SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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National Science Education Standard—Physical Science

Structure and Properties of Matter

Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart

Teacher Materials

Learning Sequence Item:

929

Gas Laws

March 1996
Adapted by: Dorothy Gabel

Solids, Liquids, and Gases: Empirical Laws and the Kinetic Theory. Students should investigate the quantitative relationships among temperature, volume, and pressure for gases (thereby arriving at Charles' law and Boyle's law). With the Charles' law experiment, students should infer the need for an absolute temperature scale (to make the volume proportional to absolute temperature) *(Chemistry, A Framework for High School Science Education, p. 60).*

Contents

This micro-unit was adapted by **Dorothy Gabel** (Indiana University, Bloomington)

929
Learning Sequence

Solids, Liquids, and Gases: Empirical Laws and the Kinetic Theory. Students should investigate the quantitative relationships among temperature, volume, and pressure for gases (thereby arriving at Charles' law and Boyle's law). With the Charles' law experiment, students should infer the need for an absolute temperature scale (to make the volume proportional to absolute temperature *(Chemistry, A Framework for High School Science Education, p. 60).*

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
How Much Space? **Activity 1**	Gas Laws and Scuba Diving **Reading 1**	Birthday Balloons **Assessment 1**	How the Right Professor Charles Went Up in the Wrong Kind of Balloon **Reading 2**
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Gas Volume and Absolute Temperature **Assessment 2**			
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Suggested Sequence of Events

Event #1

Lab Activities

1. How Much Space? (one hour demo)
2. Eating Space (one hour demo)
3. Reduce the Pressure (one hour demo)
4. Inflating the Tube (one hour demo)

Alternative or additional experiments:

5. Cartesian Diver (one hour demo)
6. Balloon Volumes (one hour)
7. Filling Bottles (one hour)

Event #2

Lab Activities

8. Pressure-Volume (one hour)
9. Temperature-Volume (1) (one hour)

Alternative or additional experiments:

10. Temperature-Pressure (one hour)
11. Temperature-Volume (2) (one hour)

Event #3

Readings from Science as Inquiry, Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science

The following readings are included in the student version of the unit:

Reading 1 Gas Laws and Scuba Diving
Reading 2 How the Right Professor Went Up in the Wrong Kind of Balloon

Suggested additional readings:

"Getting Lift." From "The Experimenter's Notebook," *Chem Matters*, February 1983, p. 13.

Assessment items are at the back of this volume.

Assessment Recommendations

This teacher materials packet contains a few items suggested for classroom assessment. Often, three types of items are included. Some have been tested and reviewed, but not all.

1. Multiple choice questions accompanied by short essays, called justification, that allow teachers to find out if students really understand their selections on the multiple choice.

2. Open-ended questions asking for essay responses.

3. Suggestions for performance tasks, usually including laboratory work, questions to be answered, data to be graphed and processed, and inferences to be made. Some tasks include proposals for student design of such tasks. These may sometimes closely resemble a good laboratory task, since the best types of laboratories are assessing student skills and performance at all times. Special assessment tasks will not be needed if measures such as questions, tabulations, graphs, calculations, etc., are incorporated into regular lab activities.

Teachers are encouraged to make changes in these items to suit their own classroom situations and to develop further items of their own, hopefully finding inspiration in the models we have provided. We hope you may consider adding your best items to our pool. We also will be very pleased to hear of proposed revisions to our items when you think they are needed.

Science as Inquiry

How Much Space?

How much space is there between gas molecules?

Overview:

In this demo, a small piece of dry ice is placed in a balloon and dropped into a graduated cylinder containing warm water (measure and calculate the volume of the dry ice before class). The balloon expands as the solid changes to a gas. The volume of the gas can be compared to the volume of the solid, and the distance between molecules can be estimated.

Materials:

1 1000-cm^3 glass graduated cylinder
1 small piece of dry ice (1 cm^3 or less when dropped into water)
1 tongs
1 small oblong balloon
water (warm, about 50 °C)

Procedure:

Add 100 mL of warm (about 50 °C) water to a 1000-mL graduated cylinder. Record the volume.

Have a student get the approximate volume of the small piece of dry ice by measuring its length, width, and height. Caution the student not to touch the dry ice. Readings should be taken to the nearest centimeter. Students then calculate the volume by multiplying length by width by height.

Next place the dry ice into a small oblong balloon by stretching the opening, holding the dry ice with tongs, and forcing it in. Knot the balloon and immediately drop it into the graduated cylinder.

After the balloon stops expanding, record the new volume. Have students calculate the approximate volume of the gas by subtracting the original 100 cm^3 volume of the water from the final volume which will be in the 800–1000 cm^3 range. It is important to use a piece of dry ice that is no larger than 1 cm^3 or the volume of gas produced will be too large and impossible to measure.

