Teacher's Preparatory Guide

Nanotechnology Invention and Design: Phase Changes, Energy, and Crystals

Overview: This 3-part lesson introduces the nanoscale effect of various energy inputs on the crystal lattice of a smart material, Nitinol, and then invites students to become nanotechnology inventors. Students will first explore how energy exchanges lead to solid-state phase changes at the macroscale and explore the applications of this nanotechnology. Students will measure the transition temperature at which the material "remembers" its shape, and then retrain the material into a new shape. Students will calculate the energy input required for the response in the smart material using the equation (1) $q = mc\Delta T$ and consider how that energy affects the crystal lattice at the nanoscale. Then students will examine models of the crystal lattice structures to make predictions about how the energy is affecting the nanoscale structures. Through class discussions of their predictions, students will link these energy exchanges to solid-state phase changes through plastic deformations in the crystal lattice structure at the nanoscale. Finally, students will become nanotechnology inventors and create a potential use for the smart material. Through their own experimental designs, students will determine which type of energy input would be the most effective at altering the nanoscale lattice and present their findings.

Purpose: This lab is designed to help students understand the nanoscale effect of various energy inputs on the crystal lattice of a smart material, Nitinol, and invites students to become nanotechnology inventors.

Time Required: Seven 55-minute classes, which include a pre-lab class and a student lab period

Level: High school Chemistry or Physical Science

Big Ideas: Forces and Interactions; Structure of Matter; Science and Technology

Teacher Background: Nanotechnology is defined as making use of the unique physical properties and interactions of nanoscale things (0.1–1000 nm) in order to create novel structures, devices, and systems.[1] A class of nanotechnology materials, called shape memory materials (SMM), are dubbed smart materials because they respond to changes in the environment. Materials scientists and engineers can design SMM that change shape in a dramatic fashion after exposure to energy inputs like heat, light, or electricity, and remember their original shape. The SMM is not only an attention grabber in class, but has many applications, such as heart stents, thermostat control wires, and couplings that close with heat. Currently scientists and engineers are working with both classes of SMM—alloys and polymers—to develop new materials, such as heat sensing fabrics for hospital patients.[2]

The subject of this lesson is the shape memory alloy called Nitinol wire discovered at the Naval Ordnance Lab in 1961 and pronounced "night-in-all". It is an alloy composed of nickel (Ni) and titanium (Ti) atoms. While most materials, like water, undergo phase changes from solid to

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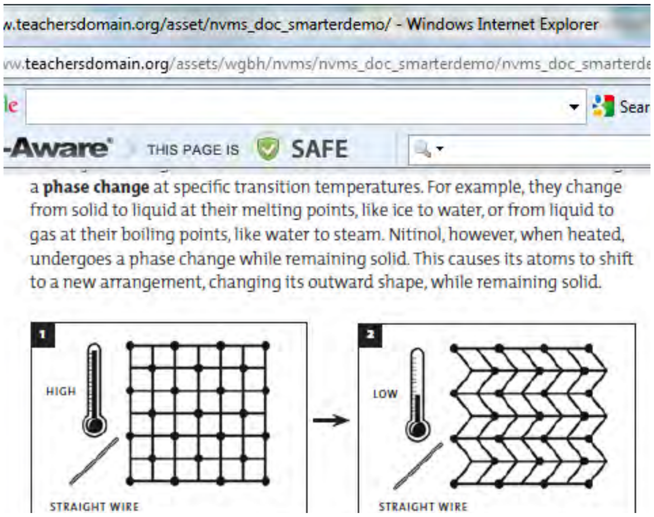
liquid to gas at specific transition temperatures, Nitinol undergoes a solid-to-solid phase change at a specific temperature (depending on its composition). This transition temperature signals when the conditions are right for the metal to use energy to move atoms to a different arrangement, changing its shape but remaining solid. Below the transition temperature, the Nitinol wire can be deformed as atoms shear and slide to new locations. The Nitinol will hold this deformed shape until it is heated again to the transition temperature (see Figure 1)[3]. Once again energy will move the atoms back to the original locations and the wire will remember the original rigid shape. The memory is based on groups of atoms shifting along grain boundaries.



a **phase change** at specific transition temperatures. For example, they change from solid to liquid at their melting points, like ice to water, or from liquid to gas at their boiling points, like water to steam. Nitinol, however, when heated, undergoes a phase change while remaining solid. This causes its atoms to shift to a new arrangement, changing its outward shape, while remaining solid.

