MAKING STUFF WITH DAVID POGUE

DEMONSTRATION

Shape Shifters: Shape-Memory Alloys & Polymers

NOVA PBS

WGBH GRATEFULLY ACKNOWLEDGES THE CONTRIBUTION OF THE MATERIALS RESEARCH SOCIETY. MRS MATERIALS RESEARCH SOCIETY Advancing materials. Improving the quality of life.

MAKING STUFF SMARTER Demonstration

Overview

TITLE
Shape Shifters: Shape-Memory Alloys & Polymers

SHOW
Making Stuff: Smarter

DESCRIPTION
In this two-part demonstration, visitors will explore two shape-memory materials (a metal and a plastic) that can be programmed to return to a previously set shape when exposed to heat.

OBJECTIVE
Visitors will learn about:
- "smart" materials that can sense and respond to their environments
- shape-memory materials, which are smart materials that can be programmed to remember specific shapes

OTHER KEY TALKING POINTS
Materials scientists are developing new smart materials to help solve problems in engineering, medicine, and everyday life.

AUDIENCE
General public, ages 10 and up

TIME
Set-up: 10 minutes
Presentation: 20 minutes. (Each part can stand alone but the two are best presented together, with the shape-memory wire first.)

All materials change in response to their environment. Most expand when heated, for example. **Smart materials** are designed by materials scientists and engineers to respond to changes in their environments—often in unusual or dramatic ways to achieve a specific purpose. NOVA's *Making Stuff: Smarter* features scientists developing new airplane wings that will one day be able to change their shape smoothly in mid-flight, as birds do. (Nature, a master of response and change, inspires the design of many smart materials.)

A **shape-memory material** is a type of smart material that can be programmed to return to a previously set shape when exposed to certain change in its environment. The materials in this demonstration display their shape-shifting properties when exposed to heat. Other shape-memory materials respond to certain wavelengths of light, changes in the magnetic field, electrical currents, or chemical solutions.

Shape-memory and other smart materials are revolutionizing medicine, manufacturing, construction, and energy. Researchers are working to develop a smart fabric that senses the presence of blood and sends a signal to a handheld computer, alerting doctors that an unconscious combat soldier may be injured. Another potential application is a **piezoelectric** city sidewalk that senses the pressure of footsteps and converts that kinetic energy into electric current that can power streetlights and buildings.

Materials scientists are asking:

- How can we design materials that respond to changes in their environment?
- How can we use those materials to make smarter stuff?

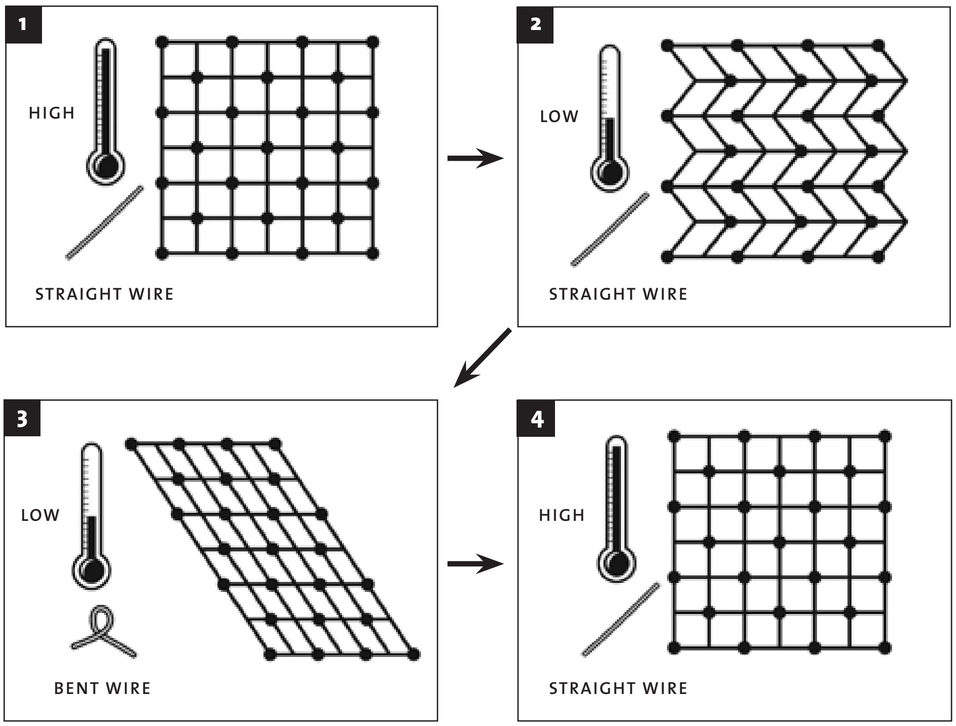
Science Background

Shape-Memory Alloys & Polymers

This two-part demonstration focuses on two **shape-memory** materials, an alloy and a polymer.