Students then compare the volume of the solid to the volume of the gas produced. The volume of the balloon can be considered negligible as compared to the volume of the gas. Students can actually calculate about how far apart molecules of the gas are by taking the cube root of the gas produced. This should be approximated.

Background:

This demo demonstrates very dramatically that there are great spaces among the molecules of gases. Hence the pressure and temperature changes can make dramatic differences in volume. Students tend to think that there is air among the molecules rather than space. For small molecules, such as those of CO_2, O_2, and N_2, the distance between two adjacent molecules is about 10 times the width of the molecules themselves at STP. When particles of gases are depicted in textbooks, distances frequently are not represented at STP, and the distances are very small in comparison with the diameter of the molecule (it is a high-pressure or low-temperature situation). This demo provides students with the opportunity to draw pictures or make models of the particles present in a solid liquid and a gas. Since the volume of the carbon dioxide in the gaseous state is approximately 1000 times that of the solid, the distance between particles must be about 10 times the length of the particle itself. You may need to make a drawing on the board showing the relationship between the three-dimensional volume and the one-dimensional length to convince students that to infer length from volume, the cube root is used.

Further Variations:

You may wish to compare the spaces between particles in a liquid to those between particles in a solid. Students could measure the volume of an ice cube and the water it produces and infer that the volumes do not vary substantially—therefore the molecules are about the same distance apart in a solid and a liquid. This variation is very important in nature, particularly for water, which is the exception to the normal change in density that occurs with most solids as they change to liquids. This discussion provides an opportunity to revisit the density concept, one that students find particularly difficult.

Created by Dorothy Gabel (Indiana University, Bloomington)

Teacher Sheet

Science as Inquiry

Eating Space?

What happens to marshmallows when pressure is reduced?

Overview:

In this demo, a marshmallow is placed under a dome on a vacuum pump. As the pressure is decreased, the marshmallow expands.

Materials:

large marshmallow
vacuum pump with dome; or side-arm flask, stopper,
heavy tubing, and aspirator

Procedure:

Place a marshmallow (or marshmallow cookie, or marshmallow Easter chicken) under a glass dome that has been placed on the platform of a vacuum pump. Turn on the vacuum and note what happens as the pressure inside the dome decreases. Ask the students if the mass of the marshmallow is increasing, or if they would gain more weight by eating the larger-volume marshmallow.

If you do not have a vacuum pump and dome, a side-arm flask with a rubber stopper fitted to an aspirator using heavy walled tubing can be connected to a water faucet. Force the marshmallow into the flask, stopper the flask, and turn on the water.

Background:

The marshmallow contains large quantities of trapped air. As the air outside the balloon is removed, this reduction in pressure on the trapped air causes it to expand, thus producing a greater overall volume of the marshmallow. If anything, the marshmallow would become slightly lighter as the reduced pressure might cause some of the air to escape into the dome. This demo provides a nice introduction to Boyle's law.

Further Variations:

The marshmallow could be heated by placing it in a beaker of hot water to show the relationship between volume and temperature.

Adapted from Summerlin, L.R. and Ealy, J. *Chemical Demonstrations,* Vol. 1. Washington, D.C.: American Chemical Society, 1988.

Science as Inquiry

Reduce the Pressure

What happens to balloons when pressure is reduced?

Overview:

A small inflated balloon is placed under a dome on a vacuum pump. As the pressure is decreased, the balloon expands.

Materials:

small balloon
vacuum pump with dome

Procedure:

Place a small balloon that has been inflated to about the volume of a softball under a glass dome that has been placed on the platform of a vacuum pump. Turn on the vacuum and note what happens as the pressure inside the dome decreases. Ask the students if the mass of the balloon is increasing.

Background:

As the air outside the balloon is removed, the reduction in pressure on the trapped air causes it to expand, thus producing a greater overall volume. No change in mass occurs because no additional air enters or is removed from the balloon. This demo provides a nice introduction to Boyle’s law and is more straightforward than the marshmallow experiment.

Science as Inquiry

Inflating the Tube

Why does the tube inflate?

Overview:

An “empty” toothpaste tube is heated. The gas remaining in the tube expands according to Charles’s law.

Materials:

toothpaste tube
tongs
Bunsen burner

Procedure:

Press the toothpaste out of the tube, completely emptying it. Screw the cap back on tightly. Hold the toothpaste tube with the tongs placed on the cap and the flattened portion parallel to the tabletop. Heat the tube gently with the Bunsen burner by passing it back and forth through the flame. The contents of the tube will expand as the tube is heated and contract as it is cooled.

