Module Title: Phase Change Experiment: Nitinol and Bobby Pins		
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Time to complete module:

- Bobby Pin Exercise: 45 minutes with discussion for introductory classes or 30 minutes for advanced classes.
- Nitinol Demonstration: 5-10 minutes

Description of module, lab or demonstration:

Through the study of two different experiments students will become exposed to the effects of heat treating, a common metallurgical process and the martensitic-like transformation of Nitinol. Both activities provide students with a simple view of the change in mechanical properties which can occur through phase transformation.

Pre-requisite knowledge and skills:

A basic knowledge of crystal structure, although it is not necessary.

Materials Category:	Structure of Materials	☑
	Metals	☑
	Ceramics	❒
	Polymers	❒
	Composites	❒
	Other	❒
Target Grade Level(s) (Check all that apply)	Middle School 6-8	❒
	High School 9-12	☑
	Two-year College 13-14	☑
	Four-year College 15-16	❒

MatEd core competencies that the training meets

- 7.001 Describe the general nature of metals
- 9.101 Describe the primary constituents of steel

List of equipment and supplies needed:

30- safety glasses (PPE)

Part 1:
- Supply of standard bobby pins- 5 per group
- Bunsen burner or Propane torch
- Tongs
- Beaker of water

*If performing the activity as a laboratory, each group will require a set of supplies

Part 2: • Nitinol wire • Beaker • Means of heating the water- for example: a ring stand and Bunsen burner	
Curriculum overview and notes to instructor:	**Instructor Background and Notes** **Part 1 Bobby Pins:** Metals can be made stronger (harder) through a number of treatments. One is called "heat treating" and is unique to steels. Steels are alloys of iron with up to 1% carbon and exist in two important crystal structures. Body Centered Cubic (BCC) at room temperature and up to 1333 degrees Fahrenheit, then the structure changes to Face Centered Cubic (FCC). This change in structure, also called a phase change, is the key to heat-treating of steels because BCC dissolves only a small amount of carbon, with most of the carbon precipitating as a second phase, an iron carbide. This is the case in standard grade construction steel. The FCC phase has a much larger solubility limit for carbon so the carbon exists in a solid solution at the high temperature. When a high carbon steel is cooled from the FCC phase, two things can happen: • Slow cooling will cause the precipitation of the carbide phase, and the material will be reasonably soft and bendable; or • Rapid cooling will prevent the precipitation of the carbide phase because not enough time is available for the atoms to arrange themselves in the carbide phase. In the rapid cooling case, the carbon atoms end up sitting at random in the BCC structure, causing a distorted structure called "Martensite." This phase is hard and brittle and will break before it bends. Part 1 demonstrates this effect. Part 1 also demonstrates the importance of structure on properties of metals, and the role that processing has in ultimate properties of a manufactured part using a simple bend test. **Part 2, Nitinol:** In certain specialty alloys, phase changes can also cause the metal remember its former shape. This is seen specifically "shape-memory alloys" such as the nickel-titanium alloy called "Nitinol." Nitinol (an acronym for Nickel Titanium Naval Ordinance Laboratories where the alloy was discovered) is an alloy of nickel and titanium in

	different combinations; Nitinol to be used in this experiment should be 50-50 Ni-Ti, which gives it a transformation temperature below 200 degrees Fahrenheit. The phase change that causes the shape-memory effect is similar to the martensitic phase change in steel. The low temperature phase is a martensitic phase (like a deformed BCC) and the high temperature phase is similar to FCC. Different from steel, the martensitic low temperature phase is soft enough to bend and shape. In this experiment, starting at room temperature (Martensite) the Nitinol wire can then be bent into any desired shape. Heating into the FCC range, the wire "remembers" its shape when it was formerly in the FCC range, and reverts to that shape. When cooled the shape remains in the FCC shape while it transforms itself to Martensite. Note that bending too much will cause the Nitinol to permanently deform, but bending around one's figure works fine.
Mode of presentation: Laboratory or Demonstration	
Module	**Abstract:** In this experiment, students are introduced to the effects of changes in crystal structure ("phase") in metals, specifically in high carbon steels and in the shape memory alloy "Nitinol." Phase changes in both of these materials cause changes in properties (for steels) and shape (for Nitinol). First the students see the effects of steel heat treatment by heating and cooling bobby pins to form the hard and brittle phase, Martensite. Then the students see the effects of another martensite-like phase change that causes shape memory effects. These effects are specifically related to processing parameters, so these examples show the influence of properties on processing, as influenced by structure. **Experimental Procedure (Part 1-Bobby Pins):** 1. Each group of students should have 5 bobby pins 2. Hold one bobby pin by the ends and pull to open it up into a straight line. Bend it back. This is one bend. Count and record the number of bends needed to break the bobby pins. 3. Heat the second bobby pin at its sharp bend until it is red hot. Let this bobby pin cool slowly in air. 4. When the bobby pin is cool, bend it back and forth as before. Count and record the number of bends needed

