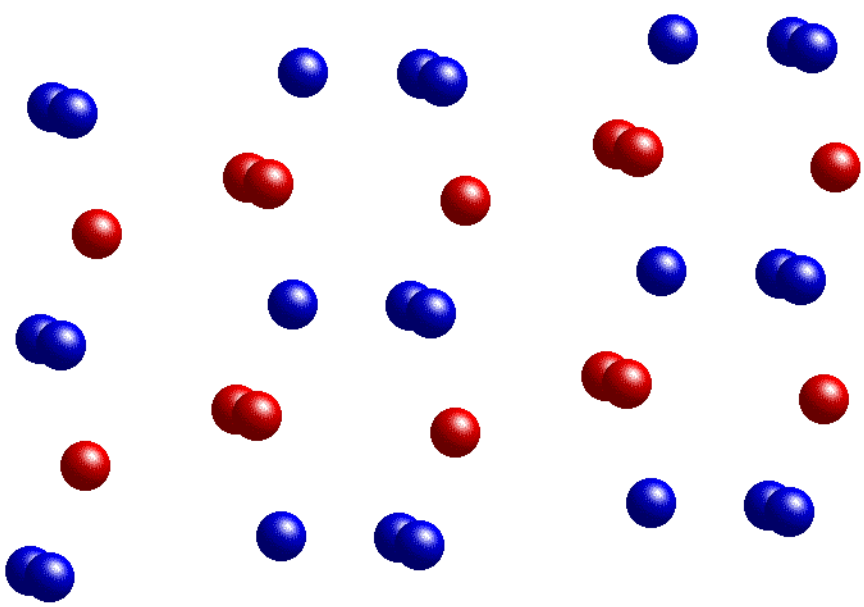
- All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.

By the end of the 12th grade, students should know that

- Atoms are made of a positive nucleus surrounded by negative electrons. An atom's electron configuration, particularly the outermost electrons, determines how the atom can interact with other atoms. Atoms form bonds to other atoms by transferring or sharing electrons.
- The nucleus, a tiny fraction of the volume of an atom, is composed of protons and neutrons, each almost two thousand times heavier than an electron. The number of positive protons in the nucleus determines what an atom's electron configuration can be and so defines the element. In a neutral atom, the number of electrons equals the number of protons. But an atom may acquire an unbalanced charge by gaining or losing electrons.
- Atoms often join with one another in various combinations in distinct molecules or in repeating three-dimensional crystal patterns. An enormous variety of biological, chemical, and physical phenomena can be explained by changes in the arrangement and motion of atoms and molecules.
- The configuration of atoms in a molecule determines the molecule's properties. Shapes are particularly important in how large molecules interact with others.

