Subject Area(s) **science & technology**

Associated Unit

Associated Lesson

Activity Title **Spring Time in Physics**

Header

Image 1, [centered]

Image 1

ADA Description: photograph of a spring standing vertically

Caption: Spring Time in Physics!

Image file: sma_image1.jpg

Grade Level **11 (9-12)**

Activity Dependency

Time Required **90 minutes (one 45 minute class period for "Spring Time in Physics" activity and discussions, a second class period for "Nitinol: A Smart Metal" activity and discussion)**

Group Size **2**

Expendable Cost per Group **US$0 (Note: nitinol wire and springs are not readily available in most classrooms, but once purchased, these materials can be used for many years)**

Summary

The broad goal of this science activity is to expose students to shape memory alloys—nitinol (a class of nickel-titanium alloys) in particular—in order to discuss current research in materials science and engineering, to contrast Hookean and shape-memory springs, and to encourage students to use internet resources to learn about science, technology, and engineering.

Engineering Connection

Engineers rely on springs to store energy, produce and damp vibrations, maintain spacing, soften impacts, and cause objects to recoil. The large assortment of shapes, sizes, and functions speaks clearly to the importance of the spring in daily life. In order to make effective use of springs, one must understand the relationship between force and displacement—Hooke's Force Law. Surprisingly, many phenomena that seem unrelated to the mass-spring system can be described by Hooke's Law, or a slight modification of it.

Lately, springs have even benefitted from atomic modifications. Surprising physical phenomena occur at the nanoscale, and engineers have begun to use nanotechnology to address macroscale problems. Shape memory alloys (considered by some to be a nanotechnology) have properties that can be exploited to improve medical and orthodontic standards of care among numerous other practical applications. Shape memory alloys are also studied by NASA in advanced aerospace application like morphing wings and adaptive engine chevrons to reduce jet take-off noise while maintaining in-flight performance.

Engineers are continuing to find uses for this relatively new class of "smart materials".

Engineering Category = **#1**

Keywords

Hooke's Law, nitinol, shape memory alloy, spring, spring constant

Educational Standards

- ITEEA, Standard 14, Grades 9-12, K. Medical technologies include prevention and rehabilitation, vaccines and pharmaceuticals, medical and surgical procedures, genetic engineering, and the systems within which health is protected and maintained.
- Texas Essential Knowledge and Skills (TEKS) §112.39. Physics, (c) (2) (F) "Scientific processes. …The student is expected to… demonstrate the use of course apparatus, equipment, techniques, and procedures, including… hot plates, …Celsius thermometers, …"

Pre-Requisite Knowledge

Introduction to the concept of "force". Basic knowledge of the atomic nature of solids.

Learning Objectives

After this activity, students should be able to:

- Observe shape memory alloy transition from deformed to "trained" state
- Describe shape memory alloy's molecular structure
- Draw simplified models of shape memory alloy structure
- Discuss (potential) applications for shape memory alloys
- Understand basic differences between springs that obey Hooke's Law and springs made from shape memory alloys

Materials List

Activity One

Each group of two needs:

- Ring stand (preferably a rugged model with large, heavy rectangular support base and 12.5mm diameter, 600mm long rod (½" x 24"))
- Two clamps for ring stand
- Set of metric hanging masses (exact values should be sufficient to cause observable extension of the springs but not to over stretch them)
- Metric ruler
- Three regular expansion springs with different spring constant values
- Nitinol expansion spring
- Large beaker (large enough to completely submerge nitinol spring with mass attached; ~1500mL beaker)
- Water (enough to completely submerge nitinol spring with mass attached)
- Small S hook
- Thermometer
- Hot plate (or Bunsen burner with ring stand and ring support)
- Tweezers

Each student needs:

- Eye protection (goggles or safety glasses)
- "Spring Time in Physics" worksheet
- (optional: a graphing calculator may be used to plot data and get best-fit lines)

Note: nitinol expansion springs can be purchased online from Images Scientific Instruments; as of April 2012, they sell "Nitinol Expansion Spring" for $16.95. Once purchased, the wire can be reused with many classes. (Link to product page: http://www.imagesco.com/catalog/nitinol/index.html ; spring is about halfway down the page just after the butterfly).

Note: Instructor should check the transition temperature for the particular nitinol springs—the specific ratio of nickel to titanium used will alter the phase-change point

Activity Two

Each group of two needs:

- Nitinol wire (roughly 10cm long; initially crumpled, but "trained" to resume a different shape)
- Thermometer
- Ring stand with clamp
- Hot plate (or Bunsen burner with ring stand and ring support)
- Water (150-200mL)
- Beaker (250mL or larger)
- Tweezers

Each student needs:

- Eye protection (goggles or safety glasses)
- "Nitinol: A Smart Metal" worksheet

Note: nitinol wire can be purchased from Edmund Scientific; as of December 2011, they sell "Wire with a Memory" in 7.62cm (3 inch) lengths, two wires per pack; each pack is $9.00. Once purchased, the wire can be reused with many classes. (Link to product page:

http://www.scientificsonline.com/wire-with-a-memory.html?&cm_mmc=Mercent-_-Google-_-NULL-_-3037308&mr:trackingCode=B06D1735-DB81-DE11-8C0A-000423C27502&mr:referralID=NA)

Introduction / Motivation

When we think of springs, the coiled helical variety is often the first to “spring” to mind. This discussion and activity will also focus on that type of spring, but it is important to remember that springs come in a wide variety of shapes and are used in an even wider array of applications.

