NATIONAL MATH + SCIENCE INITIATIVE

How Sublime

Exploring and Measuring the Triple Point of Dry Ice

MATERIALS

aprons
computer with online access
forceps
goggles
ice
paper towels
marker, Sharpie®
ruler, clear metric
scissors
spoon, plastic
food color, red
hot glue gun with glue stick
pipette, large bulb
pipette, thin stem
pliers, needle nose
thread, approx. 20 cm
Universal Indicator
3 cups, 9-oz clear plastic
dry ice

How can ice be "dry"? *Dry ice* is the common name for compressed carbon dioxide, CO_2. The term "dry" refers to the fact that no liquid is left behind when a sample of dry ice is left out at room temperature. The solid carbon dioxide undergoes a phase change directly from a solid to a gas; it **sublimes**.

Refer to the phase diagrams of water (Figure 1) and carbon dioxide (Figure 2). Both graphs contain a point at a specific temperature and pressure where all three phases exist in equilibrium. This coordinate on the graph is referred to as the **triple point** of the substance. You will also notice that both graphs indicate a **critical point**. At temperatures above the critical temperature, it is not possible to condense the gas into liquid state even with an increase in pressure.

PURPOSE

In Part I of this experiment, you will observe and explore dry ice and water ice. Properties of each substance will be noted. In Part II of this experiment, you will construct your own pressure gauge to measure the pressure associated with the triple point of dry ice.

SAFETY ALERT!

- Handle the dry ice with care. The surface temperature of the dry ice is around −78°C.
- Never touch the dry ice with bare hands. Use the scoopula or forceps when obtaining your sample.
- Wear safety goggles throughout this activity.

Figure 1. Phase diagram for water

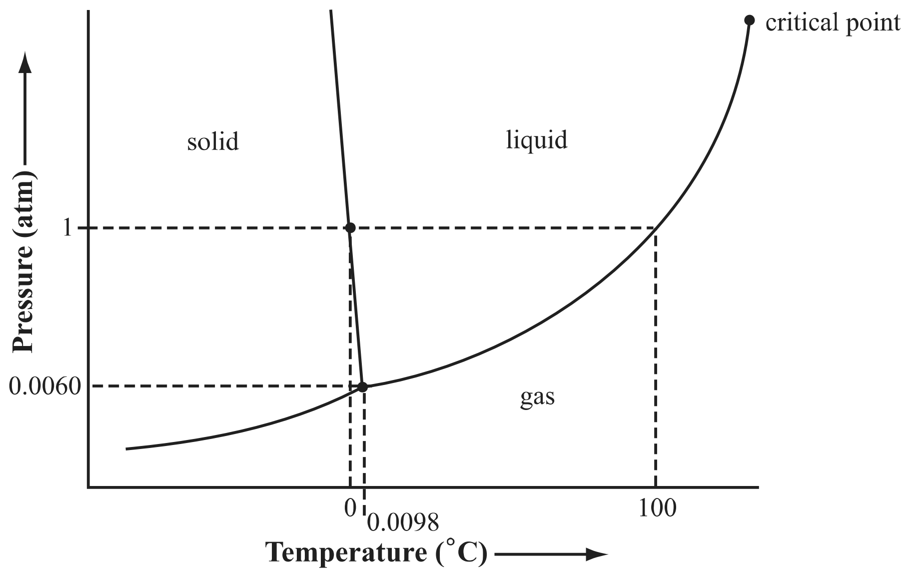
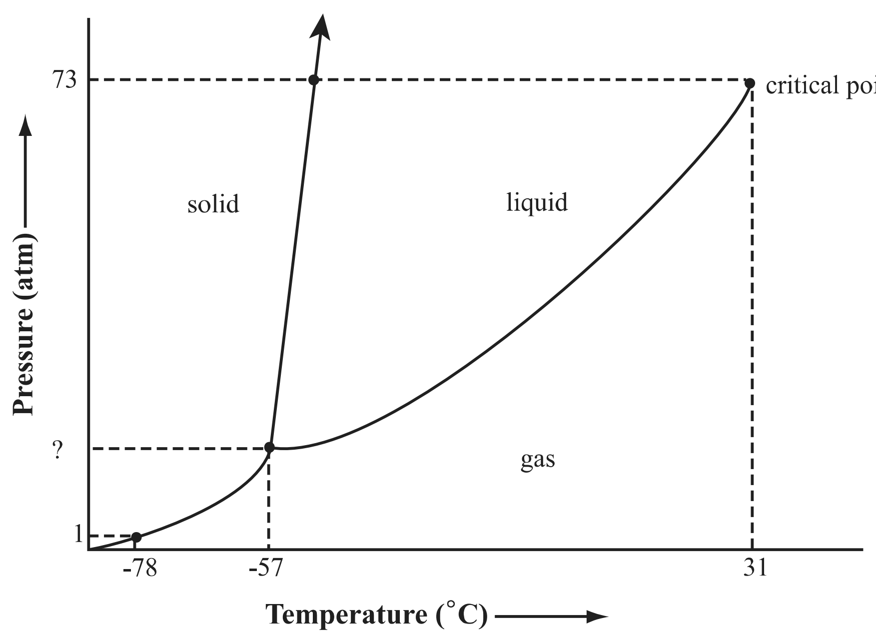