SHAPE-MEMORY ALLOY

An **alloy** is a blend of metals. The alloy in the first part of this demonstration is a nickel (Ni) and titanium (Ti) alloy named Nitinol (pronounced "*night-in-all*") whose shape-memory properties were discovered at the Naval Ordnance Laboratory (NOL) in White Oak, Maryland, in 1961 (hence the name NiTiNOL). It has a crystal structure, meaning the molecules are arranged in a rigid and regular structure, like a military marching band locked in formation. Most common materials undergo 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.



How Do Shape-Memory Alloys Work?
A shape-memory alloy has two structures or phases, which it can transition between while remaining solid. In the high temperature phase, called austenite, the atoms arrange themselves in their "memorized" or permanent shape. In this case, the wire is set straight **(1)**. As the alloy cools and enters the low temperature phase, called martensite, the cubic structure becomes folded or twinned **(2)**. In this state, the wire can be deformed, skewing the cubic structure **(3)**. The alloy will hold that deformed shape until it is heated back above the transition temperature, at which point the atoms revert to their austenite state and the wire "remembers" its previous shape and straightens **(4)**.

Below that transition temperature, the wire can be deformed because atoms shear past each other. It will hold that deformed shape until it is heated back above the transition temperature, at which point the molecules revert to their previous state. Training the wire to a new memorized shape requires a blast of thermal energy on the order of 500°C (about 900°F) and for the new shape to be temporarily maintained with applied force (such as pliers) until the wire sets and relaxes. Cooling the material ensures that the new shape becomes fixed.

Some other shape-memory alloys are copper-aluminum-nickel, copper-zinc-aluminum, and iron-manganese-silicon.

SHAPE-MEMORY POLYMER

All plastics are **polymers**, which are long chains of molecules. Shape-memory polymers, however, are combinations of two polymers, each of which has a different melting point. One polymer sets the permanent memorized shape at the polymer's melting point while the other polymer creates the temporary shape at a different, transition temperature. Heat softens this temporary shape (by breaking the crosslinks between polymer strands), and the shape-memory polymer reverts to its permanent shape. Some shape-memory polymers have up to three memorized shapes, each triggered at a different temperature.

Materials List

Part 1: Shape-Memory Alloy (Nitinol)

- Nitinol wires set straight
- straight, flexible, ordinary wire segments about the same length as the Nitinol (e.g., straightened paper clips)

Part 2: Shape-Memory Polymer

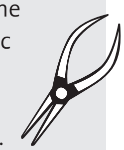
- clear container of cold water to cool shape-memory polymer
- clear container of warm water (85°F/30°C or warmer, not hot) to reset the shape
- paper towels
- samples of ordinary plastic such as polyethylene (#1 plastic, e.g., plastic soda bottles or pint-size fruit containers) or polystyrene (#6 plastic, e.g., plastic drink cups or clamshell deli containers)
- shape-memory plastic strips
- Thermos of hot water (to refresh the warm water throughout the day)
- overhead projector on which to place the clear container (for large audiences) and projection screen or wall (optional)

Both

- heat gun (also called a hot air gun) needle-nose pliers to hold material in front of the heat gun
- (optional) NOVA *Making Stuff:Smarter* video clip (see Resources) and video display equipment
- Demonstration Title Sign and applications collage (see Resources)—mount on foam core or insert into a clear plastic display rack

For Resources, visit **pbs.org/nova/education/makingstuff**

Materials and supplies for this demonstration can be found at most hardware, home improvement or office supply stores. The Nitinol wire can be found online at **teachersource.com**, and **imagesco.com**. The shape-memory plastic can be purchased at **bendableplastic.com** and **inventables.com**.