Background:

As the gas inside the tube is heated, it expands according to Charles’s law. When cooled, it will deflate.

Adapted from SS&C, National Science Teachers Association, 1993.

an alternative/extension activity for Event 1

Teacher Sheet

Science as Inquiry

Cartesian Diver

What makes the eyedropper sink?

Overview:

A eyedropper is placed in a bottle of water and sealed. As the sides of the bottle are pressed, the dropper sinks. When the pressure is released, the dropper rises.

Materials:

2-liter clear plastic soft-drink bottle with cap
water
medicine dropper

Procedure:

Fill an empty clear, two-liter soft-drink bottle to the top with water. Place an eyedropper containing a small quantity of water in the bottle. Adjust the volume until it just floats. Screw the cap on the bottle until tight. Press the sides of the bottle and the dropper sinks. Relax the pressure and the dropper rises.

Background:

As the pressure on the sides of the bottle increases, it increases the pressure on the water and forces more into the dropper, thus increasing the density of the dropper system. Note that as the water moves into the dropper, the volume of trapped air decreases according to Boyle's law. When the pressure is relaxed, the water escapes from the dropper, which becomes less dense and rises to the original position. The volume of the gas inside the dropper expands. It is important for students to note that the volume, but not the mass, of the gas changes during the activity.

Adapted from Summerlin, L.R., Borgford, C., and Ealy, J. *Chemical Demonstrations,* Vol. 2. Washington, D.C.: American Chemical Society, 1988.

an alternative/extension activity for Event 1

Teacher Sheet

Science as Inquiry

Balloon Volumes

How is gas volume related to temperature?

Overview:

In this demo, three balloons are inflated to equal volumes and changes are noted as they are cooled or heated.

Materials:

3 round balloons
hot water and ice water
2 large beakers or pans for water

Procedure:

Inflate three balloons to about the volume of a baseball. Pour hot water into one beaker or pan and ice water into the other beaker or pan. Place one balloon in each and use the third balloon as a reference.

Background:

The air inside the balloon will expand on heating and contract on cooling. This demo provides a qualitative introduction to Charles's law. As the temperature of an ideal gas increases, the volume will increase proportionately to the Kelvin temperature if the pressure remains constant. At higher temperatures, the molecules move at faster rates, thus occupying a greater volume if the pressure remains constant.

Adapted from Summerlin, L.R., Borgford, C., and Ealy, J. *Chemical Demonstrations,* Vol. 2. Washington, D.C.: American Chemical Society, 1988.

an alternative/extension activity for Event 1

Teacher Sheet

Science as Inquiry

Filling Bottles

How is gas volume related to pressure?

Overview:

Four bottles are connected to a pressure gauge. Water is poured into the first bottle at definite intervals. Changes in pressure occur according to Boyle's law.

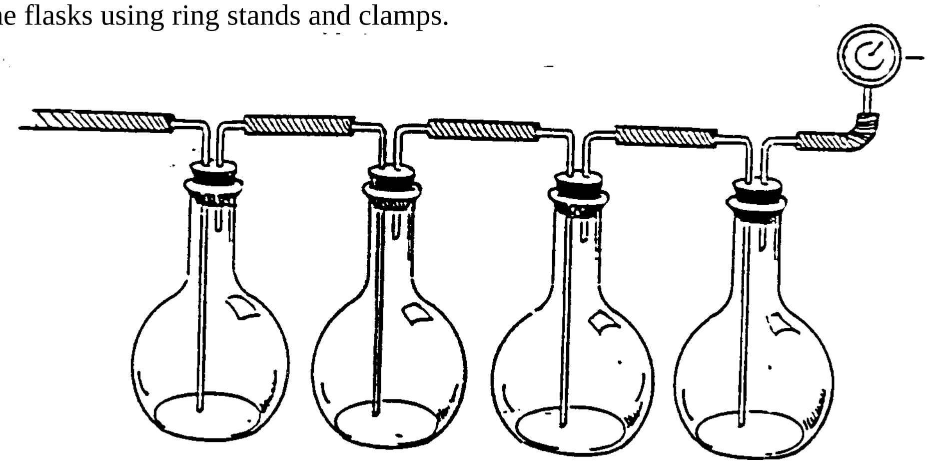
Materials:

4 equal flasks
air pressure gauge
connecting tubes in 2-holed stoppers as shown
4 12-cm copper wires
100-mL graduated cylinder
water
marking tape or pencil
ring stands and clamps to secure flasks

Procedure:

First have students obtain the total volume of one of the flasks. Divide this volume by four, pour successive volumes of water into the flask, and mark the levels with a marking pencil or tape.

