Dry Ice Demonstrations

Introduction

Four fun demonstrations using solid carbon dioxide, also known as dry ice. In the first demonstration, liquid detergent is added to a graduated cylinder containing some dry ice subliming under water, and foggy carbon dioxide bubbles spill out over the top. Once in contact with the air, however, these bubbles begin to shrink quite noticeably. Beautiful, mystical smoke rings are blown using dry ice and plastic cups in the next demonstration. In the third demonstration, dry ice is added to a bucket half-filled with water and an eerie heavy fog cascades over the rim. A soapy towel is used to create a soap film sheet. This film gradually inflates into a misty, colorful crystal ball that undulates gracefully to the air currents in the room! And finally, foggy CO_2 gas—from dry ice subliming under water—is passed through a faucetlike series of pipes. Dense CO_2 bubbles form, pinch off, and fall rapidly downward, resembling a huge leaky faucet!

Concepts

- Density
- Solubility
- Sublimation

Materials

Gloves, insulated (for all demonstrations)

For Shrinking Suds

Dish detergent, Joy® or Dawn® work best	Water, warm
Dry ice, 2–3 large chunks, 40–50 g each	Graduated cylinder, 1-L or larger

For Misty Smoke Rings

Dry ice, 100 g	Plastic cups, 9-oz, and 10-oz, 1 each*
Water, warm	Test tube, 2-cm diameter*
Bunsen burner*	

**A tall plastic beverage cup with a domed top may be used instead.*

For CO_2 Crystal Ball

Dry ice, 500-700 g, 1 or 2 fist-sized chunks	Bucket with a smooth, flat rim
Soap solution made with Joy or Dawn dish detergent	Flashlight, lantern-type (optional)
Water, warm	Paper towel or absorbent cloth
Beaker or plastic cup, 250-mL	Stirring rod

For CO_2 Leaky Faucet

Dry ice, 2–3 chunks, 100-200 g each	PVC pipe elbow joint connectors, ¾″, 2
Soap solution, 3–5%, 50 mL	Rubber band
Water, warm	Scissors
Clamps, buret, 2	Soda bottles, 2-L plastic, 2
Cup, plastic	Support stand, tall
Paper towel	T-shirt or piece of cloth, newly washed (optional)
PVC pipe, ¾″, 60″, 15″, and 4″	Tubing, plastic (Tygon), 1” OD, 6-cm

Safety Precautions

Dry ice (solid carbon dioxide) is an extremely cold solid (–78.5 °C) and will cause frostbite. Do not touch dry ice to bare skin; wear appropriate insulated gloves or use tongs whenever handling dry ice. Wear chemical splash goggles and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Follow all laboratory safety guidelines. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

Misty Smoke Rings

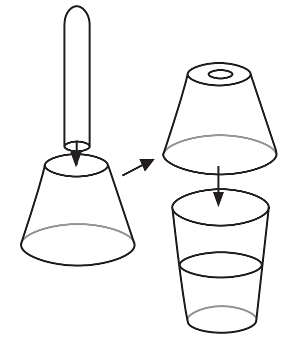

Figure 1.

1. If a dome-top beverage cup is not available, you will need to make your own using two plastic cups, one tall, 10-oz and one wide mouth 9-oz.
2. Heat the mouth of a test tube in a burner flame for about 1 minute, rotating constantly.
3. Press the hot mouth of the test tube in the center of the bottom of the wide mouth cup, until a hole is melted through. This will serve as the lid for the tall cup (see Figure 1).

CO_2 Crystal Ball

1. Roll the paper towel or cloth into a strap, 3–4 cm in width and 10–20 cm longer than the diameter of the bucket.
2. Add 3–5 mL of dish soap to a 250-mL beaker or a plastic cup. Add water to the 100 mL mark. Stir gently.

CO_2 Leaky Faucet

1. Cut the top off one 2-L soda bottle, leaving the sides curved in at the top. Save the bottom part.
2. Cut the top off a second 2-L bottle, just where the curve begins. Save the top part.
3. The saved bottom portion should fit inside the saved top portion and hold together with friction (see Figure 2).
4. Construct a large faucet head (like an upside-down "J") with the PVC pipes and elbow joints (see Figure 3).
5. Roll up a paper towel and wrap it around the mouth of the faucet, securing the towel in place with a rubber band.
6. Use Tygon tubing to secure the bottom of the "faucet" over the 2-L bottle top (see Figure 3).