Showing Video Clips from MAKING STUFF: SMARTER

If you are able to show video at the site of the demonstration, the video clip from NOVA's *Making Stuff: Smarter* can be used either as an introduction or as a follow-up to your demonstration. The clip can also be played on a continuous loop nearby to draw visitors into the demonstration area.

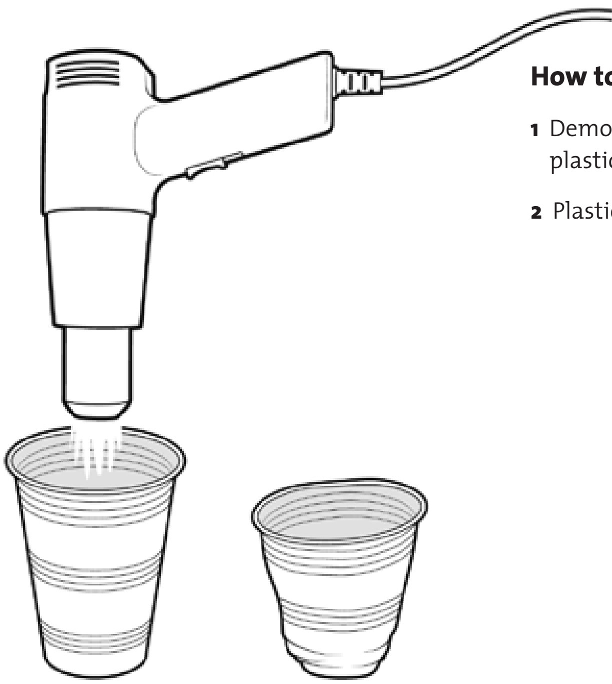
Advance Preparation

PART 1: ALLOY

1. The transition temperature for Nitinol wires varies, so bend and then test the shape-memory properties of your samples with the heat gun several times to make sure you're providing enough thermal energy.

PART 2: POLYMER

1. Test your heat gun on a common plastic sample (#1 polyethylene or #6 polystyrene) to make sure it's hot enough to shrink the plastic. Directing the heat gun down into the mouth of a plastic cup (as below) works well to quickly shrink it. Hold the cup still with the needle-nose pliers or up for better visibility.



How to Heat Common Plastic

1 Demonstrator heats common plastic with heat gun

2 Plastic will shrink but not melt

2. Cut the shape-memory sheets into several strips. Long thin strips make for easier manipulation and viewing.

3. Practice the demonstration several times before performing it for a live audience.

4. Prior to starting the demonstration, set up the materials for both parts, to make for a smoother transition. Have the containers of cold and warm water off to the side. Have a Thermos of hot water ready to use throughout the day to refresh the warm water container.

5. Post the Demonstration Title Sign on the cart/table.

Demonstration Script

PART 1: SHAPE-MEMORY ALLOY—NITINOL WIRE

1. **Welcome visitors** to the demonstration and briefly introduce the show. *"Welcome to this* Making Stuff *demonstration.* Making Stuff: Stronger, Smaller, Cleaner, Smarter *is a four-part NOVA series on materials science that will air on PBS in January 2011. This demonstration accompanies the* Making Stuff: Smarter *episode."*

2. **Engage your audience.** Announce that you're about to demonstrate some "smart materials" that can do some amazing things. Point to the wires lying on the cart and ask your audience: "*Do these wires look 'smart'?*"

3. **Set up the challenge.** "*Well, we're going to investigate to find out if they are smart materials.*"

4. **Introduce smart materials.** "*A smart material is something that can sense a change and respond to it in a way that makes it very useful.*"

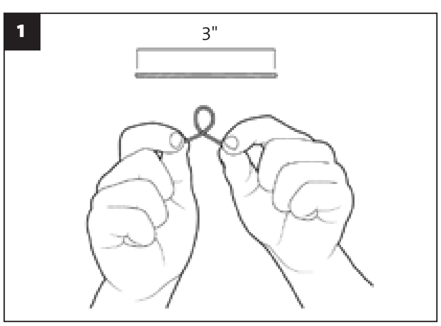
5. **Get volunteers.** Ask the audience: "*What happens to a metal when you heat it?*" As you solicit answers, pass out one or two normal wires and one or two Nitinol wires to volunteers. In answer to your question, science-savvy listeners will likely respond that metal expands or melts. Someone may incorrectly suggest it burns. Or, perhaps just note that it gets hot.