We are familiar with the helical tension (or expansion) springs in grocery store and luggage scales and helical compression springs used in pogo sticks and writing instruments (mechanical pencils and retractable pens). We may be less familiar with spiral torsion springs used in analog clocks and watches or the flat leaf spring used in vehicle suspensions and some switches. And some “machined” springs may totally alien are important for the isolation of optical benches on the Airborne Laser and the load isolation system on a cargo transportation container used on Space Shuttle/Space Station. Springs are also hidden in the space-shuttle docking collar on the Mir Space Station.

Image 2a and 2b [centered]

Image 2 (a) and (b)

ADA Description: photographs of different sizes and shapes of springs including tension, compression, torsion, and hybrid varieties

Caption: Springs are manufactured in many shapes and sizes

Image file: spring_image2a.jpg; spring_image2b.jpg

Source/Rights: Image 2a Copyright © 2012 Northwest Spring Manufacturing Inc. http://www.nwspring.com/products.php Image 2b Copyright © 2012 Badger Precision Spring, Inc. http://www.badgerspring.com/ Copyright permission not yet obtained

Image 3a and 3b [centered]

Image 3 (a) and (b)

ADA Description: photographs of (a) watch hairspring and (b) an assortment of machined springs for load and vibration isolation

Caption: Springs are manufactured in many shapes and sizes

Image file: spring_image3a.jpg; spring_image3b.jpg

Source/Rights: Image 3a Copyright © 8-29-2003 by ei8htohms http://www.tp178.com/jd/watch-school/6/article.html
Image 3b Copyright © 2012 Taylor Devices http://www.taylordevices.com/machined-springs.html
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We know intuitively (and perhaps from experience in opening a "clicky" pen) that if a spring is stretched beyond its limits, it will be bent out of shape and become permanently elongated. With that in mind consider this clip:
http://www.youtube.com/watch?v=Mh31B4Ryn9U&feature=fvwrel
Is this science fiction? A computer generated effect? Clever camera work? Let's examine conventional springs and return to this idea later. It's spring-time in Physics class!

Vocabulary / Definitions

Word	Definition
alloy	A homogeneous material that is a mixture of a metal and one or more other chemical species (not necessarily metallic), wherein the atoms of one or more species either occupy interstitial spaces or replace atoms of the other
elastic	Returning to or capable of returning to an initial form or state after deformation.
medical technology	"Prevention and rehabilitation, vaccines and pharmaceuticals, medical and surgical procedures, genetic engineering, and the systems within which health is protected and maintained" (ITEEA, Standard 14, Grades 9-12, K).
nanotechnology	Construction and manipulation of devices, materials, or features that are 1 to 100 nanometers (10^{-9} to 10^{-5} meters) in length (note: nanotechnology is a new and diverse research area; a more precise definition is still being formed by researchers)
shape memory alloys	An alloys that is able to return to a cold-forged shape from a deformed state after being heated or stressed.
spring	An elastic device that retains its original shape after being extended or compressed and can be used to store energy

Procedure

Background

1. Though springs come in a variety of shapes, attention will only be given to the coiled helical spring in this discussion and activity
2. A spring, by definition, is a device that returns to its original shape after extension or compression and can be used to store energy.
3. According to Wikipedia http://en.wikipedia.org/wiki/Spring_(device)
   a. "Springs can be classified depending on how the load force is applied to them:
      i. "Tension/Extension spring – the spring is designed to operate with a tension load, so the spring stretches as the load is applied to it.
      ii. "Compression spring – is designed to operate with a compression load, so the spring gets shorter as the load is applied to it.
      iii. "Torsion spring – unlike the above types in which the load is an axial force, the load applied to a torsion spring is a torque or twisting force, and the end of the spring rotates through an angle as the load is applied.
      iv. "Constant spring - supported load will remain the same throughout deflection cycle
      v. "Variable spring - resistance of the coil to load varies during compression
   b. "They can also be classified based on their shape:
      i. "Coil spring – this type is made of a coil or helix of wire
      ii. "Flat spring – this type is made of a flat or conical shaped piece of metal.
      iii. "Machined spring - this type of spring is manufactured by machining bar stock with a lathe and/or milling operation rather than coiling wire. Since it is machined, the spring may incorporate features in addition to the elastic element. Machined springs can be made in the typical load cases of compression/extension, torsion, etc."

Image 4 [centered]

