# THE MATERIALS THAT MOVE US: STATES OF MATTER

**Having an understanding of a material's melting and evaporation points is essential to many scientific applications; this chapter explores states of matter through a practical classroom activity and highlights the relationship between atomic structure and physical properties by creating an alloy within the classroom.**

**In this module students will be able to:**

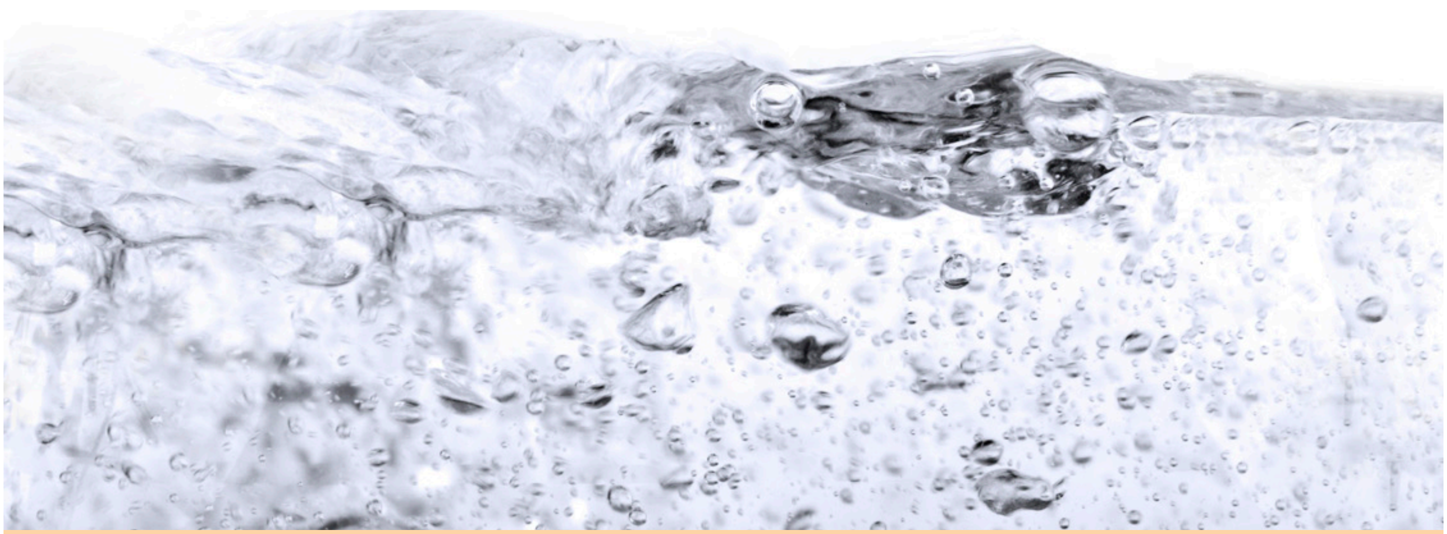
- Collect data and generate a heating curve for water
- Explain how intermolecular forces affect states of matter
- Observe the fusion and solidification points for a tin/bismuth alloy
- Experiment with alloys by recording the temperature of various combinations of tin and bismuth
- Compare the melting point of pure substance to alloys