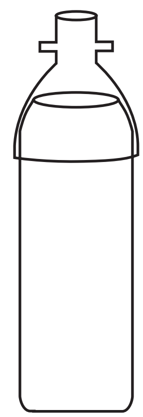

Figure 2.

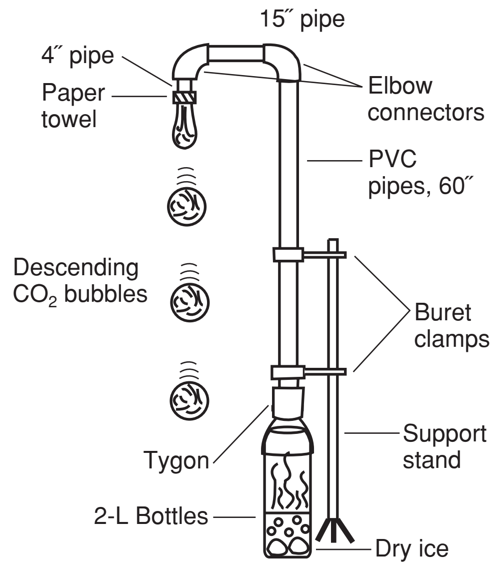

Figure 3.

Procedure

Shrinking Suds

1. Fill the graduate cylinder roughly one-third of the way with warm water.
2. Wearing gloves, drop in 2–3 chunks of dry ice and allow the students to make observations. Notice the rapid sublimation and the "fog" produced.
3. Add a small squirt (2–3 mL) of detergent to the graduated cylinder. You will soon observe hundreds of fog-filled bubbles quickly accumulating on top of the water. As new ones form, the bubbles on top get pushed upward past the mouth of the container. Then a rather unusual phenomenon occurs—the bubbles on the outside layer begin to shrink.
4. To more easily observe the shrinking suds, wet one hand and scoop out a handful of the large, golf ball-sized bubbles. Watch as they shrink in a matter of seconds to the size of BB's.

Misty Smoke Rings

1. Fill the tall cup halfway with warm water.
2. Drop in one or two 20-g chunks of dry ice.
3. Cap the tall cup with the domed lid or with the wide-mouth cup with the hole in the bottom (see Figure 1).
4. Tilt the cup slightly, then give a few small, quick squeezes to the sides of the cup to generate CO_2 smoke rings (see Figure 4).

5. If conditions are right (rate of sublimation and stillness of air in the room), the smoke rings will last for several seconds, following graceful projectile arcs. Then, as the rings approach the lab table top, they hover momentarily as they spread themselves out and dissipate.

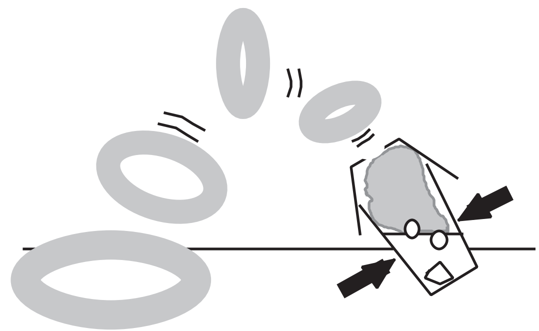

Figure 4.

CO_2 Crystal Ball

1. Fill the bucket about halfway with warm tap water.
2. Drop in one or two fist-sized chunks of dry ice. Allow students to observe as the fog eventually spills over the rim.
3. Soak the rolled up paper towel strap in the soap solution, remove the strap from the beaker and allow the excess solution to drip off.
4. Wet the rim of the bucket with the soapy strap.
5. Draw the soapy strap slowly over the rim of the bucket to create a soap film "lid" (see Figure 5).
6. As the film slowly inflates into a dome, blow gentle puffs of air at the dome and observe the way it resonates.

CO_2 Leaky Faucet

1. Add 50 mL of a 3–5% soap solution made with liquid dish detergent to a plastic cup.
2. Hold the cup of soap solution up to the mouth of the faucet to wet the paper towel and to establish a soap film across the opening.
3. Fill the bottom portion of the 2-L bottle halfway with warm water and drop 2–3 chunks of dry ice into the water.
4. Insert the 2-L bottle bottom into the top portion attached to the faucet until a good friction fit is made and the two portions hold together.
5. Observe as a procession of misty CO_2 bubbles form and fall like huge, pearly water drops from a giant leaky faucet!
6. *Optional:* Try catching and bouncing the falling bubbles on a recently washed T-shirt or piece of cloth.