Figure 1. Atom movement in Nitinol at low and high temperatures (http://www.teachersdomain.org/assets/wgbh/nvms/nvms_doc_smarterdemo/nvms_doc_smarterdemo.pdf : Illustrations: Zeke Smith)

Like all alloys, Nitinol has a crystalline structure with atoms arranged to minimize energy. These crystals have pattern structures that are repeated over and over in all directions. The regular arrangement of a crystal is represented by a lattice, which is a three dimensional array of points. These points are representations of atoms, ions, or molecules. The smallest repeating unit of a lattice is the unit cell. There are seven classes of unit cells—cubic, tetragonal, orthorhombic, monoclinic, hexagonal, triclinic, and trigonal (rhombohedral)—which represent the shape of the cell. There are a total of 14 possible combinations of the seven classes and four types of unit cells called the Bravais Lattices (see Figure 2)[4]. Changes in the crystal structure and orientation are responsible for the unique properties of Nitinol.

Unlike other alloys, Nitinol can undergo a crystal structure phase transformation (solid to solid) through thermal or mechanical input. The high temperature phase is known as austenite with a very ordered face centered cubic structure that results in a rigid material. If the austenite phase is cooled below a set temperature, it completely transforms as

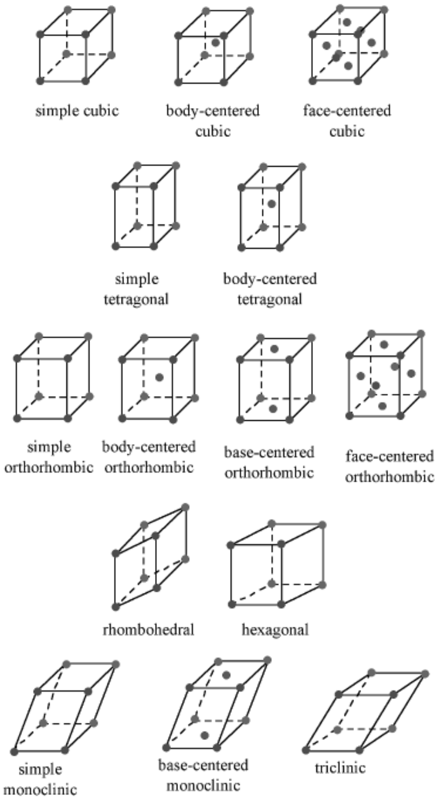


Figure 2. Bravais Lattices

Barron, A.; Smith, C. Crystal Structure, Connexions Web site. http://cnx.org/content/m16927/1.10/, Jan 28,

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the atoms slide and shear past one another, yet all we see is the same bulk material (see Figure 3)[5]. On the atomic scale, martensite has been formed with 24 variants of its less symmetric body centered tetragonal crystal structure (see Figure 4) that produce plastic deformation of shape and cause the macroscopic property of flexibility and malleability.[6]