## Class Activity

# WHAT'S THE MATTER?

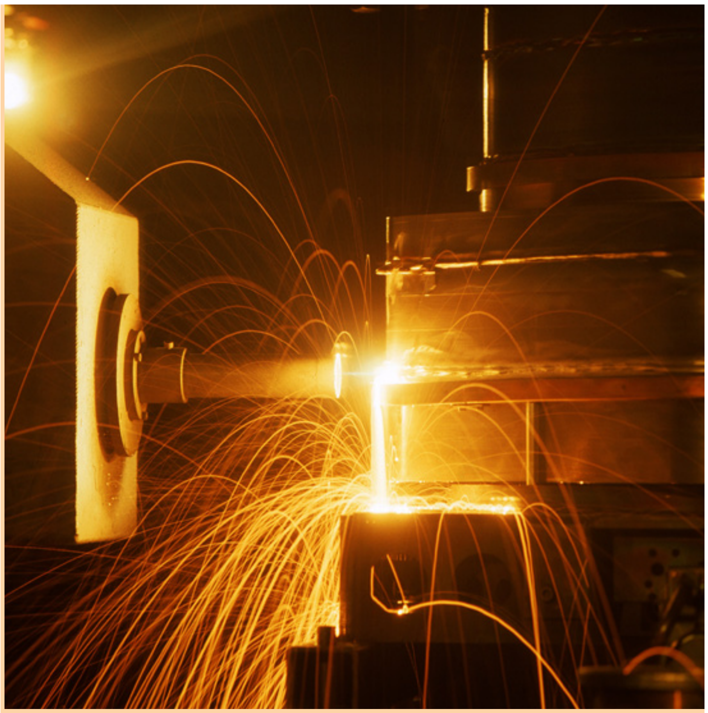
### Background

You probably haven't considered it but when the ice in your glass melts or the water in your pot begins to boil you're witnessing science at work . As the water changes from one state of matter to another (from solid to liquid or liquid to gas) a phase change is taking place right before your eyes. This everyday example probably doesn't sound that exciting, but consider for a moment that the same scientific principles at work here are also behind creating aluminum components for jet engines or titanium tanks for spaceships.

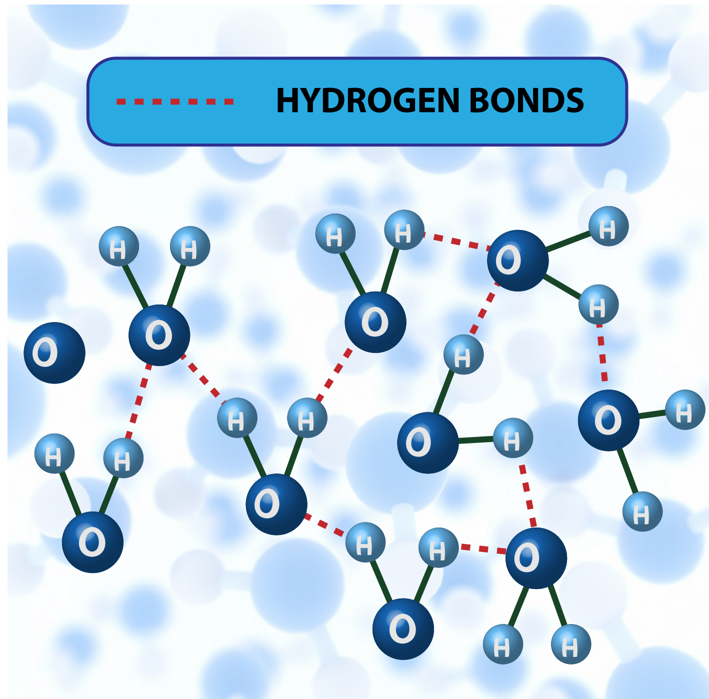


*Understanding how materials change from one state of matter to another is a fundamental concept in science. What's more, knowing the temperatures at which these changes might take place can be critical when working with a material.*

How, you might ask? Let's explore the example of an aluminum component created by electron beam welding: a process which relies on phase changes to join two parts into one with a seam that is narrower than the width of a human hair. To accomplish this, a narrow beam of  electrons is shot at the aluminum. This heats the aluminum to its melting point (1200°F) where, much like ice turning to water, the solid aluminum becomes liquid. As the two pieces of aluminum cool they solidify together to form one piece. On occasion, the beam can be so strong that it reaches the evaporation point of aluminum—that's about 4500°F: nearly half the temperature of the surface of the sun!



*Electron beam welding was embraced by the aerospace industry because it creates strong, precise welds. (Photo courtesy of TWI Limited.)*




*In order to change from solid to liquid, or liquid to gas, the molecules of a substance must vibrate with sufficient energy to break free of their bonds. (Graphic by Dave Rasel)*

The following experiment will explore phase changes in water. One difference that is important to remember is that water molecules are held together by intermolecular forces but metals (with the exception of mercury) are held together by metallic bonds. Although the forces being overcome are different, the process taking place at the molecular level is quite similar in that heat is being used to create enough energy to overcome the forces that keep something solid, liquid, or gaseous. As more heat is applied, the molecules gain more and more energy vibrating with increasing excitement until they break free of the bonds or forces that hold them in place.