to break this heat treated wire.

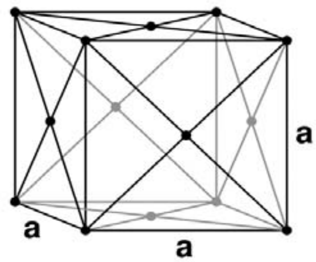
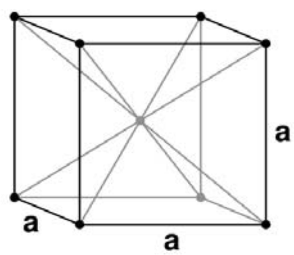
5. Fill the beaker with cold water.
6. Heat the third and fourth bobby pins in the flame until they are red hot and immediately plunge it into the water in the beaker.
7. When these bobby pins are cool, bend number 3 as before and record the number of bends needed to break it. Save the other heat treated bobby pin for process 8.
8. Heat the fourth bobby pin, one original and four broken. This process is called tempering. As before, bend the tempered wire and record the number of bends needed to break it.
9. You now have 5 bobby pins, one original and four broken. Compare the results. Discuss the differences and the effects of heat treating and tempering on the properties of this steel.
10. Discuss also what differences you might have seen if:
    - Bobby pin #2 had been quenched instead of slow cooled
    - Bobby pin #3 had not been heated enough to make it into the FCC phase;
    - Bobby pin #4 had been reheated until red hot then quenched in water followed. How important could these errors have been on the performance of similar steel?

Further Study:
Using the internet find the difference between heat treating and annealing a metal. Explain the differences. Can you find an annealing experiment that would show the differences?

Part 2 - Nitinol:
Note: Depending on the availability of Nitinol wire, this can be done as a demonstration or by groups of students.

1. Obtain a 6 in. length of Nitinol wire
2. Heat some water-keep it close to boiling temperature
3. Gently bend the wire around your finger to make a spring-like structure; sketch the shape that you have made.
4. Heat the wire in the hot water-observe the change in shape on heating; sketch the new shape of the wire.
5. Discuss possible applications of this effect

Teachers note: In fact, this effect is used in orthodontic

	stints to open up arteries and in a wide variety of sensors and toys. **Further Study:** Using the Internet, find and explain at least 2 applications of Nitinol used in dentistry, medicine, and/or toys.
Supporting handouts and supporting materials:	 **Figure 1.0:** Schematic of FCC crystal structure taken from http://en.wikipedia.org/wiki/Image:Lattice_face_centered_cubic.svg  **Figure 2.0:** Schematic of BCC crystal structure taken from http://en.wikipedia.org/wiki/Image:Lattice_body_centered_cubic.svg
References:	Wikipedia.org. (2007). *Steel*. Retrieved August 19, 2007 from http://en.wikipedia.org/wiki/Steel. Wikipedia.org. (2007). *Shape memory alloy*. Retrieved August 19, 2007 from http://en.wikipedia.org/wiki/Shape_memory_alloy Lin, R. (January 1996). *Shape memory alloys and their applications*. Retrieved August 19, 2007 from http://www.stanford.edu/~richlin1/sma/sma.html
Briefly describe how the effectiveness of the module was evaluated:	The effectiveness of the module was evaluated in "10 Simple and Effective In-class Experiments and Demonstrations for Materials Education." The review provides several notes and observations for the module.
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	for Materials Technology Education (MatEd) housed at Edmonds Community College. Dr. Stoebe is a Professor Emeritus in Materials Science and Engineering at the University of Washington and has been at the forefront of materials education in the United States.