Have students assemble the apparatus as shown in the diagram. Fasten each stopper to a flask by wrapping the wire over the top of each stopper and then securing the wire around the neck of the flask. This is similar to the way in which champagne corks are fastened. For stability, it may be necessary to secure the flasks using ring stands and clamps.



Next have students attach the first flask to the water tap and the last flask to the pressure gauge. They should record the pressure and the volume of gas present in the system at the beginning of the experiment. They can disregard the volume of gas in the connections between flasks. Have students slowly fill the first flask 1/4 full with water from the tap through the attached hose. They should record the new volume and pressure as well as any other observations. Have them repeat this process, filling the first flask 1/2 full, 3/4 full, and totally full.

Background:

The data can be discussed either qualitatively or quantitatively. Students might note that as the volume decreases, the pressure increases. They can also determine that the pressure times the volume is equal to a constant. They can graph pressure versus volume and note the shape of the curve. Because the air is in contact with water, the pressure of the gas needs to be corrected for water vapor pressure. Because this has not been presented to students at this point, it may be premature to use this experiment to show the mathematical relationship between the volume and the pressure of the gas, that is, to establish Boyle's law. However, the results should give an approximation of the law.

Adapted from SS&C, National Science Teachers Association, 1993.

Teacher Sheet

Science as Inquiry

Pressure-Volume

Is there a mathematical relationship between the pressure and the volume of a gas when the temperature remains constant?

Overview:

Air is placed in a syringe supported on a wooden base. Masses are placed on a wooden block on top of the syringe plunger and differences in volume are noted. From the data, the mathematical relationship between pressure and volume is calculated, and Boyle's law is confirmed.

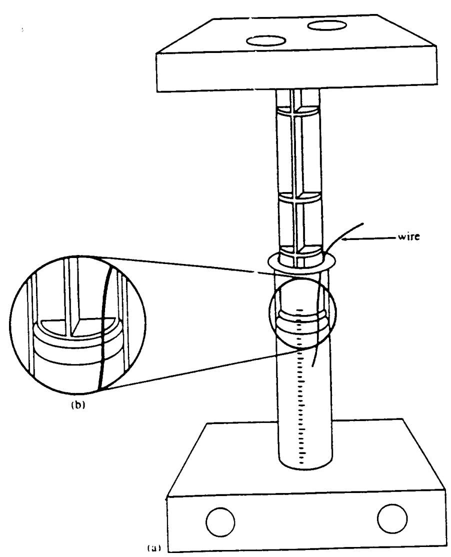
Materials:

Per group:

1 35-mL syringe with cap
1 support block
4–5 bricks (uniform books of the same mass as bricks, or kg masses can be substituted)

Procedure:

Set up the apparatus as shown here.



You or the students must first adjust the volume of gas to read 30 cm^3 by placing a string next to the plunger and adjusting the plunger until it reads 30 cm^3. Then remove the string.

Students should make a data table to record the pressure (in bricks) and the volume. They then place one brick on the system and record the new pressure and volume. This is repeated for four bricks or five bricks. The system may become unstable after four bricks have been added.

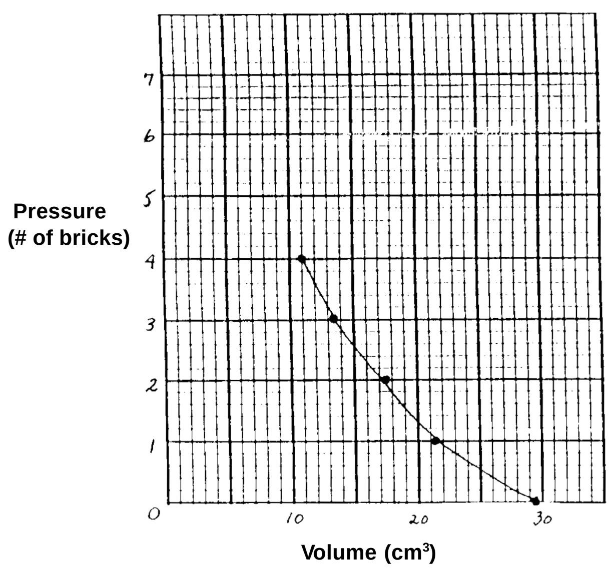
Because there is some friction involved in the system, students should take additional measurements as they remove the bricks, and then average the readings. They record the pressure in terms of the number of bricks and the volume in cm^3. You may wish to demonstrate the addition of bricks. To get good results students need to pull up on the piston slightly before adding a brick, add the brick, and then let it fall under the brick's pressure.

