A Metal to Remember

Engineers are always looking for special materials that can solve design problems. In the early 1960's, an alloy of titanium and nickel was discovered by the Naval Ordinance Laboratory that was very strange. It appeared to have a memory! A straight wire made of this alloy could be twisted into a pretzel. When heated up, it would magically straighten out! The alloy turned out to be what is called a -Shape Memory Alloy", or "SMA". The strange behavior is called the "Shape Memory Effect".

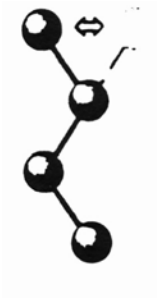
There are many practical uses for SMAs. All of the hydraulic tubing on the Navy's F-14 Tomcats are connected using SMA couplings. Extremely flexible eyeglass frames are made of SMA which is in the high temperature form at room temperature. Wires made of SMA will contract as much as eight percent of their total length when heated, so they can produce life-like motion without using gears or motors-great for robots and models!

As part of this Discover"E" project, the students will explore the Shape Memory Effect by making the tall of a scorpion whip forward using only a hair-width SMA wire.

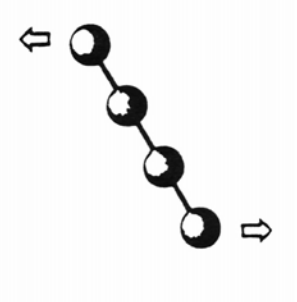
How it Works

Here is a simple way of explaining how a Shape Memory Alloy works:

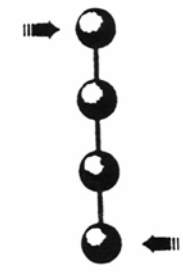
• At room temperature, all the bonds between atoms in a Shape Memory Alloy are easily flip-flopped from one side to the other, making the material pliable and easily bent.



• When you pull the scorpion tail back, the wire stretches and all of the bonds between the atoms get flipped in the same direction.



• When the wire is heated, all the bonds forcibly line up in a straight line-the high - temperature form of SMA. The wire contracts to its original shorter length



Grade Level

This lesson is designed for middle to junior high school science students. The lesson can be adapted for high school students by increasing the detail provided on the atomic structure of metal crystals, or by building some of the projects listed in the Muscle Wires Project Book (See Suggested Reading).

Overview of Exercise

- Demonstrate the Shape Memory Effect by heating and cooling SMA springs and wire. Show how the low-temperature form is easily bent, but the high-temperature form is rigid and springy.

- Explain the principle and operation of an SMA. Mention how the strange properties of an SMA come from a change that occurs in its internal crystal structure when heated.

- Show some examples of how SMAs are used. (See if any students have SMA eyeglass frames!)

- Have each student or team of students build -a scorpion with a stinger activated by a very thin SMA wire.

- Break students into teams of three or four, and have them think of a new way to use SMA springs or wire. Have the teams of students draw a sketch of their ideas and present them to the class.

For a class period less than one hour, it might be necessary to attempt only two of the above activities.

Materials

Basic Materials

1. SMA wires and springs (Note: The materials for this entire activity, with enough wires to make ten scorpions, are available in a special kit from Dynalloy. See *Where to get Shape Memory Alloy Materials*).
2. Hair dryer capable of producing heat over 70* C. (A paint stripper at low setting also works very well but should only be used by the instructor or other adult).

Materials for Making Scorpion

1. Copies of attached scorpion plans and instructions, one for each student or team of students.

2. Scissors for cutting out scorpion.

3. Corrugated cardboard or 1/8" foam core, 8-1/2"x11", one for each scorpion. (These should be prepared and available before the class period begins).

4. Manila folders (for gluing to back of tail).

5. Glue sticks or spray adhesive.

6. Stapler and staples for anchoring wire.

7. Pushpins or thumb tacks for pivot point, one per scorpion.

8. SMA wire with crimp connectors and 10" wire leads on each end (SMA wire spec: 150 micrometers, about .006"). Ten are included in kit from Dynalloy. Plain SMA wire is also available from Mondotronics. See *Where to get Shape Memory Alloy Materials*.