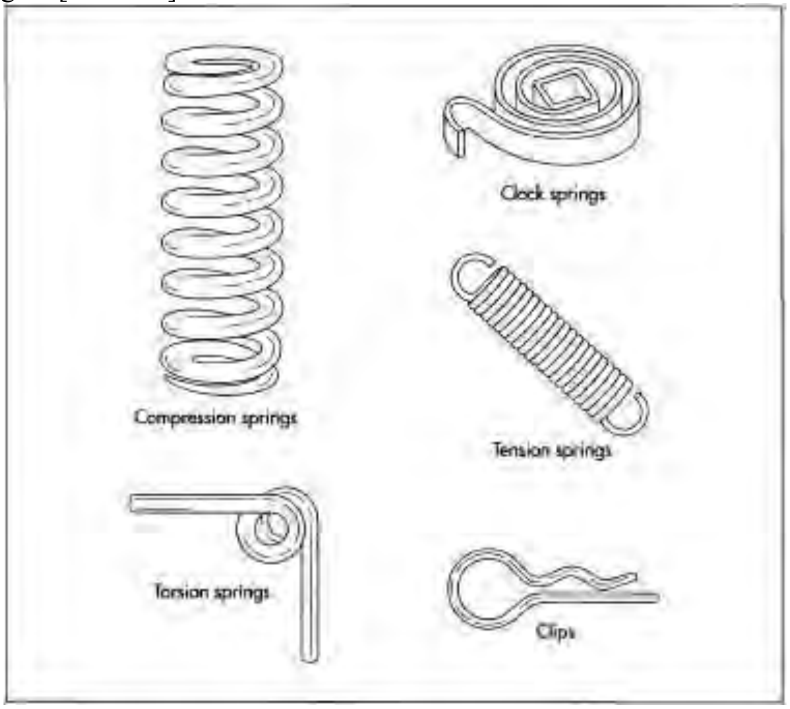


Image 4

ADA Description: schematics of compression, clock, tension, and torsion springs and spring clips

Caption: Springs can be classified by shape and by how forces should be applied to them

Image file: spring_image4.jpg

4. Robert Hooke, a contemporary and rival of Isaac Newton, published the first important book of observation using a microscope. He also coined the biological term "cell", when the appearance of thin cork slices reminded him of the small monastic quarters of the same name.
5. Hooke also identified a force-displacement relationship for mass-spring systems, which has been extended to many other situations. Many physical systems exhibit similar behavior to masses on springs and can be modeled (as a first approximation) by Hooke's Law.
    a. atoms displaced from equilibrium positions in a molecule or lattice are subjected to a spring-like restoring force proportional to their displacement from equilibrium
    b. beams loaded with a mass will be deflected by an amount proportional to the load
    c. twisted rods feel a restoring force proportional to the angular displacement (twist)
6. To derive Hooke's Force Law, consider a spring oriented horizontally and attached at one end to a wall and to a mass resting on a frictionless surface at the other.
    a. the location of the mass when the spring is neither stretched nor compressed is the "equilibrium position"; there is no force on the spring to maintain its length and the mass is not accelerating, so the force on the mass the zero here
    b. if the mass is pulled so that the spring is stretched, the force of the spring on the mass is opposite in direction to this pull—back toward the equilibrium position; the same is true is the mass is push to compress the spring: the mass will feel a force from the spring opposite to the push—toward the equilibrium position
    c. thus, the force of the spring on the mass is always directed toward the equilibrium position; this force is often called a "restoring force" because it acts to return the system to equilibrium
    d. Robert Hooke made three important observations of this mass-spring system
        i. **the force needed to move the mass *m* is directly proportional to the displacement *x* from equilibrium**—when plotted this gives a straight line
        ii. because there is no force at the equilibrium position, the line passes through the origin (x=0 at equilibrium); the spring (as long as it is not over stretched) follows the same line as the applied force is increased and decreased (there is no hysteresis)

iii. **the force on the mass to hold it at a given location is independent of the mass—it depends only on the particular spring being used**

e. These observation can be represented by $F_{applied}$=kx**,** where k is a proportionality constant called the "spring constant"
   i. k is a scalar
   ii. k is expressed in Newtons per meter, using SI units

f. We are generally interested in the force of the spring on the mass, however, so **Hooke's Force Law is written F_{spring}= -kx** (note: F_{spring} is in the opposite direction as $F_{applied}$)

g. If the mass is displaced from equilibrium and released, Newton's second law should be applied, so F_{spring}=ma or, substituting the expression above for force, -kx =ma

h. Recalling that accelerating is the time-rate of change of the time-rate of change of position, one can describe the motion of the mass by the ordinary differential equation

$$-kx = m\frac{d^2x}{dt^2} \quad \text{or equivalently} \quad \boldsymbol{0 = \frac{d^2x}{dt^2} + \frac{k}{m}x}$$

i. It can be shown that the solution to this equation is ***x(t)=A cos(ωt+φ)***, where A and ω are positive and the values of A, ω, and φ are constants determined from the boundary conditions

7. Traditional metal springs have an elastic limit and displacements beyond this point will permanently deform the spring. Springs made from a (relatively) new class of alloys, shape memory alloys, can be stretched to straightness and returned to the original shape with application of heat—no forms or mandrels are necessary to re-coil the spring
8. Shape memory alloys are known by many names: SMA, smart metal, memory metal, memory alloy, muscle wire, smart alloy. These descriptive names refer to the unique property of these alloys to return to a cold-forged shape from a deformed state after being heated or stressed.
9. The SMA "memory" is the result of a solid-solid phase change process, which is analogous to the more familiar phase change processes of melting, freezing, sublimating, and depositing. Molecules in the solid move from one lattice configuration to another with application of heat or electrical current
10. These materials hold promise to replace conventional hydraulic- and pneumatic-based actuators because SMAs have superior power-to-weight ratios.
11. Ferromagnetic memory alloys and shape memory polymers have also been developed that exhibit shape memory properties under application of strong magnetic fields or without use of metals, respectively.
12. Emerging technology that uses shape memory alloys is appearing across many fields: aircraft, dentistry, medicine, optometry, orthopedic surgery, piping, and robotics
13. SMAs are also used to make stents, a medical technology used to prevent stenosis (or narrowing) of vasculature in the body—especially in arteries. (ITEEA, Standard 14, Grades 9-12, K. Medical technologies include prevention and rehabilitation, vaccines and pharmaceuticals, medical and surgical procedures, genetic engineering, and the systems within which health is protected and maintained.) Since they want to return to their trained shape, nitinol stents tend to remain flush against the vessel wall. This is a major advantage over conventional stents which require a balloon to press the stent against the inside of the vessel.
14. A video of a nitinol stent deployment is available at http://www.youtube.com/watch?v=D8bx99ZA-eU&feature=related . The first part of the clip talks about problems on balloon inflated stents, but at 1:36 the topic changes to a discussion of the Stentys nitinol stent. Unfortunately the video uses a lot of medical jargon, but the key ideas about the technology can be grasped.