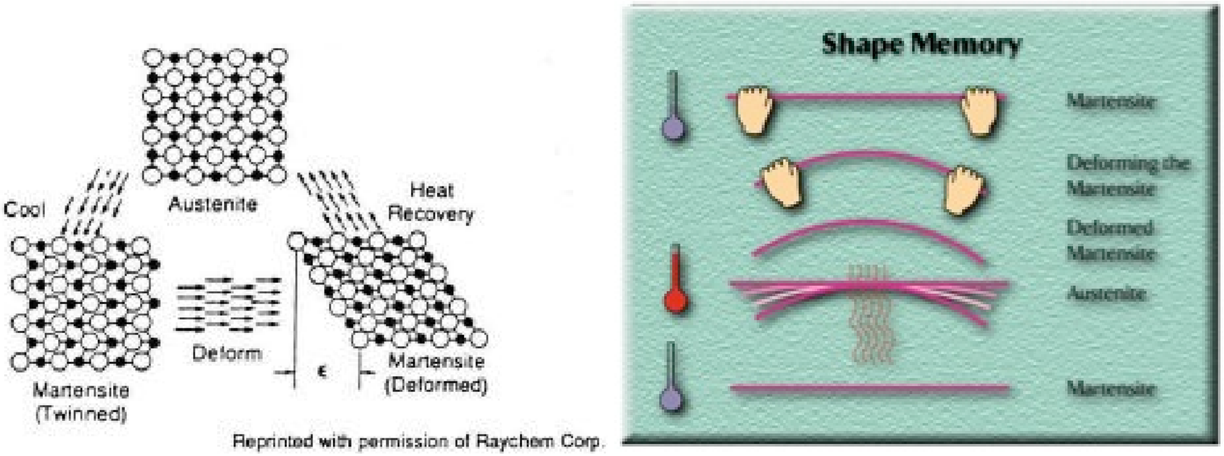

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Figure 3. Shape Memory in Nitinol at the nanoscale (left) and macroscale (right)
(http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1015&context=mate_fac)

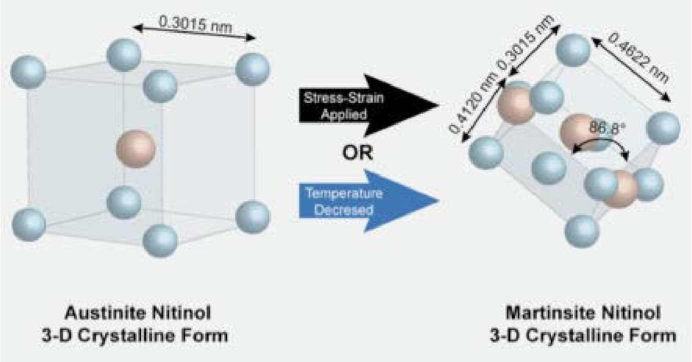

Figure 4. Transformation of Nitinol
(http://www.memry.com/nitinol-iq/nitinol-fundamentals/physical-properties)

Sources:

1. Rogers, B., Pennathur, S., Adams, J., *Nanotechnology—Understanding Small Systems*. CRC Press, 2011.
2. Teachers Domain. “Shape Shifters: Shape-Memory Alloys and Polymers” (video excerpt from NOVA’s "Making Stuff: Smarter"). (accessed August, 2012) http://www.teachersdomain.org/resource/nvms.sci.materials.smarterdemo/
3. Teachers Domain. “Shape Shifters: Shape-Memory Alloys and Polymers” (NOVA’s "Making Stuff: Smarter" demonstration). (accessed August, 2012) http://www.teachersdomain.org/assets/wgbh/nvms/nvms_doc_smarterdemo/nvms_doc_smarterdemo.pdf : Illustrations: Zeke Smith
4. Barron, A.; Smith, C. Crystal Structure, Connexions Web site. http://cnx.org/content/m16927/1.10/ (accessed August, 2012)
5. Chen, Katherine. “NiTi—Magic or Phase Transformations?” (accessed August, 2012) http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1015&context=mate_fac
6. Memry. “Physical Properties of Nitinol.” (accessed August, 2012)

http://www.memry.com/nitinol-iq/nitinol-fundamentals/physical-properties

Materials:

Per class

- goggles
- overhead projector or camera
- teacher samples of small paper clip, Nitinol wire, electrical wire (~ 7 cm each)
- hot plate or coffee maker for teacher demonstration
- 250 or 400 ml beaker or coffee pot
- water
- 3 petri dishes or clear containers
- 1 forceps or 1 tweezers
- large poster paper or whiteboard area
- class data sheet
- solid waste disposal container
- crystal lattices Nitinol—overhead transparency [R7]
- crystal lattice models—styrofoam balls & wooden skewers/ICE (http://ice.chem.wisc.edu/) or MollyMod models (http://www.molymod.com/)
- helical muscle Nitinol
- shape memory polymer (SMA)
- 1 set amazing ice melting blocks
- a few ice cubes