Figure 2. Phase diagram for carbon dioxide

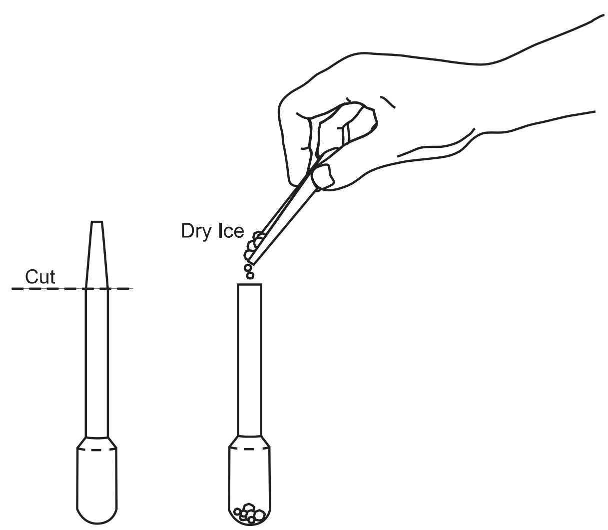


PROCEDURE

PART I: OBSERVING AND EXPLORING DRY ICE AND WATER ICE

1. Obtain a sample of dry ice and a sample of water ice from your teacher.
2. Using forceps or a scoopula, place a few small pieces of each sample on the lab bench and press down on each piece using the forceps. Record your observations in Table 1 on your student answer page.
3. Place a coin on the lab bench. Carefully place a small sample of each solid on top of the coin and press down using forceps. Observe and record the results.
4. Fill two plastic cups about one third full with tap water. Label one cup "CO_2" and one cup "H_2O". Place a few drops of Universal Indicator into each of the cups. Note the color and record the results.
5. Add the solids to their labeled cups containing the water and Universal Indicator. Observe and record the results.
6. Fill a third plastic cup about half full with tap water.
7. Obtain a large pipette. Using a pair of scissors, cut the stem of the pipette as shown in Figure 3.

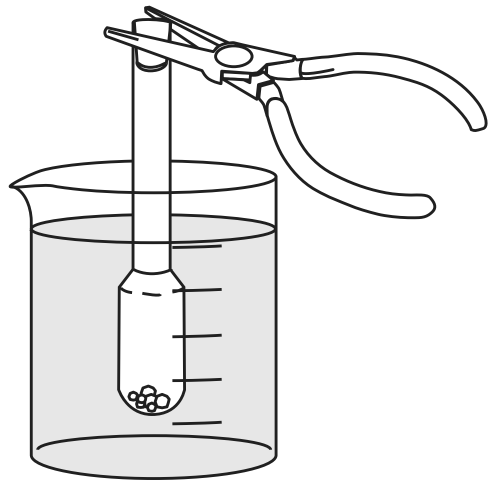
Figure 3. Fill the pipette



PROCEDURE (CONTINUED)

8. Place 8 to 10 pieces of dry ice through the stem of the pipette and into the bulb. The bulb should be about one quarter filled with dry ice.
9. Fold the tip of the pipette stem over and clamp securely with the pliers, as shown in Figure 4. Clamp securely so that no gas escapes. Immediately lower the pipette into the water until the bulb is submerged. Observe and record the results.

Figure 4. Clamp and submerge the pipette



10. Carefully release the grip on the pliers, still holding the bulb under the water. Observe and record the results. Repeat this step several times until there is no dry ice left in the bulb.
11. Repeat Step 7 through Step 10 with a sample of water ice. Observe and record the results.

PROCEDURE (CONTINUED)

PART II: MEASURING THE TRIPLE POINT OF DRY ICE

1. Construct a micro-pressure gauge by cutting the stem from a thin-stemmed pipette.
2. Use the hot glue gun to place a small amount of glue to seal the end. Tie a piece of thread around this end, as shown in Figure 5.