### Materials

- 250 mL beaker
- Hot plate
- Beaker tongs
- Ice
- Thermometer
- Water

## Class Activity

**Procedure:**

1. Fill a 250 mL beaker half full with ice and water.
2. Pre-heat a hot plate to 100°C. Do not place the beaker on the hot plate yet.
3. Insert a thermometer into the beaker containing ice and water. Make sure the thermometer does not touch the sides or bottom of the beaker.
4. Gently stir the ice and water throughout the experiment.
5. When the thermometer reaches its lowest reading, record the temperature in °C under time 0 in the data table.
6. Promptly place the beaker on the hot plate.
7. Read and record the temperature every 30 seconds for a minimum of 10 minutes after the water reaches a full, rolling boil. Continue stirring throughout the experiment.
8. Note the following times:
   - **a.** When the ice begins to melt
   - **b.** When the ice has melted entirely
   - **c.** When the water begins to boil

**Data:**

Draw a table similar to the one below, continuing to fill rows as needed.

| Time (min.) | Time (s) | Temperature (°C) |
|---|---|---|
| 0 | 0 | |
| 0 | 30 | |
| 1 | 0 | |
| 1 | 30 | |
| 2 | 0 | |
| 2 | 30 | |
| 3 | 0 | |
| 3 | 30 | |
| … | … | |

## Class Activity

### Questions

1. Graph the data, placing time on the x-axis. Label the states of matter and phase changes on the graph.
2. How did the temperature of the water/ice mixture change while the ice was melting?
3. How did the temperature of the water change between the time the ice melted and the water boiled?
4. Which phase change required the most added heat energy? Why?
5. If temperature is a measure of the average kinetic energy of particles, what can you conclude about kinetic energy during phase changes?

### Definitions

**Intermolecular Forces**
Forces of attraction (attractive and repulsive) between molecules.

**Metallic Bonds**
The chemical bond that holds the atoms of a metal together. It is formed by the attraction between the metal's atoms and free (valence) electrons that move between the fixed atoms.

**Phase Change**
A transition from one state of matter to another.

## Extension Activity

### THE SUM OF OUR PARTS?

The atomic structure of a material helps determine almost everything about it. From the material's chemical properties to its physical, thermal, electrical, and even magnetic properties, so much depends on what is occurring at the atomic level. But pure elements rarely have the specific properties that are needed for a particular application so scientists often find themselves combining two or more elements to create a completely new material that meets their needs. When at least one of these elements is a metal, we say that an **alloy** has been created.

To better understand the need for alloys, consider the use of aluminum alloys in aerospace applications. Because aluminum is a lightweight material, it can often reduce the weight of a part by replacing a heavier metal such as steel. In aerospace applications, this means creating a plane that is more fuel efficient and cheaper to operate. However, pure aluminum also has very low strength—an often undesirable trait. This is why many strength-driven aerospace applications rely on alloys. For example, scientists may mix aluminum with copper to create a material that has a high strength to weight ratio and good **fatigue** resistance.

*In order to create an alloy, metals are melted down and mixed together. Those responsible for creating the alloy must closely monitor the temperatures at which the metals are being melted.*

*Did you know that aluminum alloys are also used on spaceships? Spaceships need to be strong but they also need to be light and fuel efficient since rocket fuel is both heavy and expensive.*

So, how does that mixture of aluminum and copper become strong while remaining lightweight? The reason an alloy's properties differ from its constituent parts is because the very atomic structure of the alloy differs from the original elements used to create it. In other words, the whole isn't exactly the sum of its parts. In this activity, you'll make your very own alloy out of two metals and see how changing the ratio of your mixture affects the melting point of your alloy.

## Extension Activity

### Problem

A friend asks you to assist him with re-soldering the leaking joint of a pipe in his home. You know that the solder must be lead free for the water to be safe and, for fire-safety reasons, you also suggest that the solder melt at a relatively low temperature.