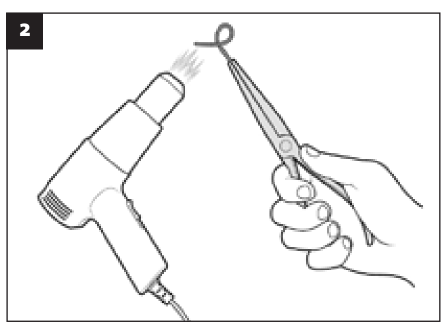
6. **Bend the wires.** Ask the volunteers to bend their wires into any shape—perhaps coils, springs, curlicues, zigzags, etc.

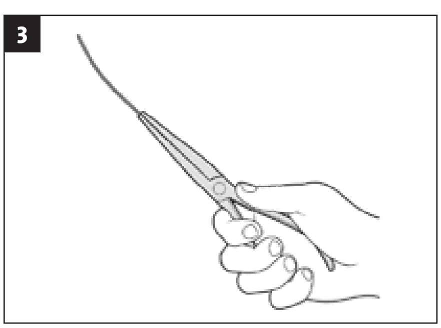
7. **Heat the ordinary wire.** Ask the first volunteer (with *ordinary* wire) to step forward. Say: "*Let's see how this wire responds to heat.*" Hold the wire with the pliers and heat it with the heat gun. Nothing will happen.

SAFETY NOTES

- Be careful not to direct the heat gun toward audience members while in use.
- Allow materials to cool completely before being handled by visitors.
- After using heat gun, set aside out of reach of visitors, to cool.







How to Demonstrate the Shape-Memory Wire

1 Demonstrator hands straight wire to volunteer to bend

2 Demonstrator holds bent wire with pliers and heats with heat gun

3 Shape-memory wire will straighten while regular wire will not

8. **Heat the Nitinol wire.** Retrieve a bent Nitinol wire from a volunteer. Say: "*So let's see how this wire responds to heat.*" Hold the wire with the pliers and heat it with the heat gun. The wire will straighten itself out.

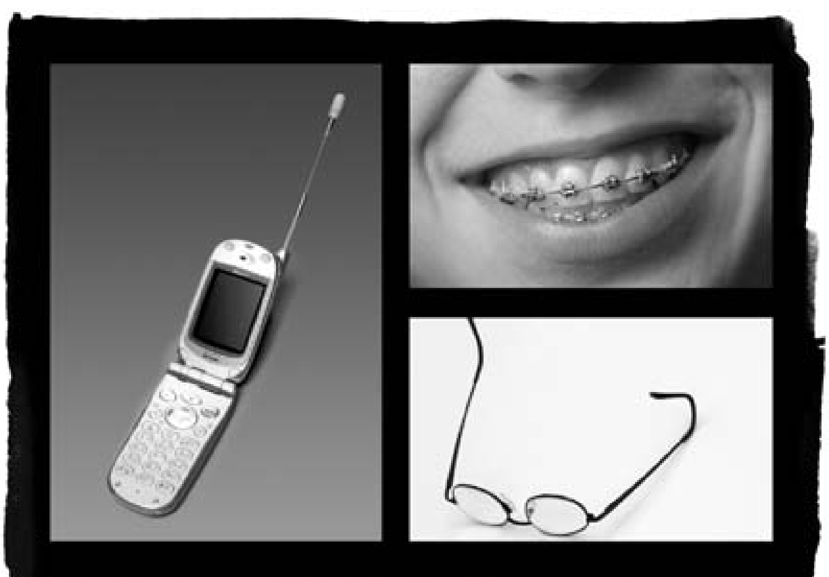
9. **Ask for predictions.** "*Do you think it could happen again?*" Make sure the wire is cool, and then ask the volunteer to reshape the wire and repeat the test.