Background:

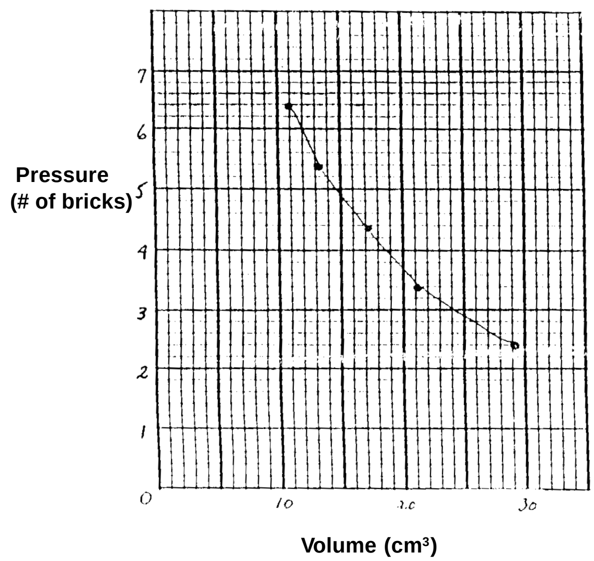
Boyle's law states that the pressure of an ideal gas is inversely proportional to its volume at constant temperature. You might think that students could discover this relationship by using their calculator to determine whether P + V, P - V, P × V, or P/V gives a constant value, and then writing the expression for the relationship, such as PV = k. However, this is not possible from this experiment because in addition to the pressure caused by the brick, the pressure of the piston, the wooden block, and the air also affects the volume. You might ask students to try the different mathematical expressions and then determine that the only reasonable relationship that might apply is the product of the two variables.

To determine the PV relationship, students should first graph the pressure due to the bricks and the volume of gas observed. By examining the graph, they can estimate this additional pressure by moving the graph vertically until the P × V = k relationship (Boyle's law) holds as is illustrated in the two graphs below.

Pressure vs. Volume for Air at Room Temperature



Pressure vs. Volume for Air at Room Temperature (Adjusted for Piston and External Air Pressure)



Students should then find the value of k from the graph, take the average value from the four readings, and express the relationship mathematically. Using the mathematical expression, the formula $P_1V_1 = P_2V_2$ can be derived from $P_1V_1 = k$ and $P_2V_2 = k$; therefore they are equal to each other. Students can then use the relationship to find unknown values of P or V when the other three values are known, and the temperature remains constant.

Adapted from *Introductory Physical Science*, Third Edition. Prentice Hall, 1974 .

Teacher Sheet

Science as Inquiry

Temperature-Volume (1)

Is there a mathematical relationship between the temperature and the volume of a gas when the pressure remains constant?

Overview:

The volume of air inside a pipette is found by filling it with water and determining the number of drops it contains. Pipettes of the same volume are filled with air and placed in beakers of water at different temperatures. Once the gas has expanded at a given temperature, the tube is sealed, placed in a cool water bath, and water is allowed to enter the pipette. The number of drops of water entering the pipette represents the volume of air that has escaped at the higher temperature. This volume (in drops) added to the initial volume (in drops) represents the volume of the gas at the higher temperature. After data have been collected over a 70 degree range, the volume of the gas versus the temperature can be plotted on graph paper and extrapolated back to absolute zero. The temperature scale on the graph can then be converted to the Kelvin temperature scale. From the graph, the mathematical relationship between volume and the temperature measured in Kelvins is calculated by determining the slope of the line. Charles's law is confirmed.

It is recommended that new pipettes be used for each determination to assure that they are dry. Students should be warned not to place the pipettes in water heated to above 90 °C or they may melt.

Materials:

Per group:
8 small-scale pipettes
2 250-mL beakers
hot plate or Bunsen burner with ring stand, ring, and wire gauze
thermometer in °C
water

Procedure:

Students need to make a data table of the initial volume measured in drops and the initial temperature of the water bath at room temperature. Students first determine the number of drops in a small-scale pipette by filling it completely and then counting the number of drops it contains by emptying it. The volume should be around 100 drops. This measurement is used in all subsequent determinations.

After the first measurements are taken, the water bath is heated until it is approximately 10 degrees warmer. Students place another dry small-scale pipette in the heated water bath for a few minutes, then pinch the end to prevent air from entering or escaping, place the sealed pipette in the original water bath that is maintained at room temperature, and open the seal by releasing the stem under the water. As the gas cools, water should flow into the pipette. Students measure the number of drops that are in the pipette (by counting the drops as they empty it) and add this to the original number of drops to obtain the volume of the gas at the elevated temperature. They then record the new volume and temperature in their data table.