Per group of 2-3 students

- goggles (one per student)
- hot plate (shared by 2 groups)
- 250 ml beaker
- water
- ring stand
- test tube clamp
- thermometer or temperature probe
- tape
- pen/pencil
- stir rod
- Nitinol wire (~ 8 cm)
- 2 metal forceps
- 1 beaker tong or hot gloves
- Tea light candle
- matches
- phase change diagram[R8] (one per student)

The number of the following will depend on how each group designs their experiment

- 2 AA batteries and holder
- non-contact thermometer
- alligator clips
- multimeter
- shape memory polymer
- Helical Nitinol Muscle
- hair dryer

Advance Preparation:

1. ***Order or purchase needed supplies well in advance so you can try the lab first.*** Materials you will need may be found here:

Source/Website	Material
Grocery or Hardware Store	• small paper clips • electrical wire • large poster paper • candle and matches • needle nose pliers • wooden skewers • styrofoam balls • AA batteries • hair dryer
Educational Innovations, Inc. http://www.teachersource.com	• Nitinol Memory Wire $5.25/ft. • Amazing ice melting blocks 22.95

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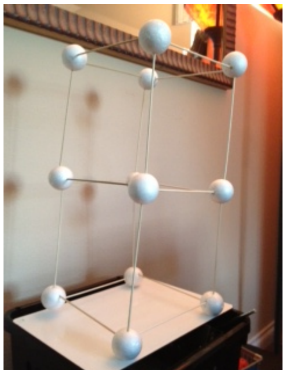
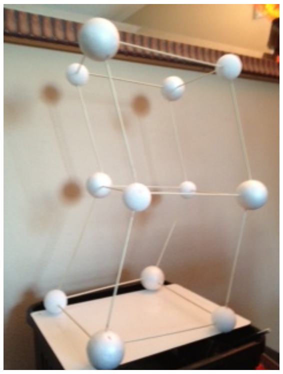
iCelsius http://www.icelsius.com Novatech International http://www.novatech-usa.com/Products/Digital-Traceable-Thermometers/4371	• iPhone temperature probe (optional) $49.00 each OR • digital thermometer $23 (optional)
Inventables https://www.inventables.com/technologies/shape-memory-polymer--2	• shape memory polymer 21300-01 • Helical Nitinol Muscle 21451-01
Harbor Freight Tools http://www.harborfreight.com/non-contact-pocket-thermometer-93983.html	• non-contact thermometer
Fisher Scientific http://www.fishersci.com or any scientific supply company	• hot plates or water bath • crucible tongs • ring stand • test tube clamp • 250 mL beakers • beaker tongs or hot gloves • thermometers • stir rod • metal forceps or tweezers • petri dish or small clear containers • battery holders (AA) • alligator clips • multimeter

2. ***Make preparations before students arrive.***
   a) Before Day 3, build 1 set of large basic 3D models of the NiTi overhead transparency structures for students to view using styrofoam balls and wooden skewers—prep time about 15 min.





Safety Information: Safety glasses are required when using glassware and the wire as it may spring back quickly. Hot plates and beakers placed on them may be very hot so use caution and proper equipment, such as beaker tongs or forceps. Nitinol wire may be hot.

Suggested Instructional Procedure:

Time	Activity
Day 1	**The day before the lab**
10 min	*Demonstration Warmup* Demonstrate how Nitinol behaves differently from other alloys (steel paperclip, electrical wire, etc.) using heated water (see *Day 1 Guided Dialog* section). This will heighten student's interest with a discrepant event and introduce them to how shape memory alloys behave differently from other alloys.
25 min	In their journals, ask students to answer the questions in the *Day 1 Guided Dialog* section. Then share, record, and display their answers in the classroom. Engage students' prior knowledge of phase changes, heat, temperature, kinetic molecular theory, and alloys by reviewing the terms and having students answer the questions outlined in the *Day 1 Guided Dialog* section.
10 min	Discuss safety in the lab and proper disposal. Distribute the *Student Worksheets*. In order to prepare students for the lab, review the $q=mc\Delta T$ problem (#5 on the *Pre-lab Student Worksheet*) together. Start off with the trick blocks (look identical but one is aluminum and the other is plastic) to melt ice cubes. Have 2 student volunteers come up and hold each block and test their "hotness". It is a great discrepant event to get them thinking about the variables involved in heat transfers. Follow up with "Is this the whole story? What happens next? " Then show the video of ice melting at http://www.mcrel.org/nanoleap/multimedia/melting.swf
10 min	Ask students to complete the questions on the *Pre-lab Student Worksheet*. They can use their textbook for help on the heating curve. This will get students thinking about phase changes in relationship to how the energy input is being used. Students can finish it for homework if needed.
Day 2	**The day of the student lab**
5 min	Have students get safety equipment and check lab group assignments. Review the *Pre-lab* as a class, emphasizing the key terms and question in the *Day 2 Guided Dialog* section.
25 min	Have students follow the procedures in the *Student Worksheet*. Students should post data-transition temperature on a class data sheet.
5 min	Clean up as suggested in the *Day 2 Guided Dialog* section.
10 min	Examine and record class data together. Is there a pattern? What do data outliers mean?
10 min	*Activity to Determine Understanding* Give students a phase change diagram[R8] with questions to answer in order to find out what students think about the changes occurring at the macroscale and nanoscale.
Homework	Assign homework: *Analyze the Results* and *Draw Conclusions* sections of the *Student Worksheet*.

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Day 3	**The day of the student activity/discussion**
5 min	*Class Discussion Warmup* Review terms and ask questions in *Day 3 Guided Dialog*. Then show the class the Nitinol—overhead transparency[R7] and the large 3D models. Ask the students to complete the *Prediction Activity: Individual* in the *Day 3 Procedure* section.
10 min	Ask the students to complete the *Prediction Activity: Group* in the *Day 3 Procedure* section.
25 min	Ask the students to complete the *Prediction Activity: Teacher Facilitated Discussion* in the *Day 3 Procedure* section.
10 min	Show the video[R9]: "Shape Shifters: Shape-Memory Alloys and Polymers" from Nova's "Making Stuff: Smarter" Series (2011) at http://www.teachersdomain.org/resource/nvms.sci.materials.smarterdemo/. This will show students how shape memory materials can be applied in the real world now and in the future, and introduce the idea that different energy inputs can be used to make the Nitinol change. Ask the students to complete the questions in the *Day 3 Procedure: Video* section.
5 min	*Review to Determine Understanding* Review the answers as a class and discuss to determine the students' understanding of how energy exchanges lead to solid-state phase changes. Students should record the results in their journals.
Days 4/5/6	**The days of the student design, testing, and lab analysis**
5 min	*Demonstration and Warmup* Demo with helical muscle Nitinol, training more complex shapes, and shape memory polymers (SMA) in order to reinforce the idea that different energy inputs can be used to make the shape memory materials (alloys and polymers) change and that each material can have different transition temperatures and different applications. Show the video[R10]: "Shape Shifting Tools" at http://www.sciencentral.com/articles/view.php3?article_id=218392685&cat=3_5 and the video[R11]: "Robot Muscles" at http://www.sciencentral.com/articles/view.php3?article_id=218392785, both from Science Central Archive (2006).
40 min	Based on their experience and using their imaginations, have students create a potential use for the smart material and test various energy inputs by having students work on lab design and implementation, and then analyze the data to answer the questions: 1. How will different energy inputs affect the response of the SMM design? 2. What type of energy input would be the most effective for your SMM design? Students will create a group poster with the following sections: brief introduction, methods, hypothesis, graph, results, conclusion.
10 min	Clean up.

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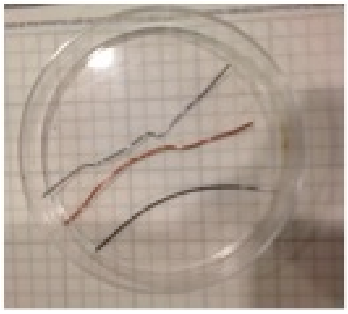
Day 7	**The day of the student presentations**
5 min	Have students go to lab stations and set up for round robin. Then have them decide who will stay at the station for round 1, 2, and 3.
40 min	*Presentations* Groups present posters in round robin. Each group will have 1 person stay at the station for each round while the others walk around the room viewing others work and completing an evaluation form.
10 min	Clean up.