Image 5 [centered]

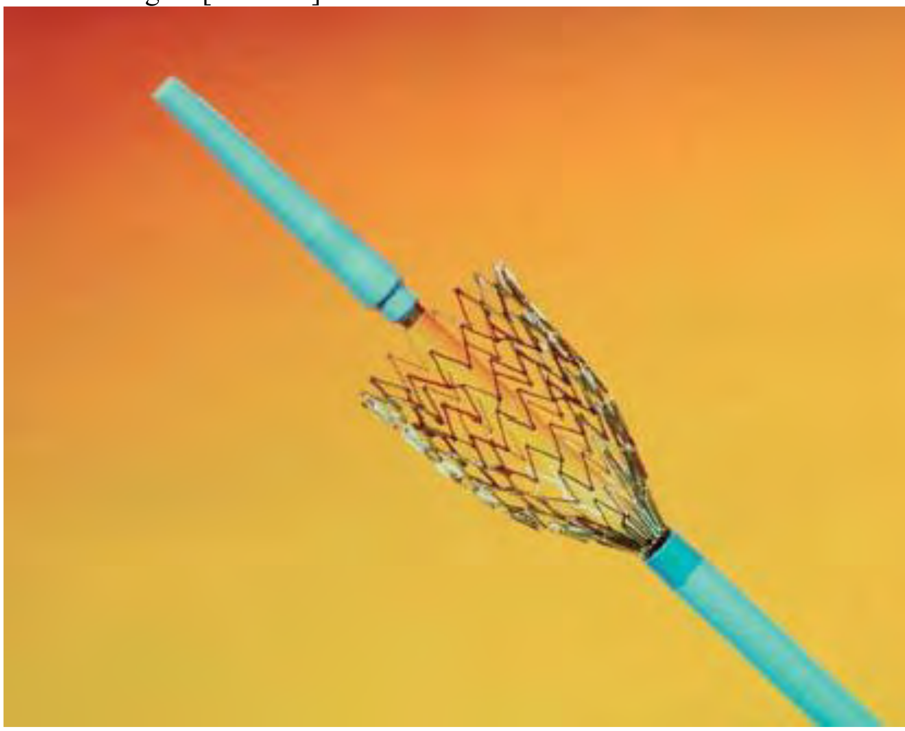


Image 5

ADA Description: photograph of a nitinol stent being pulled from the sheathing catheter

Caption: Self-expanding stents can be packed into small diameter catheters; as the catheter is retracted, the body's temperature will be sufficient to expand the stent

Image file: spring_image5.jpg

Source/Rights: Copyright © 2012 Nitinol Devices & Components Inc. http://openlearn.open.ac.uk/mod/oucontent/view.php?id=397861&section=10.9.1 Copyright permission not yet obtained

Image 6 [centered]

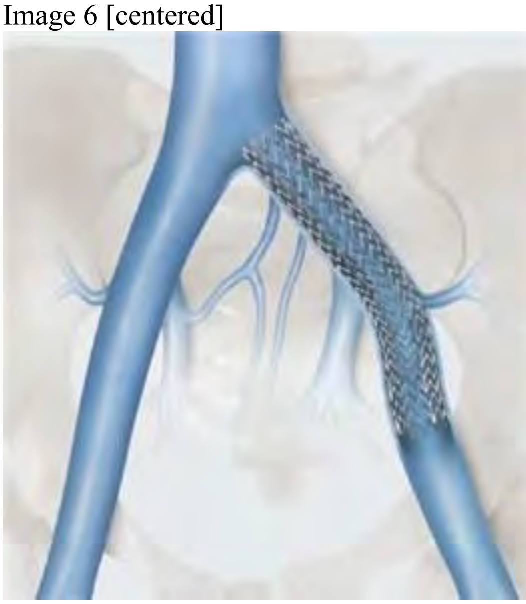


Image 6

ADA Description: schematic of the Cook® Zilver® Vena™ Venous Self Expanding Stent deployed in the common iliac vein

Caption: Self-expanding nitinol stents can easily conform to the geometry where they are inserted

Image file: spring_image6.jpg

Source/Rights: Copyright © 2012 Cook Medical (a part of Obex.) http://www.obex.co.nz/Product/Index/590 Copyright permission not yet obtained

