PTV Made Simple with Liquid Nitrogen

Kinetic Molecular Theory and PTV

Introduction

A simple device and liquid nitrogen will allow the experimental verification of the Boyle's law relationship between the pressure and volume of a gas as well as the Charles's law relationship between the temperature and volume of a gas.

Concepts

- Boyle's law—pressure/volume relationship of a gas
- Charles's law—temperature/volume relationship of a gas

Materials

Liquid nitrogen	Gloves, high/low temperature, insulated
Balloons	Overhead projector
Boyle's law apparatus (see *Tips*)	Syringe
Dewar flask, demonstration	Tongs

Safety Precautions

Liquid nitrogen is very, very cold. The extremely low temperature may cause frostbite almost immediately. Never handle liquid nitrogen without protection. Wear insulated gloves, chemical splash goggles, and a chemical-resistant apron. Do not work with liquid nitrogen in an enclosed or poorly ventilated area. Nitrogen gas will tend to displace the air, limiting the amount of oxygen in the area, and may cause asphyxiation.

Procedure

Part 1. Boyle's Law

1. Set up a Boyle's law apparatus (see the *Tips* section).
2. Prepare a data table to record volume versus the total pressure.
3. Take initial readings of volume and pressure and use the apparatus as directed to change the pressure and observe/record how the volume changes.
4. Have the students plot the data on a sheet of graph paper. Plot the pressure on the independent x-axis and the volume of air on the dependent y-axis.

Part 2. Charles's Law

1. Blow up a number of balloons.
2. The Dewar flask should be about one-half full of liquid nitrogen. Place the balloons, one at a time, into the Dewar flask. The balloons should be pushed into the flask with the tongs. ***Do not use bare hands***.
3. Allow the balloons to sit in the liquid nitrogen for about one minute.
4. Using tongs and wearing insulated gloves, remove a balloon from the liquid nitrogen. Notice the size and rigidity of the rubber balloon when it is first removed from the liquid nitrogen. Observe the balloon as it warms up and re-inflates.
5. In light colored balloons such as yellow and pink, a liquid may be observed at the bottom of the deflated balloon as it is removed from the nitrogen. Ask the students to predict the identity of the liquid.

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. Excess liquid nitrogen may be allowed to evaporate in a well ventilated area, such as a hood. The balloons may be placed in the trash according Flinn Suggested Disposal Method #26a.

Tips

- A variety of apparatus and devices may be used to demonstrate Boyle's law in Part 1. This video was originally filmed using a manufactured product which has since been discontinued. Alternative devices that may be used include the Boyle's Law Apparatus, Flinn Scientific Catalog No. AP9223 and the Boyle's Law in a Bottle Super Value Laboratory Kit, Flinn Catalog No. AP6855.
- Liquid nitrogen is available from local welding supply houses or universities. Look up "Gases, liquid" or "Welding supply" in the phonebook. The cost ranges from approximately $2 to $8 per liter. In rural areas, liquid nitrogen may be used by local farmers or veterinarians to freeze cattle sperm.
- A Dewar flask is needed to transport the liquid nitrogen. Do not use the demonstration flask. Providers of liquid nitrogen will often lend or rent out the use of a Dewar flask. Some schools share a Dewar flask because of the expense and infrequent use.
- If a demonstration Dewar is unavailable, a good temporary substitute would be a Styrofoam® cube like the ones Flinn Scientific ships 2.5-L acid bottles in. The cube can hold a large amount of liquid nitrogen and the Styrofoam is a very good insulator.

Discussion

In 1660, Robert Boyle, a British scientist, performed an experiment that measured the volume of a trapped gas as the pressure on the gas changed, with temperature being held constant. He observed that when the temperature and the number of moles of a sample of gas are held constant, its volume is inversely (or indirectly) proportional to the pressure applied. This is known as *Boyle's Law*. Volume (V) decreases with increasing pressure (P). Mathematically, this inverse proportionality may be expressed as

$$P \bullet V = k \text{ (where } k \text{ is a constant),}$$

or alternately as

$$P_1V_1 = P_2V_2,$$

where P_1 and V_1 are the initial pressure and volume of gas and P_2 and V_2 are the final pressure and volume.

A plot of V versus P forms a curve called a hyperbola showing that the volume doubles as the pressure is halved. Rearranging the equation to give $V = k\,(1/P)$ and constructing a plot of V versus 1/P, a straight line is observed with a slope equal to the constant k.

An air-filled balloon cooled in liquid nitrogen can be used to demonstrate Charles's law. The average kinetic energy of air molecules (nitrogen, oxygen, and carbon dioxide) in the balloon decreases as the temperature is reduced and the molecules slow down. The gas molecules undergo fewer collisions with the "walls" of the balloon and thus exert less pressure on the balloon, causing it to deflate. Some of the gas molecules (nitrogen and oxygen) reach a low enough temperature that they will condense into the liquid phase.

When the balloon is brought back to room temperature, the molecules in the liquid phase evaporate into a gas, and sometimes even boiling is evident. The gas molecules continue to heat up and they move faster and faster. The fast-moving molecules exert a great amount of pressure on the walls of the balloon, thus inflating it.

The balloon is sometimes accidentally torn when it is very cold and rigid. A balloon at room temperature is a solid, but very elastic. The elasticity is due to the ability of chemical bonds in rubber polymer molecules to uncoil, stretch out, and then return to their original shape. The liquid nitrogen slows down and even stops the molecular motion in the rubber, thus limiting its ability to stretch. When stress is placed on the cold balloon, it tears easily because it has lost its elasticity.

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
Constancy, change, and measurement
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, motions and forces, interactions of energy andmatter

Reference

Please see *Be Cool to Your School—Uses of Liquid Nitrogen* by Lee Marek for additional activities and lessons using liquid nitrogen.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *PTV Made Simple with Liquid Nitrogen* activity, presented by Lee Marek is available in *Kinetic Molecular Theory and PTV*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

The *PTV Made Simple with Liquid Nitrogen* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP9223	Boyle's Law Apparatus
AP6855	Boyle's Law in a Bottle—Super Value Laboratory Kit
AP8938	Dewar Flask, Wide Mouth Demonstration, 2 L
AP8560	Dewar Flask, Storage, 4 L
AP8613	Be Cool to Your School—Uses of Liquid Nitrogen
AP1732	Syringe, without Needle, 35 mL

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