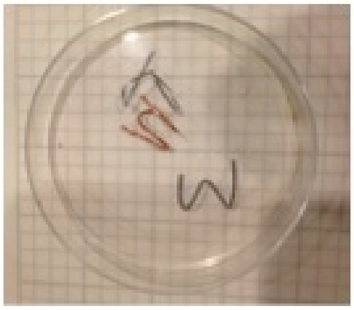
Teaching Strategies: Pre-lab activity can be done as a "Think, Pair, Share" to structure the discussion. Students first think and write quietly in their journals, then pair up with a partner to share ideas, and finally share out the ideas as a class. Posting prior knowledge from the pre-lab activity is a great tool to facilitate a deeper understanding and help students make connections to the new content. Ideally the lab activity is done in pairs, but groups of 3 are suitable. Assigning group members roles may help—facilitator (reads instructions and ensures the group is on task), materials manager (responsible for safe and proper usage of equipment), and recorder (carefully records the group's observations and ensures all data is taken properly).

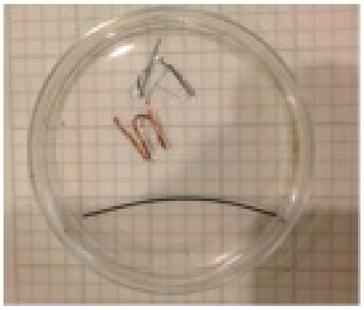
Day 1 Guided Dialog

Demonstration

Demonstrate how Nitinol behaves differently from other alloys (steel paper clip, electrical wire, etc.) using heated water (a tea kettle works well). Water temperature around 53°C will give a slow change, while 60°C will be instantaneous.


Wires alone for observation.


Wires twisted by students.


Wires in contact with hot water.

In their journals, ask students to:

1. Describe how the Nitinol behaved differently. *It straightened out, while the others stayed coiled.*
2. Write down 2 questions about the demonstration. *Why did it get straight? How hot is the water?*
3. Explain whether or not they think it is a phase change using their observations? *It is not a phase change because it is still a solid, not a liquid or gas.*
4. How do you think this material could be useful? *It could be used to straighten things like teeth or pull things like a spring.*

Then share, record, and display their answers in the classroom.

After the pre-lab demonstration, review the meaning of these terms:

Alloy *A substance created by melting two or more elements together (at least one being metal) which then crystallizes into a solid solution, mixture, or intermetallic compound upon cooling.*

Thermal energy *Energy due to chaotic molecular motions that is affected by temperature, sample size, and composition.*

Heat *A transfer of thermal energy that occurs when objects with different temperatures are placed into contact. Heat is a process, not a property of a material.*

Temperature *An intensive property of an object associated with its hotness or coldness. The direction of spontaneous heat flow is determined by temperature (always from hot to cold).*

Phase change *A change in the state (i.e. phase) of matter; such as a solid to a liquid or a liquid to a gas. Phase changes are deemed physical instead of chemical changes.*

Ask students guiding questions to provoke thought and review what they already know:

1. How is an *alloy* different from an *element*? *An alloy is made of two or more elements that are physically combined.*
2. What is *temperature* a measure of? *It is the average kinetic energy of the particles.*
3. How do you know if something is hot or cold? *You feel it to sense the direction of the energy transfer—away from your hand feels cold, toward your hand feels warm.*
4. What are examples of *phase changes*? *Examples are melting, freezing, boiling, solidifying, vaporization, and condensation.*
5. What happens to the particles during a *phase change*? *The energy input does not cause a temperature increase so the average kinetic energy of the particles is not increasing; rather the potential energy is increasing causing the position or arrangement of the particles to change.*

Discuss lab safety and proper disposal. Distribute *Student Worksheets* to students so they may complete the Pre-lab Student Worksheet.

Finally, Review the $q=mc\Delta T$ pre-lab problem (#5) together.