15. Because of the crucial importance that nanosized features have on SMA functionality, some researchers classify SMAs as a nanotechnology. Nanotechnology, however, is a very diverse field and a single definition (that satisfies all researchers who claim to be nanotechnologists) is yet to be found. Nevertheless, we can consider nanotechnology to refer to construction and manipulation of devices, materials, or features that are 1 to 100 nanometers (10^{-9} to 10^{-5} meters) in length.
16. Though more frequently encountered in materials science and electrical engineering research laboratories, nanotechnology can be found in everyday life. Some familiar products that may contain nanoparticles are:
    - car paints (particles enhance shine, water repellence, and durability)
    - sunscreen and make-up (particles better reflect damaging light)
    - hair-styling flat-irons (particles give greater smoothness, more even heat distribution and durability)
    - golf balls (particles reduce spin, thus straightening the flight path)
    - cancer treatment (particles eliminate tumors without traditional radiation)
17. Companies are rushing to bring even more products to the marketplace. Nanotechnology is helpful in medicine, where doctors are hoping that the effectiveness of pharmaceuticals and the sensitivity of sensors can be increased. (Nano-sized wires and circuits will further reduce the size of electronic devices and improve digital displays. Stronger and lighter materials are being developed by examining their nano-scale structure. The applications of using these very small materials are presently being explored tremendously, from electronics, medicine, energy efficiency, material science and so much more, with the basic purpose of improving our lives, improving what devices and technology that now exist.

Before the Activity

Gather materials, pair students for the activity, and distribute materials and handouts

With the Students

Day One

1. Present Introduction/Motivation material outlined in the section above
2. Introduce students to Hooke's Force Law
3. Instruct the students how to use the hot plate safely and how to read the thermometer (Texas Essential Knowledge and Skills (TEKS) §112.39. Physics,… (c) (2) (F) "Scientific processes. …The student is expected to… demonstrate the use of course apparatus, equipment, techniques, and procedures, including… hot plates, …Celsius thermometers, …)
4. Students follow the steps listed on the "Spring Time in Physics" handout
    a. Students hang the "S" hook from the clamp on the ring stand
    b. Hang the regular springs and nitinol spring from the hook and measure expansion after adding masses
        i. expansion only has to be large enough to be measured
        ii. advise to students to be careful and not overload the springs
        iii. make sure students measure elongation consistently
    c. Again hang the nitinol spring from the "S" hook, this time dangling spring over beaker resting on heat source, making sure there is sufficient space between the bottom of the spring and beaker to allow for masses and spring expansion
    d. Fill beaker with water to completely cover spring
    e. Attach thermometer to ring stand, turn on heat, and monitor temperature
    f. When water has exceeded the transition temperature by ~10˚C, measure the new spring length
    g. Using tweezers remove spring, attach masses, and replace spring on the hook
    h. Wait about two minutes and measure the elongation

   i. Repeat steps (g) and (h) above with different masses
   j. When finished measuring heated nitinol spring, turn off heat source, wait for water to cool before cleaning up (or use gloves/mitts)
   k. Complete the "Spring Time in Physics" handout as time permits, finish as homework

Day Two

1. Recap lesson from *Day One*
   a. Call attention to nitinol spring shortening in hot water
   b. Inform students they will get a chance to investigate nitinol further
   c. Ask students whether they have heard of shape memory alloys
2. Instruct the students how to use the hot plate safely and how to read the thermometer (Texas Essential Knowledge and Skills (TEKS) §112.39. Physics,… (c) (2) (F) "Scientific processes. …The student is expected to… demonstrate the use of course apparatus, equipment, techniques, and procedures, including… hot plates, …Celsius thermometers, …)
3. Students follow the steps listed on the "Nitinol: A Smart Metal" handout
   a. Students fill their beakers with water
   b. Students allow water to heat on a hot plate until water reaches roughly 50-90˚C (this temperature depends on the specific alloy of nitinol used)
   c. Students turn off heating on hot pate (to ensure water does not boil)
   d. Students dip the nitinol wire in hot water
   e. Students observe and record the results
   f. Students may allow wire to cool, crumple it, and repeat steps a through e
4. Students put away materials
5. Class discusses observations
6. Instructor shares information about how the transition is achieved molecularly
   a. discussion of alloys—ask students what an alloy is, for some examples of alloys, and what the purpose of alloying is
      i. alloy definition
         1. draw interstitial alloy:
         2. draw substitutional alloy:

Image 7, [left justified]

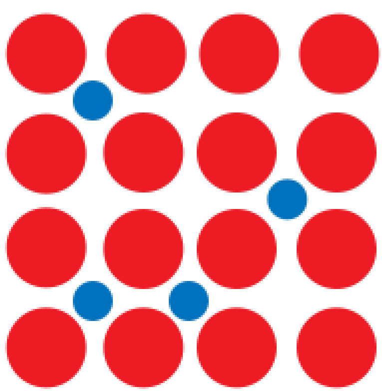


Image 7

ADA Description: a schematic showing a regular array of large circles with smaller circles distributed unevenly in the gaps

Caption: An interstitial alloy is one in which atoms of a second element are incorporated by filling in between atoms of the first element

Image file: spring_image7.png

Source/Rights: Copyright © John Aplessed, Wikimedia Commons, http://en.wikipedia.org/wiki/File:Alloy_Interstitial.svg