10. **Explain** to visitors that they just witnessed an example of shape memory. And that:
    - "*Nitinol (a nickel-titanium alloy) is a shape-memory material—one of many classes of smart materials that can be programmed to do things that ordinary stuff cannot.*"
    - "*What happened was, at a certain temperature, the atoms in the wire shifted back to their 'remembered' shape—a straight form. This can be done over and over again.*"
    - "*By contrast, the ordinary wires are passive. They respond to low levels of heat by expanding and higher levels of heat by melting (not burning) but they do not have shape-memory properties.*"

11. **Relate the science to everyday life.** "*Perhaps you are wondering why you should care about shape-memory alloys.*" Then ask everyone to smile. Inquire: "*Who's wearing braces (or has worn braces)?*" Ask a brace wearer how it feels to have them tightened. Suggest that Nitinol wire braces can save people from this periodic agony. The main wire running across all the teeth is programmed to bend into an arch at body temperature to apply constant and gradual pressure on the teeth.

12. **Brainstorm other uses.** "*Can you think of some other uses of Nitinol wire?*" (It is currently used in thermostats, automatic shut-off valves, and some fasteners. Some other future uses might be car bumpers.)

Applications



Applications of Shape-Memory Alloys

- thermostat control wires or other devices that could be used to prevent burns (e.g., anti-scald devices on showers) or on fire sprinkler valves
- staples (or couplings) that close themselves with heat
- flat, compact space antennae that save space during launch and then unfold themselves in orbit
- heart stents that expand after insertion to hold open clogged cardiac arteries
- cell phone antennaes or eye glasses frames that regain their shape if bent

PART 2: SHAPE-MEMORY POLYMER

1. **Refine the concept** of smart materials: Ask: "*Is every material that changes shape a smart material?*" Accept all responses.

2. **Introduce plastic.** Show your audience the common plastic (polyethylene or polystyrene sample) and explain that the scientific term for plastic is polymer, which is a long chain of molecules.

3. **Ask for predictions.** Ask what a blast of heat is likely to do to the plastic. (Some might suggest it will change into some other shape. Agree that this is certainly a logical assumption, especially since the very definition of plasticity is the ability to be bent, molded, extruded, deformed, or otherwise reshaped.) Accept all responses, then heat the plastic with the heat gun until it stops shrinking. (Tip: Directing the heat gun down into the mouth of a plastic cup works well.)

4. **Invite interaction.** Pass around "before" and "after" samples of the shrunken plastic for comparison. Challenge your guests to make the shrunken plastic revert to its previous form—as the Nitinol wire did. Solicit suggestions. Try reheating it; no effect. Try stretching it; it won't budge. Emphasize that this shape change is a one-way street.

5. **Introduce smart plastic.** Say: "*Now we are going to see some smart plastic.*" Pass out the shape-memory polymer strips and invite guests to play with them to test their shape-memory properties. Ask visitors to bend the material into the desired shape (a coil works best, the tighter the better) and return it to you.

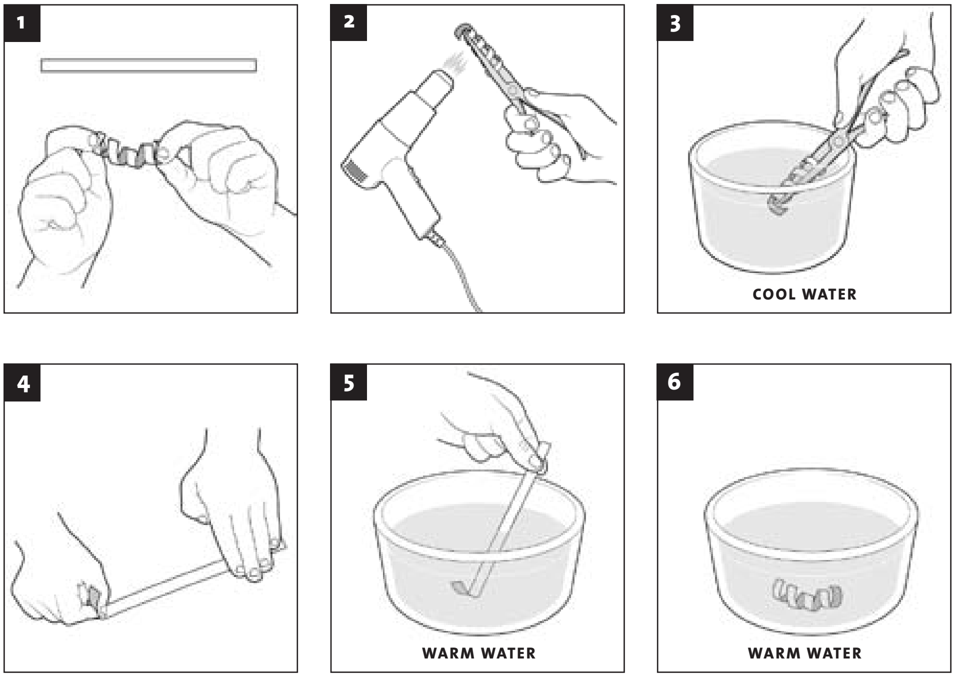
6. **Set the coil shapes.** Hold the coil shape in place with the pliers and heat with the heat gun on low for about 30 seconds. Submerge the plastic in the beaker of cold water to cool for 15 seconds.