This procedure is repeated until the temperature reaches about 80 °C. Students then make a graph of the data, plotting the volume in drops on the vertical axis and the temperature in degrees Celsius on the horizontal axis. The teacher may wish to suggest that students make their graph toward the center of the graph paper to allow for extrapolation of the line produced back to absolute zero.

From the graph, students will be able to determine that the relationship between volume and temperature is linear. If a new line is drawn using the Kelvin scale for the horizontal axis, the relationship between temperature expressed in Kelvins and volume is directly proportional when the pressure of the gas is constant.

Background:

Charles's law states that the volume of an ideal gas is directly proportional to its temperature expressed in Kelvins (K) at constant pressure. From the graph that students prepare of volume versus temperature, students will be able to see that the relationship between volume and temperature is linear. If a new line is drawn using the Kelvin scale on the horizontal axis, the relationship between temperature expressed in Kelvins and volume is directly proportional when the pressure of the gas is constant. Hopefully, students will reach this conclusion when they see that the line goes through the origin. Students can then write the equation for V/T = a constant (the slope of the line), and the relationship of $V_1/T_1 = V_2/T_2$ can be established. Although students can use this equation to solve Charles's law problems, it is advisable to have students think through the relationship and simply multiply an original volume that is given in a problem by a factor of the Kelvin temperature that will either increase or decrease the volume according to what is predicted by the student.

Sample Problem:
500 mL of helium is heated from 25 °C to 50 °C. If the pressure remains constant, what volume will the helium occupy?

Solution:
Charles's law states that the volume is directly proportional to the Kelvin temperature if the pressure remains constant. Therefore, it is necessary to change each temperature to Kelvins and arrange them in a factor that can be used to increase the volume. To do this, the factor must have the larger number on top (in the numerator).

$$500\text{ mL} \times \frac{(50 + 273)\text{ K}}{(25 + 273)\text{ K}} = 500\text{ mL} \times \frac{323\text{ K}}{298\text{ K}} = 542\text{ mL}$$

Adapted from *MicroChemistry* by Russo.

an alternative/extension activity for Event 2

Teacher Sheet

Science as Inquiry

Temperature-Pressure

Is there a mathematical relationship between the temperature and the pressure of a gas when the volume remains constant?

Overview:

The volume of air inside the Florence flask is held constant. The pressure of the air in the flask is determined by reading a gauge that is sensitive enough to record small changes. Students obtain an initial reading of the pressure at room temperature, at 0 °C by placing the bulb in ice water and at 100 °C by placing it in boiling water. By graphing the data and extrapolating, students determine absolute zero. The pressure/temperature (measured in Kelvins) relationship is then determined from the graph.

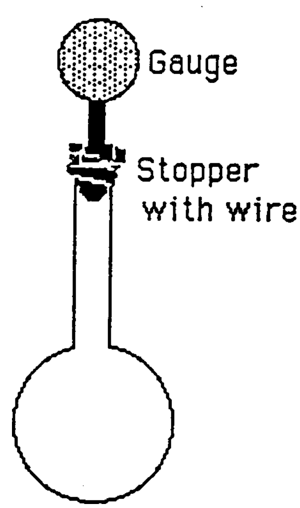
Materials:

Per group:

1 Florence flask
1 pressure gauge with stopper
1 beaker/pail of ice water to hold flask
1 beaker/pail of boiling water to hold flask
wire
hot plate
thermometer in °C
water

Procedure:

Students need to assemble an apparatus as shown here:



The wire is used to wrap the stopper somewhat like a champagne bottle. The volume of the flask is constant. As the temperature changes, the pressure will vary.

Have students assemble the apparatus. They then make a data table and record the initial temperature and pressure. They should place the flask in ice water and record the new temperature and pressure. This is repeated with the boiling water.

Students make a graph of the data, plotting the pressure on the vertical axis and the temperature in degrees Celsius on the horizontal axis. You may wish to suggest that students make their graph toward the center of the graph paper to allow for extrapolation of the line produced back to absolute zero.

From the graph, students will be able to determine that the relationship between pressure and temperature is linear. If a new line is drawn using the Kelvin scale for the horizontal axis, the relationship between temperature expressed in Kelvins and pressure is directly proportional when the volume of the gas is constant.