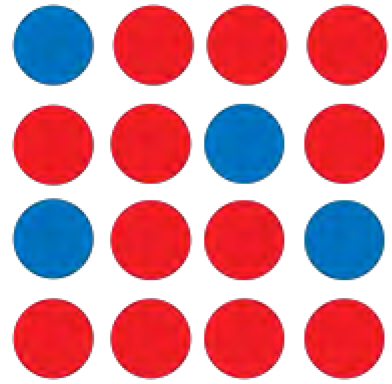
Image 8, [right justified]

Image 8

ADA Description: a schematic showing a regular array of circles most are colored red, but a few of the circles (seemingly at random) are blue

Caption: A substitutional alloy is one in which atoms of a second element are incorporated by replacing atoms of the first element

Image file: spring_image8.png



ii. familiar alloy examples: steel, bronze, brass, jewelry gold

iii. purpose: obtain material properties different from those of a material made entirely of any single element

b. discussion of nitinol, in particular

i. Nitinol is a SMA made from careful combination of nickel and titanium.

ii. Unlike most alloys, the atoms in SMAs are able to move reversibly from one crystal state to another. (Wikipedia "A reversible transformation does not involve this diffusion of atoms, instead all the atoms shift at the same time to form a new structure, much in the way a parallelogram can be made out of a square by pushing on two opposing sides")

iii. atoms in nitinol transition from austenitic to martensitic structures

1. austenite: simple cubic unit cell
2. martensite: parallelepiped unit cell

7. Instructor models of transition

a. draws atoms in lattice

Image 9, [centered]

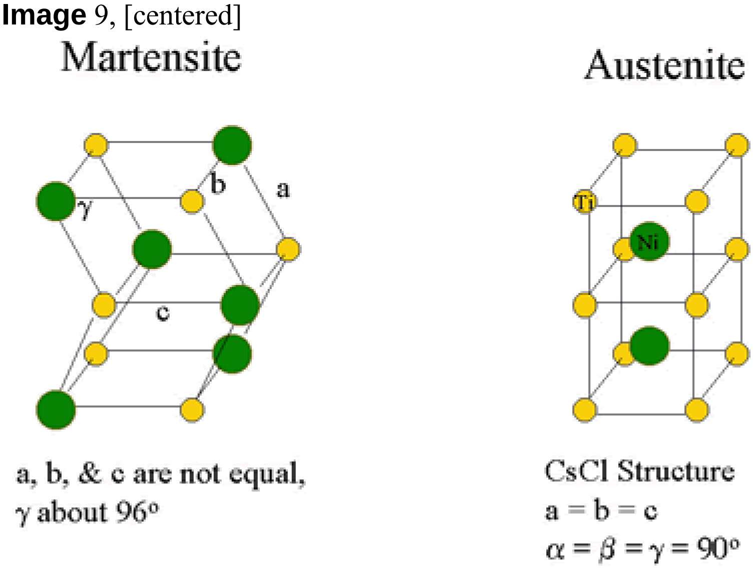


Image 9

ADA Description: Simplistic lattice models of martensite (left side of image) and austenite (right side of image). In martensite, nickel and titanium atoms are arranged at the corners of a parallelepiped. In austenite, titanium atoms are arranged at the corners of perfect cubes, while nickel atoms are in the center of the cubes.

Caption: Schematic representations of the martensite and austenite lattices

Image file: spring_image4.gif

Image 10, [centered]

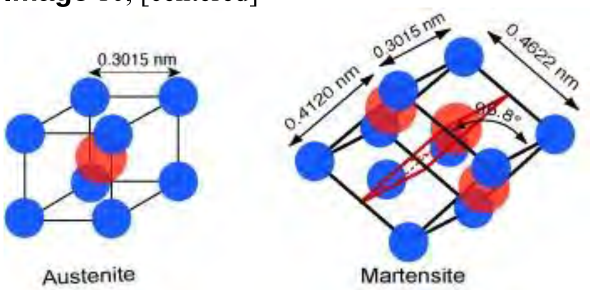


Image 10

ADA Description: Simplistic lattice models of martensite (left side of image) and austenite (right side of image). In martensite, nickel and titanium atoms are arranged at the corners of a parallelepiped. In austenite, titanium atoms are arranged at the corners of perfect cubes, while nickel atoms are in the center of the cubes.

Caption: Schematic representations of the martensite and austenite lattices with atomic spacings given

Image file: spring_image10.jpg

   b. shows (or passes around the room) a ball-and-stick molecular model, if available

8. Ask students for their opinions on how SMAs could be used in everyday life
9. Give examples of uses of SMAs in everyday life
   a. aircraft
   b. stents
   c. orthodontics—braces
10. Call students attention to the fact that the interesting features of SMAs are due to changes at the atomic length-scale
11. Define nanotechnology
12. A very nice overview of related shape-changing material applications (~13 minutes) produced by NOVA has been posted on YouTube at http://www.youtube.com/watch?v=i6n8cpLKzHE&feature=relmfu There are a total of five related movies on "smart materials are available.