**Task:**

You are asked to make a recommendation for effectively fixing the broken part. You know that individually, tin and bismuth have high melting points, but suspect that an alloy composed of both metals will have a lower melting point. You and your partner will need to record the amount of tin (Sn) and bismuth (Bi) used (by mass %) to create the alloy and monitor the temperature of the alloy over time. After collecting all data you will plot the Mass % Bi versus temperature to generate a graph showing the melting point at various concentrations of bismuth to tin.

**Safety Precautions:**

- Students must wear close-toed shoes, goggles, gloves, and aprons at all times during this activity.
- If exposed to skin, wash area thoroughly with soap and plenty of water.

**Procedure:**

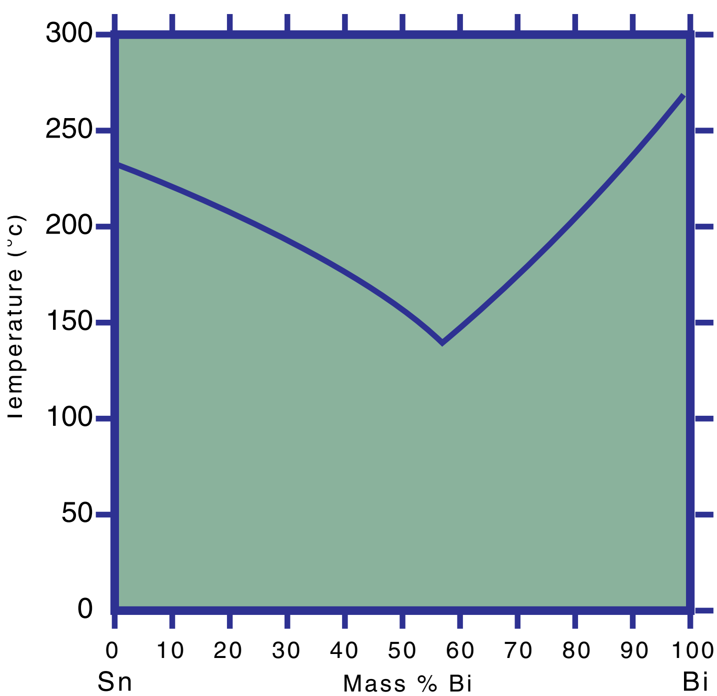
1. Gather materials including:
    - Safety goggles
    - Lab aprons
    - Gloves
    - Bismuth shot
    - Granular tin
    - Balance
    - Hot plate
    - 5 Pyrex beakers (400 mL)
    - Thermocouple sheath
    - Data collection device and software
    - Beaker tongs or heat resistant gloves
    - Hot pads or wire gauze
2. Measure out the following combinations (by mass) of tin and bismuth into 5 different Pyrex beakers:
    a. 0% Sn/100% Bi
    b. 40% Sn/60% Bi
    c. 50% Sn/50% Bi
    d. 60% Sn/40% Bi
    e. 100% Sn/0% Bi
3. Place the beaker on the pre-heated hot plate to melt the metals, stirring with a glass stirring rod.
4. Heat the metals until they are completely melted. Using the thermocouple sheath and data collection device, monitor and record the temperatures up to the point at which the metals are fully melted.

## Extension Activity

5. Remove the beaker from the hot plate and place on a heating pad to cool.
6. Observe the shiny surface to see the first crystal formation and record the temperature at which this occurs. Solidify completely by waiting until the temperature reaches below 138°C.
7. Re-heat the metals to above 138°C and record the temperature at which the metals begin to melt and the final melting point.
8. Plot the mass % Bi versus temperature (°C) at which the material is fully liquid.

## Questions

1. **What are the melting points of pure tin and pure bismuth?**
2. **What was the lowest melting point recorded during the experiment?**
3. **What mass % of each metal was used to reach the melting point identified in #2?**
4. **Compare your graph to the graph below. How are they similar? How are they different?**
5. **The 60% bismuth and 40% tin alloy is primarily used as alternatives to lead-based solders for low-temperature applications. Research other products that are created using this alloy.**




## Definitions

**Alloy**
A combination of metals or a metal and another element to create a substance with more desirable properties such as resistance to corrosion or greater strength.

**Fatigue**
Fatigue is the weakening of a material caused by repeatedly applied loads. If the loads are too heavy microscopic cracks will begin to form. These will eventually reach a critical size and the crack will spread suddenly, causing the material to fail.

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