Background:

The pressure of an ideal gas is directly proportional to its temperature expressed in Kelvins (K) at constant volume. From the graph that students prepare of pressure versus temperature, they will be able to see that the relationship between pressure and temperature is linear. If a new line is drawn using the Kelvin scale on the horizontal axis, the relationship between temperature expressed in Kelvins and pressure is directly proportional when the volume of the gas is constant. Hopefully, students will reach this conclusion when they see that the line goes through the origin. Students can then write the equation for T/P = a constant (the slope of the line), and the relationship of $T_1/P_1 = T_2/P_2$ can be established. Although students can use this equation to solve temperature/pressure problems, it is advisable to have students think through the relationship and simply multiply an original pressure that is given in a problem by a factor of the Kelvin temperature that will either increase or decrease the pressure according to what is predicted by the student applying the relationship.

Standard pressure is considered to be the pressure at sea level of 1 atmosphere or 760 mm Hg or 760 torr. Standard temperature is 0 °C or 273 K. The abbreviation for standard temperature and pressure is STP.

Sample Problem: 500 mL at 700 torr of helium is heated from 25 °C to 50 °C. If the volume remains constant, what pressure will the helium exert?

Solution: The pressure/temperature relationship states that the pressure is directly proportional to the Kelvin temperature if the volume remains constant. Therefore, it is necessary to change each temperature to Kelvins, and arrange them in a factor that can be used to increase the pressure. To do this, the factor must have the larger number on top (in the numerator).

$$700 \text{ torr} \times \frac{(50 + 273)\text{ K}}{(25 + 273)\text{ K}} = 700 \text{ torr} \times \frac{323\text{ K}}{298\text{ K}} = 759 \text{ torr}$$

Adapted from SS&C Trial Materials, National Science Teachers Association, 1993.

Further Variations:

The apparatus described above for obtaining the pressure/temperature relationship is available from scientific supply companies (Sargent-Welch) and can be purchased for demonstration purposes. A suggested variation of the above laboratory experiment that must be done as a demonstration is to use the commercially prepared gauge in the following manner. Prepare three baths in 2-liter beakers (boiling water, ice water, dry ice-amyl alcohol or dry ice-acetone mixture. Pump air into the bulb using a bicycle pump until the pressure is about 20 $lb/inch^2$. Record this initial reading at room temperature. Then place the bulb in the other baths and record the pressure. This will produce four measurements—78 °C, 0 °C, about 25 °C, and 100 °C. Students then plot and analyze data as described above.

Adapted from *Chemistry: An Experimental Science* (ChemStudy), W. H. Freeman and Co., 1963.

an alternative/extension activity for Event 2

Teacher Sheet

Science as Inquiry

Temperature-Volume (2)

Is there a mathematical relationship between the temperature and the volume of a gas when the pressure remains constant?

Overview:

The volume of air is trapped inside a capillary or small-diameter glass tube. The capillary or tube is attached to a thermometer and placed in water at various temperatures. As the temperature of the water bath increases, the trapped air expands. By measuring the diameter of the tube and the height of the column of air, the volume can be calculated over a temperature range of 100 degrees. The volume of the gas versus the temperature can be plotted on graph paper and extrapolated back to absolute zero. The temperature scale on the graph can then be converted to the Kelvin temperature scale. From the graph, the mathematical relationship between volume and the temperature measured in Kelvins is calculated by determining the slope of the line. Charles's law is confirmed.

Materials:

Per demonstration:

ice
water
2 600-mL beakers
hot plate or Bunsen burner with ring stand, ring, and wire gauze
thermometer in °C
small-diameter glass tubing (12 cm long) or capillary tube
band cut from rubber tubing

Procedure:

You will need to prepare the capillary or glass tubing in advance. Fill the tube with oil and then seal one of the ends of the tube by holding it in a Bunsen burner flame. It should look like Figure 1.

You may wish to measure the cross-sectional area and to calculate the volume of the air in the tube in cubic centimeters by multiplying the height of the air column (in centimeters) by the cross-area section (p$r^{2)}$. Whether students plot height or volume, their results should produce a straight line.

Fill a 600-mL beaker with ice water and position the capillary tube and thermometer as shown in Figure 2. Place a rubber band cut from a piece of rubber tubing on the capillary tube to mark the upper edge of the trapped air. Measure the bottom edge of the trapped air and use the

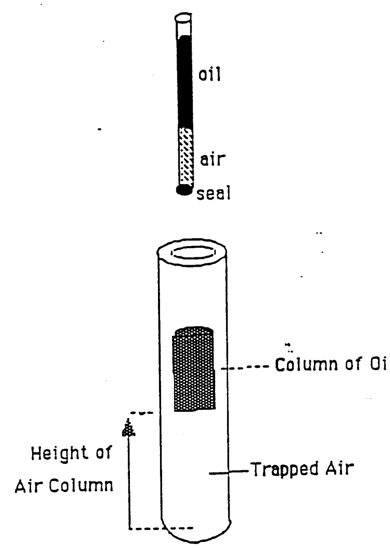


Figure 1

difference as the height of the air column. Replace the cold water beaker with one filled with water at room temperature, submerge the capillary tube and thermometer again, move the band to the top of the air column, and take a new reading. Heat the water and take readings at 20° intervals until the water boils.