9. Battery holder(s) for two AA (1.5V) size batteries, Radio Shack Part No. #270382A. (Having more battery holders will allow more students to try out their scorpion tails at the same time).

10. Batteries, two AA (1.5V) size batteries for each battery holder.

11. Paper and pencils for sketching ideas.

12. This is an imperfect world. Have a staple remover and extra supplies on hand!

Lesson Outline

1. Discuss the role that materials play in engineering and how engineers select materials that have unique properties to solve design problems. Explain how one

such material is an alloy of titanium and nickel which displays the "Shape Memory Effect".

2. Demonstrate the Shape Memory Effect by stretching the springs and heating them up with a heat gun or hair dryer (For safety, only the instructor should use the heat gun). The springs are capable of being Will stretched to about 14 centimeters, and shrink to 29 millimeters when heated. Wires may be bent into various shapes and when heated will straighten out to the "remembered" straight position. Point out how different the wire is when it is hot (i.e. stiff) as opposed to how easily bent it is when cool. Allow each student the opportunity to feel the low and high temperature properties by bending and heating the wires.

3. Explain how SMAs work. Describe how the bonds between the atoms are easily "flopped" in the low temperature phase but become very rigid and "cubic' when the material is heated.

4. Distribute construction materials (items 1-8 above) and have each student or team build the scorpion following the attached plans. (Build one first to use as an example and to familiarize yourself with the project.) Monitor the construction to make sure students stay on track.

5. Have the students/teams test their scorpions by touching the two wire leads to the battery terminals to make the stinger move. (A heat gun or hair dryer will also work but less effectively. Pass the stream of hot air over the wire to make it contract). Make sure that the SMA wire is tightly attached on both ends and that it is firmly anchored with a staple about 3 mrn (1/8") from the pivot point. Disconnect the battery and pull the tail back to stretch the wire out, then repeat the cycle, judge the scorpions and pick a class winner for the best-built scorpion with the greatest tail movement!

6. If time permits, have students gather in groups and think of a new way to use SMA materials. Have teams draw a sketch of their ideas and present them to the class.

Extensions

Make a permanent electrical circuit with a switch and soldered connections to activate the scorpion tail. Explain how the resistance of the SMA wire (about one ohm per inch) causes the wire to heat up until it reaches the activation temperature and contracts. Use Ohm's law (E=IR) to show how much current is flowing in the SMA wire, and how increasing the battery voltage will speed up the movement of the tail by increasing wire current.

Build one of the projects listed in the *Muscle Wires Project Book*

Where to Get Shape Memory Alloy Materials

Dynalloy Inc.,
18662 MacArthur Blvd.,
Suite #103,
Irvine, CA 92715,
Phone: 714-476-1206,
Fax: 714-476-3167.
Available: Kit of materials for performing the Discover "E" activities described above. (Includes 1 spring, 6 thick bendable wires and 10 thin wires with crimps and leads (for ten scorpion tails) and 2 battery holders.) Approximate cost: S22 + S & H. Also available, additional wires and SMA sample kits.

Mondo-tronics Inc.,
524 San Anselmo Ave.,
#107-70,
San Anselmo, CA 94960
Phone: 415-455-9330/800-374-S764.
Available: A variety of interesting kits, projects, books, and SMA materials.

Shape Memory Applications, Inc.
1034 W. Maude Ave.,
Suite 603,
Sunnyvale, CA 94086
Phone: 408-730-5633.
Available: SMA springs, wires, and engineering kits.

Suggested Reading

Muscle Wires Project Book, 3rd Edition by
Roger G. Gilbertson,
available from
Mondo-tronics,
524 San Anseltno Ave., #107-70,
San Anselmo, CA 94960
Phone: 41S-455-9330/800-374-5764.

