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Wet Dry Ice Lab

Phase Changes and Phase Diagrams

Introduction

As dry ice sublimes in a closed system, its three phases are clearly viewed and its phase diagram takes on concrete meaning to students.

Concepts

- Phase changes
- Phase diagrams
- Triple Point
- Sublimation

Materials

Cup, clear plastic, 8- or 10-oz

Dry ice

Flinn ChemCam™ Video Camera (optional)

Gloves, insulated

Hammer, small

Pipets, Beral-type, wide-stem, 2

Pliers

Scissors

**Use a Flinn ChemCam video camera to provide a close-up of the demonstration.*

Safety Precautions

Dry ice is extremely cold, handle only with insulated heavy cloth gloves and never with wet hands; frostbite is possible with only brief exposure. The demonstrator and all observers must wear chemical splash goggles. Do not attempt this demonstration on a larger scale in plastic bottles or other containers—the plactic may shatter violently and cause injury. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Pulverize the dry ice into small pieces about the size of rice grains or sugar crystals. *Observe that the dry ice does not melt, it sublimes. The resulting "fog" is due to water vapor condensing on the extremely cold CO_2 gas that is produced.*
2. Cut off the tapered end of a wide-stem, Beral-type pipet. Scoop about 8–10 pieces of dry ice into the stem of the pipet and tap the dry ice down into the bulb.
3. Add tap water to a clear plastic cup to a depth of about 4–5 cm.
4. Fold the open end of the pipet stem over and clamp it shut with a pair of pliers. (No gas should be able to escape from the pipet.) Immediately lower the pipet bulb into the water in the cup.
5. Observe the phase changes. *The dry ice will sublime (turn to a gas). After about 20–30 seconds, the dry ice will melt and liquid will appear in the pipet bulb. Soon after, the liquid will begin to boil, and the pipet bulb will swell. Three phases will be visible at the same time (solid, liquid, and gas).*
6. Release the grip on the pliers to relieve some of the pressure in the pipet. *A loud pop is produced and the CO_2 immediately returns to a solid—the dry ice looks like fluffy snow.*
7. Repeat the demonstration by folding the open end of the pipet stem over again and reclamping the pipet shut with the pliers. *The CO_2 appears to liquefy quicker than it did the first time. Depending on the amount of dry ice used, the process may be repeated 3–4 times.*

8. Your students will undoubtedly ask: "What will happen if you don't release the pressure?" Repeat the demonstration, but don't release the pressure when the liquid ("wet dry ice") begins to boil. *Caution: Everyone should be wearing goggles as explained in the Safety Precautions. The pipet will continue to expand until the gas "explodes" and the bulb ruptures. Water goes everywhere, the cup cracks, and your nerves may be a little more frayed—but the students think it is great fun!*

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. Allow the dry ice to sublime in a well-ventilated area, such as a hood, and the used pipets may be placed in the trash according to Flinn Suggested Disposal Method #26a.

Tips

- This activity is written as a demonstration, but it is safe enough to be used as a student activity. Monitor students so they do not add too much dry ice to their pipets and strictly enforce the "wear your goggles rule."
- Wide-stem pipets (Flinn Catalog Nos. AP2253 and AP8480) work best. Use only plastic cups (plastic will absorb the shock and the cup will crack, not shatter). The water in the cup acts as a heat source for sublimation and melting. It also keeps condensation from forming on the outside of the pipet, which would make it difficult to see the contents.
- Do not attempt this demonstration on a larger scale, such as in a plastic bottle. The pressurized bottles shatter with great force, causing serious injuries in some cases. Accidents of this type have been reported in school science labs.

Discussion

Dry ice is usually a fascinating and fun material for your students. From making "fog" to "boiling in water," it is well-known for creating special effects. Carbon dioxide, however, also has fascinating and very useful chemical properties. At room temperature and pressure, solid carbon dioxide will warm to –78 °C and then begin to sublime to carbon dioxide gas. The carbon dioxide gas is, initially, also at –78 °C, which causes moisture in the air to condense and form the characteristic fog that dry ice is famous for.

One interesting feature of carbon dioxide is that at atmospheric pressure, it only exists as a solid or gas. In order to exist as a liquid, carbon dioxide must be subjected to a pressure of at least 5.11 atmospheres. Most chemicals will exist as a solid, liquid, or gas depending on temperature and pressure. This relationship between phase, pressure, and temperature can be presented graphically in the form of a phase diagram (see figure below).

A phase diagram has temperature as the independent *(x)* and pressure as the dependent *(y)* axis. Three distinct regions are represented as regions of pressure and temperature relative to the state of the substance as solid, liquid, or gas. The boundaries between regions show the values of pressure and temperature when two phases are in equilibrium. For example, sublimation occurs at the boundary between solid and gas, evaporation/condensation occurs at the liquid–gas boundary and melting/freezing occurs at the solid–liquid boundary. The point at which all three phase boundaries meet is called the *triple point* and signifies the temperature and pressure at which all three phases exist and are in equilibrium.