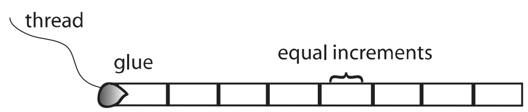


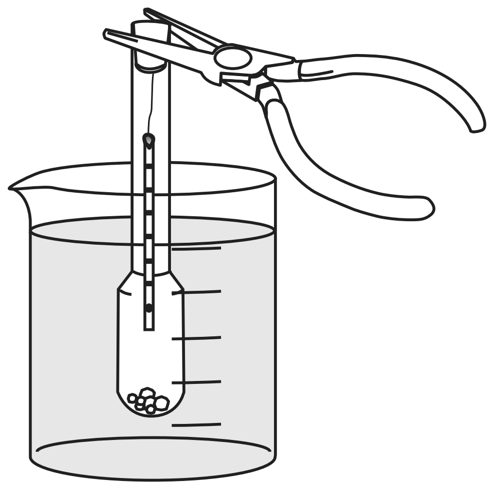
Figure 5. Micro-pressure gauge

3. Beginning with the sealed end, mark the stem of the pipette in 1.0 cm or otherwise equal increments.
4. Prepare another large pipette as you did in Part I by cutting off the tip.
5. Check the length of the micro-pressure gauge by placing it inside the large pipette. Cut the pressure gauge so that its length just comes to the top of the bulb.
6. Place a drop of colored water into the pressure gauge by squeezing the center of the stem with pliers and placing the open end into a cup of colored water. Gently release the grip to allow the water to be drawn into the pressure gauge. Based on the position of your colored water droplet, count the number of increments occupied by the trapped air sample. Record this value in Table 2 on your student answer page.

PROCEDURE (CONTINUED)

7. Obtain a small sample of dry ice and fill the bulb about one quarter full. Slide the pressure gauge into the large pipette, fold the tip, and firmly grip both with the pliers. Be sure to place the setup into the water as shown in Figure 6 and observe.

Figure 6. Measuring relative pressure



8. As the pressure climbs inside the pipette, you will notice the colored water plug rising in the micro-pressure gauge. Note the position of the colored water droplet when the dry ice begins to liquefy.
9. Gently release the grip and repeat until there is no more dry ice in the bulb.
10. Clean up your station as instructed by your teacher.

PRE-LAB EXERCISES

1. Draw Lewis structures for water and for carbon dioxide.

2. Refer to Figure 1 in the introduction.

   a. Compare the scales of the *y*-axes for the two phase diagrams. Give the approximate range of pressures for each diagram, including units.

   b. Consider samples at standard pressure, 1 atm, and room temperature, 20°C. Determine the state of matter in which each sample of water and carbon dioxide would exist.

   c. State a set of conditions under which both water and carbon dioxide would be solid.

   d. Compare the solid-liquid equilibrium lines for water and carbon dioxide. What does the slope of this line indicate about the density of the solid?

DATA AND OBSERVATIONS

PART I: OBSERVING AND EXPLORING DRY ICE AND WATER ICE

Table 1. Observations of Dry Ice and Water Ice

Condition	Dry Ice	Water Ice
Sitting on the table		
Sitting on a coin		
pH of Universal Indicator solution before adding solid		
pH of Universal Indicator solution after adding solid		
Placed in cup of tap water		
Bulb under water		
After releasing pressure		

DATA AND OBSERVATIONS (CONTINUED)

PART II: MEASURING THE TRIPLE POINT OF DRY ICE

Table 2. Pressure Gauge Volumes and Pressures		
V_1	Number of increments of trapped air in the pressure gauge before sealing CO_2 pipette	____ out of ____
P_1	The atmospheric pressure today (in atm)	
V_2	Number of increments of trapped air in the pressure gauge at the triple point	____ out of ____
P_2	The pressure inside the gauge (in atm)	

ANALYSIS

1. Explain the observations for the behavior of dry ice on the tabletop and on the coin.

2. Calculate the change in pH for each substance when added to water.

ANALYSIS (CONTINUED)

3. Consider the reaction of dry ice with water.
   a. Write a balanced chemical equation of this reaction.

   b. Name the product and relate its formation to the pH change that occurs.

4. Calculate the pressure in the pressure gauge using Boyle's law,

$$P_1V_1 = P_2V_2$$

   and record your results in Table 2.

5. Ask your teacher for the theoretical value for the triple point of dry ice and calculate the percent error. Cite possible reasons for any discrepancies.

CONCLUSION QUESTIONS

1. What purpose was served by submerging the pipette in a cup of water? Why was a plastic cup used instead of a glass beaker?

2. Why were pliers used to secure the opening of the stem of the pipette? How might the experimental results for the triple point have differed if the pliers were not tightly gripped?

3. Despite having a molar mass of 18.0 g/mol, water is a liquid at room temperature whereas carbon dioxide, with a molar mass of 44.0 g/mol, is a gas at the same conditions. Explain why this statement makes sense using bonding theories and intermolecular forces.

4. Research uses of solid carbon dioxide. Describe three of the most interesting uses that you find. Be sure to cite your sources.