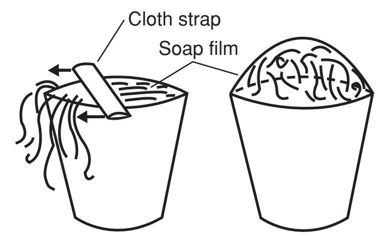

Figure 5.

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. Soap solutions may be rinsed down the drain according to Flinn Suggested Disposal Method #26b.

Tips

- Just for fun and to add to the effect, set up a few small ring toss targets for the Misty Smoke Rings, such as pencils held upright with balls of modeling clay.
- After the dry ice has been added to the bucket for the CO_2 Crystal Ball, place a lit lantern-type flashlight face-up in the bucket, then draw the soap film across. The crystal ball will now glow in the dark! Colored filters may be placed over the light to produce different colors!
- Try igniting the CO_2 Leaky Faucet "drips" to show that, unlike methane or hydrogen bubbles, carbon dioxide bubbles do not ignite; in fact, they will extinguish a flame! Thus, not only do different gases vary in their physical properties such as density, they also vary in their chemical properties such as flammability. Point out to the students, however, that these two properties are not in any way linked—that is, there are some low density gases such as helium that do not burn, and plenty of high density gases such as propane and ether that do burn!

Discussion

The stable state for CO_2 at normal room conditions is the gaseous state. Since barometric pressure (1 atm) is well below CO_2's triple point pressure (5.1 atm), the liquid state for CO_2 is not stable. Thus, solid CO_2 (dry ice) tends to change directly to a gas; that is, it sublimes.

Out in the air, it is hard to notice this sublimation, for the CO_2 gas produced is clear and colorless. When placed in water, however, this sublimation becomes much more obvious, for now the escaping CO_2 can be observed as large, rapidly evolving bubbles. Also, water serves as a better heat sink than air, and so the sublimation is sped up substantially.

It is important to point out that the thick fog that is observed is not the CO_2 gas; it is actually H_2O in the liquid state—small, suspended droplets of condensation produced as warm vapor from the water comes in contact with the cold subliming CO_2, much like the fog you see when your warm, humid breath is exhaled into cold winter air.

In the Shrinking Suds demo, the foggy CO_2 bubbles tend to shrink when exposed to air simply because the CO_2 gas, being relatively soluble in water, can diffuse readily across the soap film membrane. With air on the outside of the bubble, the higher CO_2 concentration is obviously on the inside, and the net diffusion would thus be outward. For the same reason, N_2 and O_2 from the air in the room would diffuse into the bubble. This should counteract the shrinking caused by the exiting CO_2, but since CO_2's solubility in water is dramatically greater than air's, the net effect is one of shrinking. The inward diffusion of air could explain, however, why the bubbles reach a certain minimum size of about 1–2 mm in diameter and then stabilize. This minute volume very well might represent the air that has diffused in while the CO_2 was diffusing out. Perhaps this could even be used in a quantitative way to illustrate the relative solubility of the CO_2 and air, respectively. For example, if a CO_2-filled bubble with an original diameter of 2.75 cm ($V = 10.9\ cm^3$) shrank down to an air-filled bubble with a diameter of 0.12 cm ($V = 0.00090\ cm^3$), this would imply that 10.9 cm^3 of CO_2 diffused out through the bubble membrane in the same time that only 0.00090 cm^3 of air diffused in. Does this indicate that CO_2 is 12,000 times more soluble than air?

It is also worth noting that the CO_2 bubbles do not appear to shrink as they are rising up inside the container, for there they are surrounded by other bubbles that presumably contain an equally high concentration of CO_2. This is not to say that CO_2 diffusion between bubbles is not occurring. Rather, because the CO_2 concentrations are essentially the same on either side of the soap film, the diffusion rates into and out of the bubbles in the cylinder are more or less the same.