Using Shape Memory Alloys,

by D.E. Hodgson,
available from
Shape Memory Applications, Inc. 1034 W,
Maude Ave., Suite 603,
Sunnyvale, CA 94086
Phone: 408-730-5633.

SS-Nitinol-The Alloy with a Memory,
C.M. Jackson, et.al.,
NASA Publication SP-5110,
Washington, DC, 1972.

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National Engineers Week
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Instructions for Making SMA Scorpion

Step 1: Collect Materials

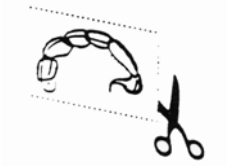
Assemble and lay out all the materials described in section Materials for Making Scorpion. Put batteries in battery holder(s). Have pieces of 8 1/2" x 11 " cardboard or foam core cut out before class to save time.

Step 2: Cut Out Scorpion and Tail

Using scissors, students will cut out the top of the scorpion, following the outline of the upper body. Cut out the box enclosing the scorpion tail along the dotted lines.

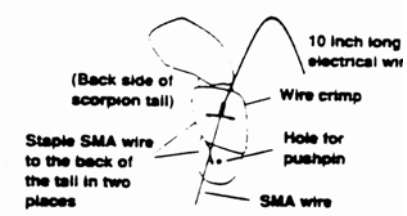
Step 3: Glue to Sturdy Backing

Using either a glue stick or spray adhesive, attach the scorpion body cut-out to a piece of corrugated cardboard or "A" foam core board, lining up the bottom of the scorpion with the bottom of the cardboard as shown. Then, using either a glue stick or spray adhesive, attach the scorpion tail cut-out to a manila folder.



After gluing the scorpion tail to the manila folder, cut along the outline of the tail. Using a pushpin, make a small hole in the tail at the marked pivot point to assist in locating the staples.

Step 4: Attach SMA Wire to Tail

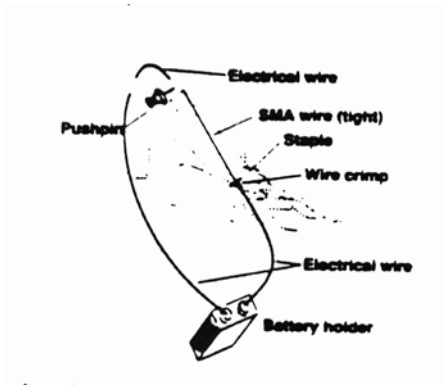


Turn the scorpion tail upside down. Staple one end of the SMA wire to the tail below the crimp as shown. The staple must be touching the SNIA wire to keep it from pulling free. Staple the SMA wire to the back of the tail again about 3 –mm (1/8") away from the pushpin hole. The correct placement of this staple is important! Now, turn the tail over.

Step 5: Attach Tail to Body with Pushpin

Using a pushpin, attach the tail to the scorpion body by pushing the pushpin through the tail, then into the cardboard at the location marked. Loop the electrical wire lead as shown below. Make sure the tail can move freely around the pushpin.