If a 5.63 g metal alloy sample was originally at room temperature, 22.9 °C, and the specific heat capacity of the alloy is 0.27 J/g°C , how much energy must be absorbed before the metal can change phase at 37.1°C? Show all work below.

q = *heat energy*
m = *mass*
c = *specific heat*
ΔT = *change in temperature*

$q = (5.63\ g)x(0.27\ J/g\cdot°C)[(37.1\ °C - 22.9\ °C)]$
$q = (5.63\ g)x(0.27\ J/g\cdot°C)x(14.2\ °C)$
$q = 21.6\ J$

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Day 2 Guided Dialog *Before* the lab, review the pre-lab answers and the following:

Kinetic energy *Energy of motion.*
Potential energy *Energy of position.*

Ask students guiding questions to provoke thought and review what they already know. For example: How is energy related to the movement of atoms? *Energy added to a system will cause the kinetic energy of the atoms to increase (resulting in a temperature increase), or the potential energy of the atoms to increase (resulting in a phase change).*

List any last minute details that the students must remember, including reiterating all safety precautions. Now, begin the lab.

Cleanup: Return goggles and materials clean and dry to the designated area(s). Turn hot plates to low and refill beakers with water for the next class. If it is the last class of the day, unplug hot plates and empty beakers using beaker tongs or heat gloves.

Enhancing Understanding: Cover this section *after* the activity.

Activity to Determine Understanding

Give students a phase change diagram[R8]. Have them answer the following:

1. Label the heating curve with as many terms as you can and circle the area you think the transition for the Nitinol is occurring. *Answers will vary but should include evaporation, condensation, fusion, and solidification. The area that should be circled is in the solid phase.*
2. How can a phase change be happening if there is no visible change of state? *The rearrangement of the atoms on the nanoscale is too small to be seen with our eyes. These phase changes are called solid-solid phase changes.*
3. How do you think the absorbed energy is being used by the Nitinol at the nanoscale (Ni and Ti atoms)? *The atoms are absorbing the energy, resulting in either temperature (kinetic energy) or phase changes (potential energy).*
4. Draw a *Before* and *After* picture to show how the particles have changed. *In the Before picture the particles are closer together, not moving as much, or are in a different position.*

Going Further: Students who have a good grasp of the content of the lab can be further challenged with this question:

What do you think would happen if you tried to create a new shape in the Nitinol wire with a Bunsen burner? Explain. *It would be easier or quicker to train the new shape because more energy is put into the material. Actually, too much energy can damage the structure.*

Day 3 Guided Dialog *Before* beginning the discussion, review the meaning of these terms:

Physical change *A rearrangement of atoms/molecules that doesn't affect their internal structures.*
Chemical change *A change involving the making or breaking of bonds between atoms at the molecular level and resulting in the creation of a new chemical substance.*
Latent heat *Heat that is absorbed and doesn’t cause an increase in temperature. For example, "latent heat of vaporization" means the amount of heat needed to convert a liquid to vapor at a specific temperature.*

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Ask students questions to provoke thought and review what they already know:

1. Is a phase change a chemical or physical change? How do you know? *It is a physical change because no new substance is being formed and there are no indicators of a chemical reaction*.
2. How are atoms affected differently in a physical vs. chemical change? *In a chemical change the bonds between atoms are changed, but in a physical change the atoms are simply rearranged without breaking or making bonds.*
3. What is special about the plateau on the phase change graph in your Pre-lab? *There is no temperature change. It represents the latent heat of phase change.*
4. How is the energy input being used on the plateau different from how the energy is used on the sloped areas? *On the slopes the energy is kinetic as the particles move faster in place, while on the plateaus the energy is potential as the particles are changing position.*

Day 3 Procedure

Prediction Activity: Individual

Show the class the Nitinol—overhead transparency[R7] and the large 3D models. Ask the students to record their answers in their journals to the following questions:

1. How are the shapes different? *Answers may vary. Different angles, straight versus bent, different atoms.*
2. How are the shapes similar? *Answers may vary. Square-like shapes with 2 in each.*
3. What general shape do you think is the most stable? Explain. *Answers may vary. Austenite because right angles are more stable.*

Prediction Activity: Groups

In groups, have students predict which shape requires the most energy to be changed and assign the terms austenite and martensite phases to the shapes based on their experimental data from the previous day.