7. **Straighten the coils back out.** Pass the plastic coils back to the visitors to straighten. When straightened, ask them to drop it into the beaker of warm water.

8. **Observe the shape memory.** When dropped into the water, the plastic strip should begin to recoil. (Note: This may occur slowly, but movement should be visible immediately.) Explain that shape-memory polymers are actually two polymers combined, each with different melting points. One polymer responds at a certain temperature to set the permanent memorized shape of the object and the second polymer responds at a different temperature to set the temporary shape. The water temperature is higher than the temperature at which the plastic reverts from its temporary shape (straight) to its memory shape (coil trained by the heat gun). Say: "*It remembers the shape that you gave it.*" Repeat with a few more visitors' samples.

How Does Heat-Shrink Plastic Work?

- The large family of heat-shrink **thermoplastics** (such as polyethylene or polystyrene) works the same general way.
- During manufacturing, the heat-shrink plastic is stretched out, molded, and rapidly cooled to lock in a shape.
- Heat causes the molecules to relax back to their pre-stretched state—and the plastic to shrink.
- It's a one-way street: The plastic won't shrink past a certain point, and it won't revert to its stretched, molded shape unless melted and remanufactured.



How to Demonstrate the Shape-Memory Plastic

1 Demonstrator hands straight plastic strip to volunteers to coil

2 Demonstrator holds coiled strip with pliers and heats with heat gun

3 Demonstrator plunges coil (still in pliers) into cool water

4 Volunteer straightens coil

5 Volunteer drops coil into warm water

6 Plastic strip will regain its coiled shape

9. **Further define smart materials.** Ask: "*What makes this material smarter than the common plastic samples?*"

   Some answers are:

   - It can be programmed to remember a shape.
   - It's a two-way street; the plastic can remember its memorized shape again and again, no matter how many times you deform it.
   - You can also reprogram it. Thus, the plastic can both "remember" and "re-learn."
   - The action happens automatically in response to a stimulus—no human intervention or mechanical parts are needed.

10. **Relate the science to everyday life.** Discuss some of the applications (see page 72), which are not on the market yet, but are under development and being tested.

11. **Encourage your guests to think like inventors** and brainstorm other ways that shape-memory polymers could be used in the future.

Applications

Real and Potential Applications of Shape-Memory Polymers

- clothes embedded with shape-memory plastic strips; body heat causes them to unwrinkle or crease themselves
- polymer or composite car parts that, if crumpled in an accident, could be repaired by heat
- autonomous kinetic sculptures made of shape-memory materials
- sutures (at right) that tie themselves and keep wounds closed at an optimal tension
- smart utensils such as forks that, when placed in hot soup, turn into a spoon
- stents that can be inserted into arteries and then expand to hold them open

Glossary

- **alloy**–a blend or combination of two or more metals
- **phase change**–a change from one state of matter (solid, liquid, or gas) to another; for example, from solid to liquid or liquid to gas
- **piezoelectric**–a type of material that responds to an applied force by producing electricity; also, when an electric field is applied, it will produce a force (Buzzers are commonly made from quartz, which is a piezoelectric material.)
- **polymer**–a long chain of molecules; all plastics are polymers
- **shape memory**–a property of materials in which various shapes can be programmed to form in response to certain changes in the environment, such as heat or light
- **smart material**–a material that senses a change in its environment and responds in a specific way
- **thermoplastics**–plastics that are capable of melting and can change phase from solid to liquid and back again
- **thermoset plastics**–plastics that scorch or burn without melting first

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