Attachments

"Nitinol: A Smart Metal" handout (docx)

"Nitinol: A Smart Metal" handout (pdf)

"Spring Time in Physics" handout (docx)

"Spring Time in Physics" handout (pdf)

Safety Issues

- Use eye protection (goggles or safety glasses) during this activity
- Use caution near the heat source and when handling hot beakers, water, and wires

Troubleshooting Tips

- If the wire "resists" being bent or shaped, it is possible that the wire's temperature is still above or near the transition temperature; try dipping the segment into a beaker of ice water.
- If the wire "resists" returning to its "trained" shape, it is possible that the wire's temperature is not high enough; try increasing the water temperature or carefully passing the wire through a flame.
- If the ring stand tips during "Spring Time in Physics" activity, try adding more weight (like textbooks) to the base

Investigating Questions

Assessment

Pre-Activity Assessment
Baseline

- Ask students is they have ever heard of SMAs
- Ask students whether it is possible to teach a metal to do something

Activity Embedded Assessment
Observe and Describe

- Students verify Hooke's Law
- Students record observation that spring constant of nitinol can be changed by heating
- Students record observations of deformation and restoration of the shape of nitinol wires

Post-Activity Assessment
Spring Homework Assignment (included on "Spring Time in Physics" handout)

- Describe how the nitinol spring behaved before and after being heated
- Did Hooke's Law hold for all of the springs tested? Include evidentiary support.

SMA Homework Assignment (included on "Nitinol: A Smart Metal" handout)

- Write one paragraph describing why the nitinol wire behaves in the manner observed in class
- Find the name or composition of one (or more) shape memory alloy(s)
- Write two paragraphs describing technology that uses shape memory alloys (students given potential areas to explore: aircraft, dentistry, medicine, optometry, orthopedic surgery, piping, and robotics); include
    - alloy composition
    - detailed description of application
    - advantage of SMA in this application

Activity Extensions

Activity Scaling

For lower grades, the discussion of the SMAs could be kept at a more superficial level by eschewing detailed discussion of the SMA atomic structure.

Additional Multimedia Support

- A very nice overview of related shape-changing material applications (~13 minutes) produced by NOVA has been posted on YouTube at http://www.youtube.com/watch?v=i6n8cpLKzHE&feature=relmfu
- There are a total of five related clips on the general topic of "smart materials"
    - PART I—"Gecko Adhesive Fit for Spiderman": http://www.youtube.com/watch?v=gzm7yD-JuyM&feature=relmfu

- PART II—"Battle Jacket, Self-Healing Protective Coating": http://www.youtube.com/watch?v=R6qHY1H6piE&feature=relmfu
- PART III—"Shape Shifting Material, Drug Delivering Nano Particles": http://www.youtube.com/watch?v=i6n8cpLKzHE&feature=relmfu
- PART IV—"Magneto Rheological (MR) Fluid": http://www.youtube.com/watch?v=SBXQ-6uI8GY&feature=relmfu
- PART V—"Invisibility Cloak": http://www.youtube.com/watch?v=qD37iLWRdD4&feature=relmfu

- A video of a nitinol stent is available at http://www.youtube.com/watch?v=D8bx99ZA-eU&feature=related . The first part of the clip talks about problems on balloon inflated stents, but at 1:36 the topic changes to a discussion of the Stentys SMA Stent. Unfortunately the video uses a lot of medical jargon, but the key ideas about the technology can be grasped. Last accessed 15 December 2011.

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Other

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Supporting Program

National Science Foundation AWARD # 0840889—New, GK-12 Program at the University of Houston: Innovations in Nanotechnology and Nanosciences using a Knowledge, Applications, Research, and Technology (KART) Approach—Pradeep Sharma, Ph.D., Principal Investigator

SPRING TIME IN PHYSICS

Engineers rely on springs to store energy, produce and damp vibrations, maintain spacing, soften impacts, and cause objects to recoil. This activity will focus on the helical coiled expansion spring, but it is important to remember that springs come in a wide variety of shapes and are used in an even wider array of applications. Indeed, the large assortment of shapes, sizes, and functions speaks clearly to the importance of the spring in daily life. In order to make effective use of springs, one must understand the relationship between force and displacement—Hooke's Force Law, an important law in classical mechanics.

Robert Hooke made three important observations for a mass-spring system

i. **the force needed to move the mass *m* is directly proportional to the displacement *x* from equilibrium**—when plotted this gives a straight line
ii. because there is no force at the equilibrium position, the line passes through the origin (x=0 at equilibrium); the spring (as long as it is not over stretched) follows the same line as the applied force is increased and decreased (there is no hysteresis)
iii. **the force on the mass to hold it at a given location is independent of the mass—it depends only on the particular spring being used**

With these, **Hooke's Force Law is written $F_{spring} = -kx$** . This lab will be used to check whether this simple relationship holds and to find the value of the spring constant for a set of springs.

Each group of two (or three) needs:

- Ring stand
- Two clamps for ring stand
- Set of metric hanging masses
- Metric ruler
- Three regular expansion springs with different spring constant values
- Nitinol expansion spring
- Large beaker
- Water (get water as instructed later in the instructions)
- Small S hook
- Thermometer
- Heat source—do NOT turn on the heat source until indicated in the instructions
- Tweezers

INSTRUCTIONS

1. Hang the "S" hook from the clamp on the ring stand
2. Hang one spring from the hook, measure expansion after adding masses, and record data in the table
    a. measure extension for five different masses
    b. expansion only has to be large enough to be measured
    c. be careful and not overload the springs
    d. be sure to measure elongation consistently—use the same reference location after each addition of mass (using the top of the spring works well)
3. Repeat Step 2 until each spring has been extended with five different masses
4. Once all four springs have been extended, again hang the nitinol spring from the "S" hook, this time dangling spring over beaker resting on heat source, making sure there is sufficient space between the bottom of the spring and beaker to allow for masses and spring expansion
5. Fill beaker with water to completely cover spring
6. Attach thermometer to ring stand, turn on heat, and monitor the water temperature
7. When water has exceeded the transition temperature by ~10˚C, measure the new spring length
8. Using tweezers remove spring, attach masses, and replace spring on the hook
9. Wait about two minutes and measure the elongation
10. Repeat steps (9) and (10) above with a total of five different masses
11. When finished measuring heated nitinol spring, turn off heat source, wait for water to cool before cleaning up