Prediction Activity: Teacher Facilitated Discussion

Involve students in the scientific thinking process of data analysis and problem solving by having them share and process through teacher facilitated discussion using their data and the teacher presented models. Students may record their group decisions on white boards or large paper to prepare to share their predictions based on data. This will help students understand how energy exchanges lead to solid-state phase changes through plastic deformations in the crystal lattice structure at the nanoscale.

Video

Show the video: “Shape Shifters: Shape-Memory Alloys and Polymers” from Nova’s "Making Stuff: Smarter" Series (2011). In their journals, ask students to answer the following:

1. Why is Nitinol special?
2. What causes the change in the Nitinol?
3. Why do you think different energy inputs would be useful?

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Enhancing Understanding: Cover this section *after* the activity.
Discuss the following vocabulary terms:

Austenite *The rigid, springy, high-temperature phase of Nitinol with a face-centered cubic lattice.*

Crystal structure *The organized arrangement of the atoms within a material.*

Martensite *The soft, bendable, low-temperature phase of Nitinol with a body-centered tetragonal lattice*.

Phase *A specific form of matter that exists within a certain range of temperature and pressure. This includes gas, liquid, solid and plasma. A material may have several solid phases that exist at different temperatures and pressures.*

Plastic deformation *Change in shape or size of a solid body without fracture.*

Going Further: Students who have a good grasp of the content of the lab can be further challenged with these questions:

1. How would a large input of energy by heating it to 500°C affect the crystal lattice structure? *In the austenite phase, the Ni and Ti atoms within one of the many crystalline regions, called grains, are almost perfectly arranged, but there are defects. Heating the Nitinol to that temperature creates a new set of defects by allowing the atoms to relax into lower energy positions.*
2. Why would electricity cause a change in the Nitinol? *The latent heat is provided by resistive heating as current flows through the Nitinol.*
3. Using Ohms Law ($V = IR$), where V is voltage, I is current, and R is resistance, and $P = IV$, where P is power or Joule heating, the following equation can be derived, $P = I^2R$ which could be used to perform calculations from multimeter observations.

Assessment:
Students should be able to:

- interpret phase change diagrams
- differentiate between temperature increases and latent energy
- perform heat calculations
- relate energy exchanges to changes in crystal structure at the nanoscale
- describe how solid-to-solid phase changes are caused by plastic deformations in the crystal lattice of Nitinol
- explain why Nitinol is a nanotechnology material
- design an experiment to determine which type of energy input would be the most effective at altering the nanoscale lattice of their SMM design
- analyze and present their experimental findings

Grading will be based on:

- completion of Pre-lab
- quality of data collection
- answers to the *Drawing Conclusion* questions
- a rubric for their final presentations

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Resources: You may wish to use these resources either as background or as a resource for students to use in their inquiry-based design.

Students:

1. Images Scientific Instruments. “Nitinol / Flexinol® Actuator Wire.” (accessed August, 2012) http://www.imagesco.com/articles/nitinol/04.html
2. Memry. “Physical Properties of Nitinol.” (accessed August, 2012) http://www.memry.com/nitinol-iq/nitinol-fundamentals/physical-properties
3. TiNi Alloy Company. “Introduction to Shape Memory Alloys.” (accessed August, 2012) http://www.tinialloy.com/pdf/introductiontosma.pdf
4. Talking Electronics. “Nitinol.” (accessed August, 2012) http://talkingelectronics.com/projects/Nitinol/Nitinol-2.html
5. Defense Technical Information Center. “On the Stressing of Annealed Nitinol: The Electrical Resistance and Calorimetric Effects.” (accessed August, 2012) http://www.dtic.mil/dtic/tr/fulltext/u2/a184465.pdf
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Teachers:

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National Science Education Standards (Grades 9-12)
Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry

Content Standard B: Physical Science
- Structure and properties of matter
- Conservation of energy and increase in disorder
- Interactions of energy and matter

Content Standard E: Science and Technology
- Abilities of technological design

Next Generation Science Standards

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles

HS-PS2-6. Communicate scientific and technical information about why the molecular-;eve; structure is important in the functioning of designed materials.

HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system.

HS-PS3-5. Develop and use a model of two objects interaction through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects die to the interaction.

HS-ETS1-1B. Developing possible solutions.

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