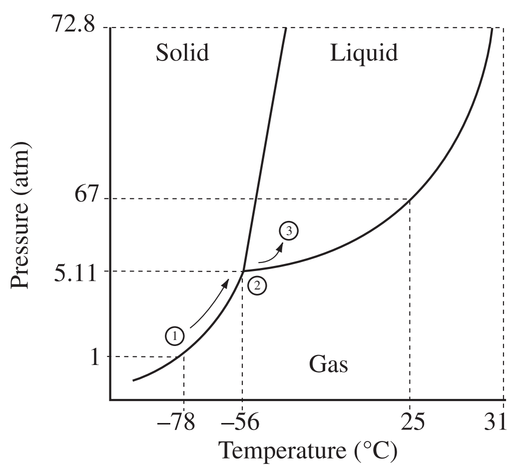


Figure 1. Phase Diagram of Carbon Dioxide

The phase diagram for carbon dioxide is shown in Figure 1. If a sample of dry ice is placed on the desk at normal atmospheric pressure (1 atm. or 14.7 psi) and room temperature (25 °C), the solid will sublime spontaneously, maintaining its temperature of –78 °C (point ①) until the solid disappears completely. The gas formed will absorb heat from the room until it obtains a stable gaseous state at 25 °C. If a sample of dry ice is sealed in a closed system such as the triple point apparatus, the pressure begins to rise allowing the solid to exist at a higher temperature. Most of the energy absorbed from its surroundings will result in an increased temperature and corresponding increase in vapor pressure. The effect of this increased energy is a series of pressure–temperature equilibria along the solid–gas line between points ① and ② on the phase diagram.

Once the triple point is reached (point ②), the energy absorbed causes the solid to melt. The solid–gas and liquid–gas phases are also in equilibrium. While this phase change occurs, the temperature and pressure remain constant at 5.1 atm. and –56.6 °C as long as the solid, liquid, and gaseous phases are in contact with each other. If the solid becomes covered with liquid, an equilibrium no longer exists between all three phases, and both the temperature and pressure will increase into the liquid portion of the phase diagram (point ③).

When the pipet is opened and the pressure is released, solid carbon dioxide is formed almost instantaneously due to a reduction in temperature and pressure. The temperature decrease is due to rapid vaporization (boiling) of liquid CO_2 to gaseous CO_2. The heat of vaporization of carbon dioxide is roughly 16 kJ/mol whereas the heat of fusion is –9 kJ/mol. The energy required to boil the liquid lowers the temperature of the system and causes the liquid carbon dioxide to freeze.

$$CO_2(l) \rightarrow CO_2(g) \qquad \Delta H = 16 \text{ kJ/mol}$$

$$CO_2(l) \rightarrow CO_2(s) \qquad \Delta H = -9 \text{ kJ/mol}$$

This demonstration also presents a good opportunity to discuss the various units that are used when measuring pressure.

Connecting to the National Standards

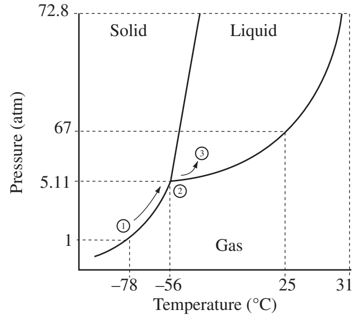
This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evolution and equilibrium
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter

Answers to Worksheet Questions

1. Note what was happening in the pipet at the following moments during the demonstration.
   a. When the solid CO_2 was first enclosed in the pipet
   The pressure inside the pipet rose and the carbon dioxide began to sublime, turning into a gas.
   b. When the pressure stabilized
   There is carbon dioxide present in all three states, solid, liquid, and gaseous.
   c. When the solid CO_2 was covered by the liquid carbon dioxide
   The pressure began to rise again.
   d. When the pressure in the pipet was released
   The liquid carbon dioxide froze back into its solid state.
2. Explain how the triple point was reached within the pipet.
   When the dry ice was sealed in the pipet, the pressure within the pipet began to rise. Solid carbon dioxide, which in normal room temperature and pressure sublimes, was able to remain in its solid state at a higher temperature. Both the temperature and the pressure continued to increase in a way that allowed both the solid and gaseous carbon dioxide to exist at once. Eventually the pressure and the temperature reached a point where the solid began to melt as well. At this point, all three states were in equilibrium with one another.

3. Below is a phase diagram for CO_2. Label each area on the diagram with the appropriate phase. Also mark and label the triple point.



Acknowledgment

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References

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Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Wet Dry Ice Lab* activity, presented by Bob Becker, is available in *Phase Changes and Phase Diagrams* and in *Dry Ice Demonstrations,* part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Wet Dry Ice Lab* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Demonstrating the Phase Changes of Carbon Dioxide—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP4505	Demonstrating the Phase Changes of Carbon Dioxide—Chemical Demonstration Kit
AP2253	Beral-Type Pipets, Wide-Stem, Pkg. 20
AP8480	Beral-Type Pipets, Wide-Stem, Pkg. 500
AP4416	Dry Ice Maker

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Wet Dry Ice Lab Worksheet

Discussion Questions

1. Note what was happening in the pipet at the following moments during the demonstration.

   a. When the solid CO_2 was first enclosed in the pipet

   b. When the pressure stabilized

   c. When the solid CO_2 was covered by the liquid carbon dioxide

   d. When the pressure in the pipet was released

2. Explain how the triple point was reached within the pipet.

3. Below is a phase diagram for CO_2. Label each area on the diagram with the appropriate phase. Also mark and label the triple point.