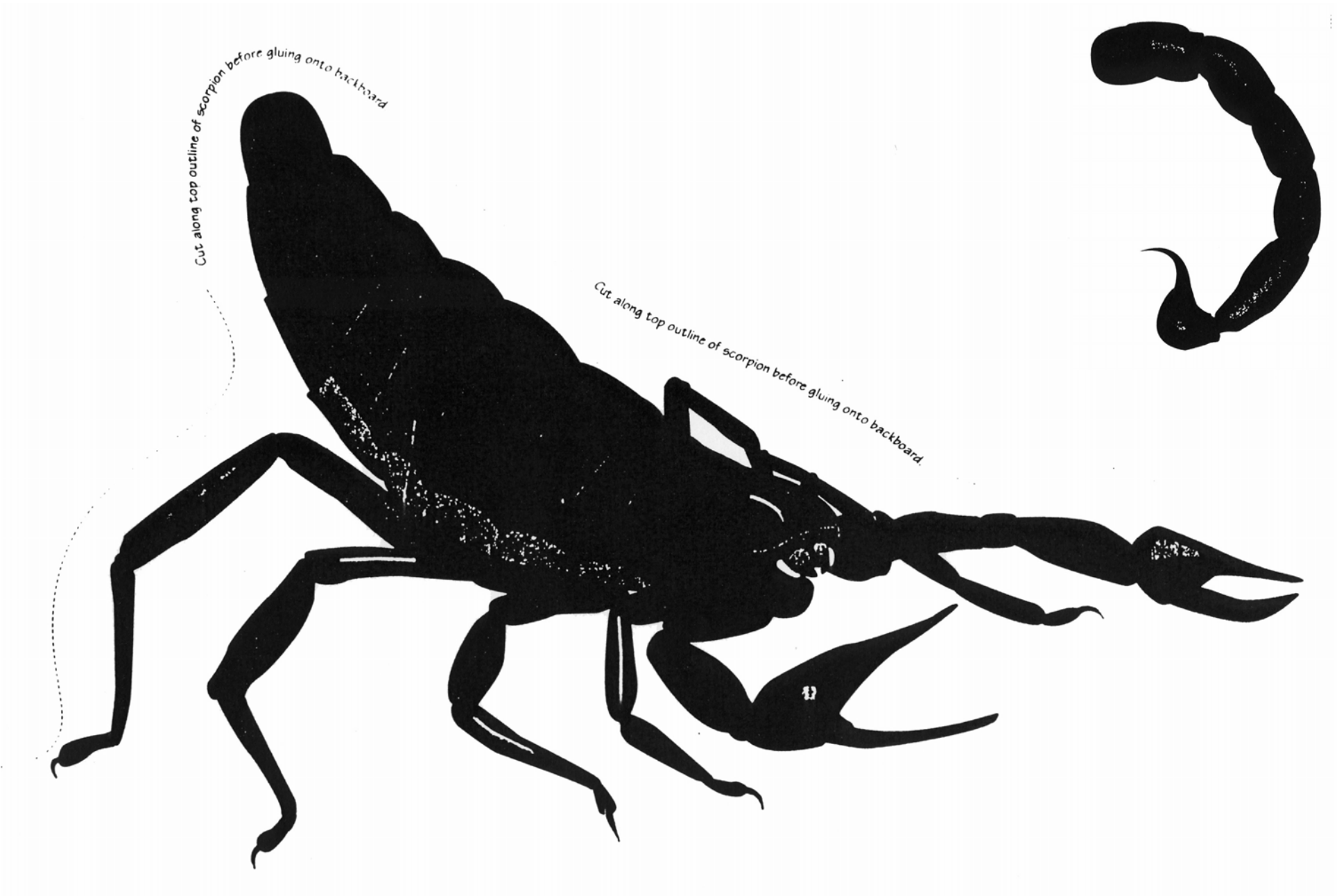
Step 6: Route Wire and Set Bottom Staple



Loop and route the wire leads as shown. Pull the scorpion tail all the way back by hand, then, grasp the bottom electrical lead and gently pull until the tail begins to move up. Be careful not to pull too hard on the electrical leads or they may come out of the crimp. When the tail Is in the position shown, and the SMA wire is tight, staple the bottom of the SMA wire to the Scorpion body near the base of the first leg just above the crimp, as shown, to keep the bottom of the wire from pulling free. (The SMA wire must be tight when the tail is pulled back to the left of the body.)

Step 7: Finish and Test Scorpion Tail

You can make your scorpion stand by attaching an easel to its back with masking tape. To rest your scorpion, make sure the scorpion tail is pulled back and that the SMA wire is tight. Touch one end of each wire lead to the two battery terminals for about one second. As the wire heats, it will contract and the tail will whip forward. Disconnect the battery, pull the tail back by hand to stretch the SMA wire out again and then repeat the process. Make sure that the staples are firmly over each end of the SMA wire, and that the crimps are on the outside of the staples. The wire must be tight for the scorpion tail to work properly!


Cut along top outline of scorpion before gluing onto backboard
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