NiTi Solid-State Phase Transition





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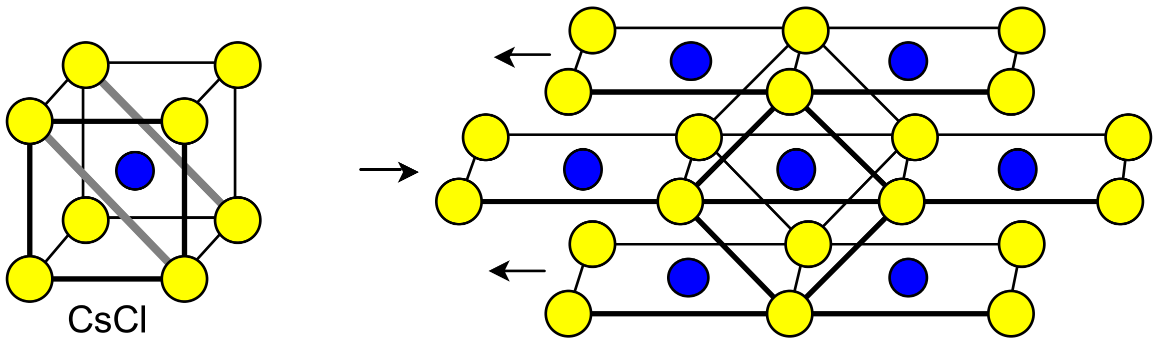
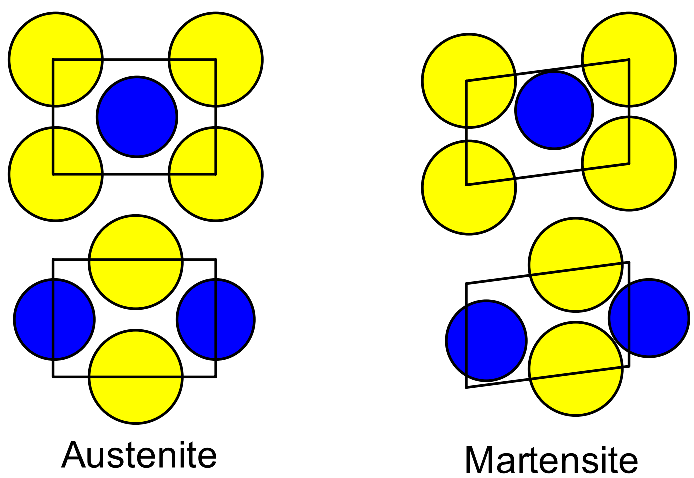
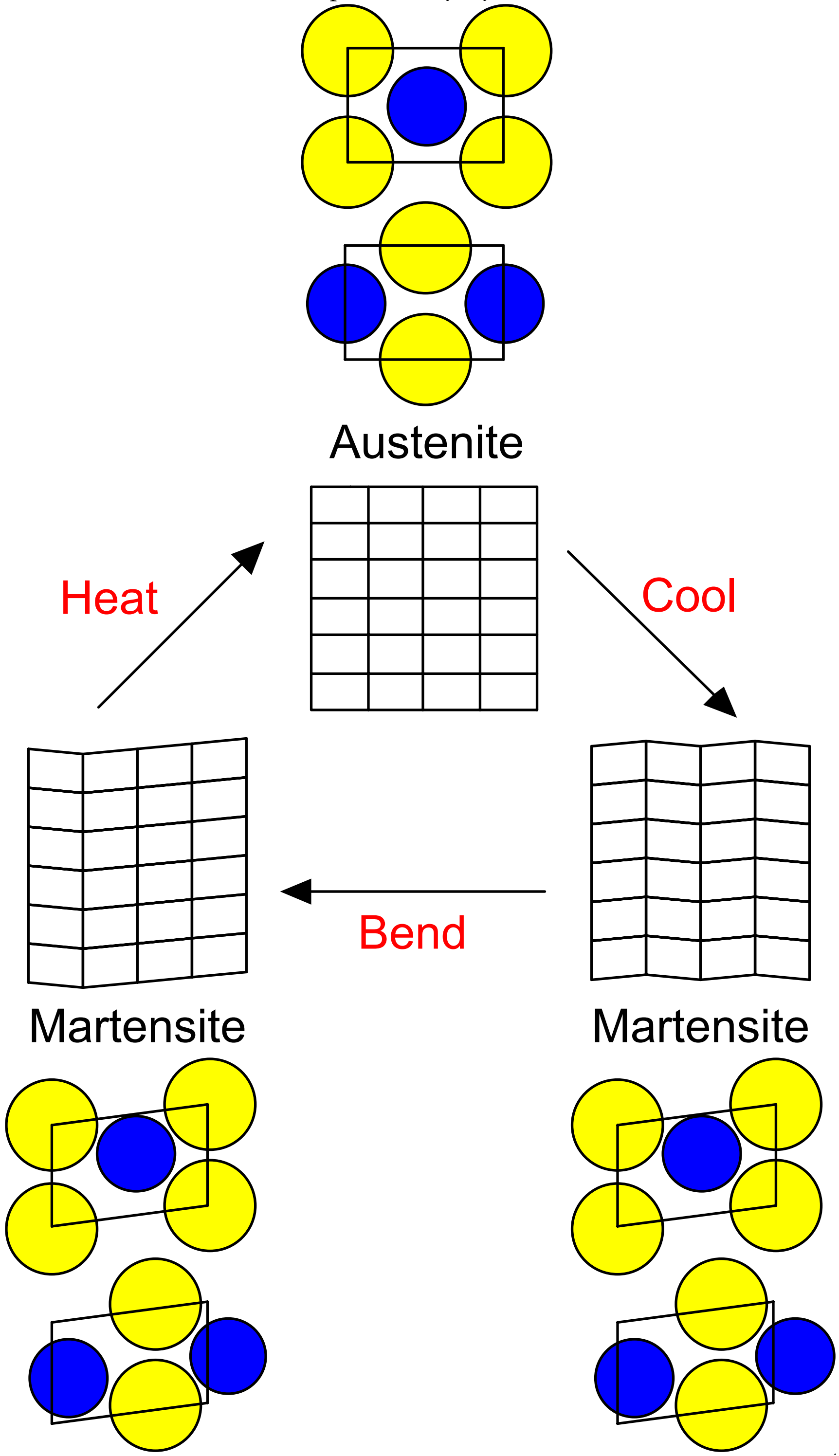


Representation by layer sequence in the unit cell:



Shape Memory Cycle



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Phase Transition Temperature
and Composition