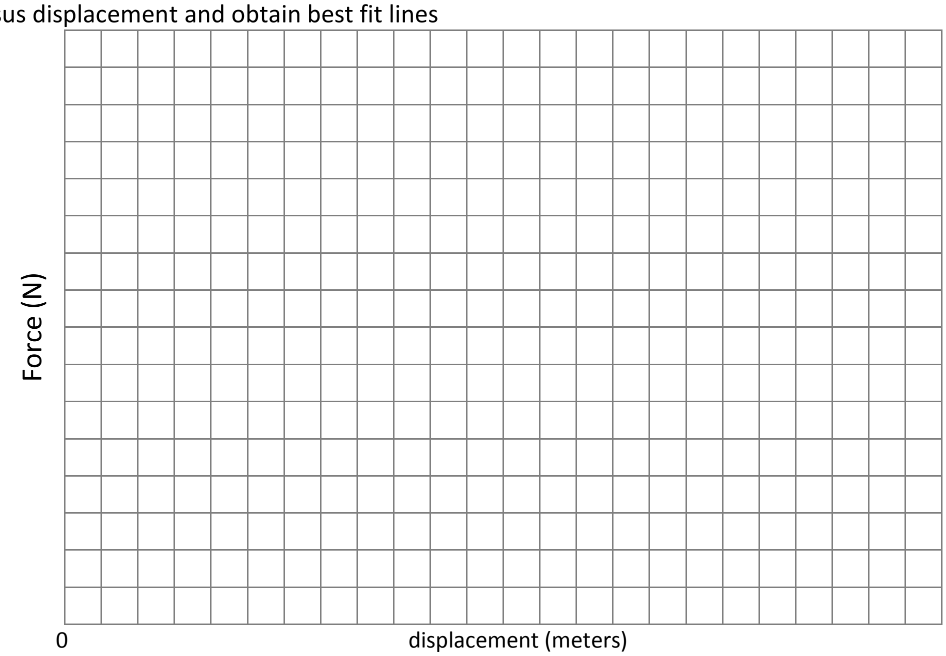
Fill in the chart:

Displacement is the difference between total length and equilibrium length

Force is calculated by multiplying the mass by the gravitational acceleration g (g=9.81 m/s^2)

Spring #	Total length (cm)	Total length (m)	Displacement (m)	mass (kg)	force (N)
1					
1					
1					
1					
1					
2					
2					
2					
2					
2					
3					
3					
3					
3					
3					
Nitinol cold					
Nitinol cold					
Nitinol cold					
Nitinol cold					
Nitinol cold					
Nitinol hot					
Nitinol hot					
Nitinol hot					
Nitinol hot					
Nitinol hot					

Plot force versus displacement and obtain best fit lines



Using the best fit lines, what is the value of the spring constant for each spring? How do these values compare to those provided by the manufacturer (i.e., compute percent error)?

Describe how the nitinol spring behaved before and after being heated.

Did Hooke's Law hold for all of the springs tested? Include evidentiary support.

NITINOL: A SMART METAL

alloy: a metallic material made from two or more chemical elements, at least one of which is a metal

shape memory alloy: a blend of metals that has the ability to transform from a deformed state to a “learned” cold-forged state upon application of heat or stress

nitinol: a shape memory alloy composed of nickel and titanium where the nickel represents 55-56 weight-percent of the final alloy

Because of their ability to return to an original shape when heated or stressed, shape memory alloys (SMAs) are frequently called smart metals, memory metals, memory alloys, muscle wires, or smart alloys. SMAs are finding uses in many industries and clinics because of their shape memory properties. Though “memory” is a convenient descriptive term, the return to the original shape occurs because heat (or sometimes externally applied stress) allows the atoms in the alloy to move into a more favorable orientation.

ACTIVITY:

1. Form groups of two or three and collect the following materials
    a. Nitinol wire (initially crumpled, but “trained” to resume a different shape)
    b. Thermometer
    c. Hot plate
    d. Water (150-200mL)
    e. Beaker (250mL or larger)
2. Fill the beaker with 150-200mL of water
3. Allow the water to heat on the hot plate until the water reaches roughly 50-90˚C (this temperature depends on the specific alloy of nitinol used)
4. Turn off heating on hot pate (to ensure water does not boil—high temperatures may damage the wire)
5. Dip the nitinol wire in hot water
6. Observe and record the results
7. Allow wire to cool, re-crumple it, and repeat the steps above

HOMEWORK:

1. Write one paragraph describing why the nitinol wire behaves in the manner observed during class.
2. Find the name or composition of one (or more) shape memory alloy(s).
3. write two paragraphs describing technology that uses shape memory alloys (students given potential areas to explore: aircraft, dentistry, medicine, optometry, orthopedic surgery, piping, and robotics); include
    - alloy composition
    - detailed description of application
    - advantage of SMA in this application