The Misty Smoke Rings are generated in much the same way as normal smoke rings. The quick pulse of air sends smoky mist out through the top hole of the cup lid. Backwards-spinning eddy currents occur as the outer edge experiences drag from the surrounding air. These seem to circulate completely around the ring (see Figure 6). Rather than follow the more-or-less straight-line path of normal smoke rings, however, the high density of the cool, moisture-laden carbon dioxide causes these misty smoke rings to follow a graceful parabolic path. As the rings are about to land on a flat horizontal surface, two more remarkable things happen. First, the rings hover as if on a cushion of air about 1–2 centimeters above the surface. Second, as they hover, the rings quickly spread out then disappear as the mist of tiny water droplets from which they are made evaporates into the warmer air.

In the CO_2 Crystal Ball demonstration, once the soap film lid is established, it quickly forms into a misty dome—dramatically resembling a fortune-teller's "crystal ball," only considerably more fluid and pliable. Strategically blown puffs of air can set up any number of resonance frequencies. (This effect could perhaps be used in conjunction with the time-honored vibrating string analogy for modeling electron energy levels as harmonic frequencies!)

If left undisturbed, the film will quickly produce intense horizontal rainbows of color circling the dome. These are due to the interference patterns of the reflecting light. This happens in all soap films as a result of varying film thicknesses, but these colors seem especially pronounced in the crystal ball, perhaps because of the misty white backdrop.

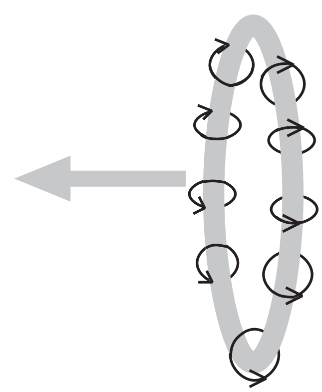

Figure 6.

After some time, another peculiar observation can be made. The dome stops growing, even though one can still hear the dry ice subliming vigorously in the bucket below. The explanation for this phenomenon centers on the relatively high solubility of CO_2 and its ability to diffuse readily through the soap film. First let us assume that the CO_2 is subliming at a more or less constant rate, and that this rate of sublimation is considerably greater than the rate at which the CO_2 can diffuse through the original soap film "lid" drawn across the bucket. The film is thus pushed outwards into a dome. As the film grows, however, and its surface area increases, so does the rate at which the CO_2 can diffuse through it. Hence, an equilibrium-like state is eventually reached where the rate of diffusion is equal to the rate of sublimation. In short, the dome reaches a point where it is "leaking" as fast as it is being filled, and so its size remains more or less constant. Actually, of course, the sublimation rate is decreasing as the dry ice gets used up. At first, this deceleration is too gradual to play much of a role in the demonstration, but as the chunks of dry ice begin to dwindle (and as the water temperature drops and layers of ice begin to form on the dry ice, insulating it from the rest of the water) the rate of sublimation can decrease quite substantially. When this happens, if the soap film has lasted long enough, one can see the dome start to shrink back down into the bucket.

The misty bubbles fall from the CO_2 Leaky Faucet remarkably fast due to the relatively high density of CO_2. This is not to say that Galileo was wrong—that denser bodies have a greater gravitational acceleration. Rather, because of air resistance, all falling objects eventually reach terminal velocity—when the frictional force acting upward upon them matches the gravitational force acting downward. With all else being equal, objects that have a high density (and thus a high mass to surface area ratio) take longer to reach their terminal velocity; they therefore accelerate for a longer period of time and end up falling faster.

Connecting to the National Standards

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

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter, motions and forces
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, motions and forces

Acknowledgments

David Brooks of the University of Nebraska, Lincoln, was the first to show the presenter the wonderful effects that can be achieved by incorporating soap films into dry ice demonstrations.

References

Boys, C. V.; *Soap-Bubbles, Their Colours and the Forces Which Mold Them;* Dover, 1959.

Isenberg, C.; *Problem Solving with Soap Films: Part I;* Physics Education, September 1975, 10, 452–456.

Isenberg, C.; *Problem Solving with Soap Films: Part II;* Physics Education, November 1975, 10, 500–503.

Noddy, Tom; *Bubble Magic;* Running Press, 1988.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

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

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

Catalog No.	Description
AP4416	Dry Ice Maker
C0241	Cleaner, Liquid, Detergent
SE1031	Gloves, Cotton and Canvas
GP9090	Cylinder, Borosilicate Glass, 1000-mL
AP6009	Bucket, Plastic Utility Pail
AP5998	Support Stand, 36" Rod

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