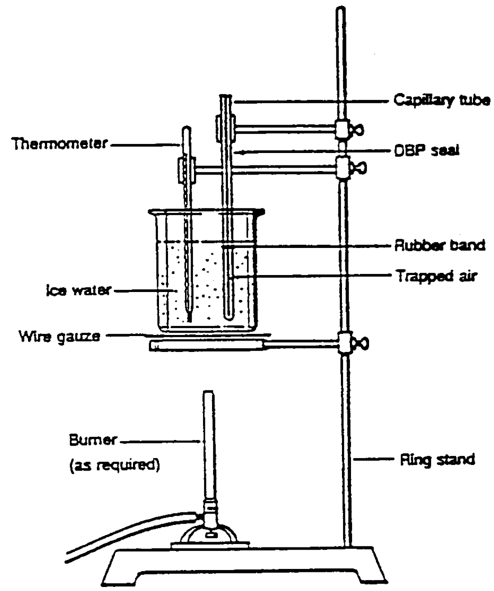


Figure 2

Students need to make a data table to record the height of the column of air at the various temperatures as the water bath is heated from ice (in a separate water bath) and room temperature to 100 °C. Readings at about every 20 °C can be taken. Students then make a graph of the data, plotting the volume, expressed as a height or converted to cm^3 by multiplying the height by the cross-area section (πr^2) of the capillary tube, on the vertical axis and the temperature in degrees Celsius on the horizontal axis. You may wish to suggest that students make their graph toward the center of the graph paper to allow for extrapolation of the line produced back to absolute zero.

From the graph, students will be able to determine that the relationship between volume and temperature is linear. If a new line is drawn using the Kelvin scale for the horizontal axis, the relationship between temperature expressed in Kelvins and volume is directly proportional when the pressure of the gas is constant.

Background:

Charles's law states that the volume of an ideal gas is directly proportional to its temperature expressed in Kelvins (K) at constant pressure. From the graph that students prepare of volume versus temperature, students will be able to see that the relationship between volume and temperature is linear. If a new line is drawn using the Kelvin scale on the horizontal axis, the relationship between temperature expressed in Kelvins and volume is directly proportional when the pressure of the gas is constant. Hopefully, students will reach this conclusion when they see that the line goes through the origin. Students can then write the equation for V/T = a constant (the slope of the line), and the relationship of $V_1/T_1 = V_2/T_2$ can be established. Although students can use this equation to solve Charles's law problems, it is advisable to have students think through the relationship and simply multiply an original volume that is given in a problem by a factor of the Kelvin temperature that will either increase or decrease the volume according to what is predicted by the student.

Sample Problem:
500 mL of helium is heated from 25 °C to 50 °C. If the pressure remains constant, what volume will the helium occupy?

Solution:
Charles's law states that the volume is directly proportional to the Kelvin temperature if the pressure remains constant. Therefore, it is necessary to change each temperature to Kelvins and arrange them in a factor that can be used to increase the volume. To do this, the factor must have the larger number on top (in the numerator).

$$500\text{ mL} \times \frac{(50 + 273)\text{K}}{(25 + 273)\text{K}} = 500\text{ mL} \times \frac{323\text{ K}}{298\text{ K}} = 542\text{ mL}$$

Adapted from SS&C Trial Materials, National Science Teachers Association, 1993

Science in Personal and
Social Perspectives

Birthday Balloons

Item:
A bag of balloons has the following label:

Material	latex
Thickness	5 mils
Burst Capacity	6 inches
Colors	various
Logo	happy birthday

Why is the burst capacity of six inches not a useful valid measure? How should it be expressed?

Answer:
Capacity should really specify volume and pressure, not just length.

Science as Inquiry

Gas Volume and Absolute Temperature

Item:

Charles' law states that the volume of a gas at constant pressure is directly proportional to its absolute temperature. Explain why the temperature referred to must be in degrees Kelvin rather than degrees Fahrenheit or Celsius.

Science as Inquiry

The Shrinking Balloon

Item:

An inflated balloon in a warm room will get smaller when taken outside on a cold day and will return to its original size when taken back into the warm room. Explain what happens to the particles of gas in the balloon as each of these changes occurs.

Science as Inquiry

Different Gases, Different Pressures?

Item:
If you were given one mole of each of several different gases in the same temperature and pressure environment, how would their pressures compare? Explain.

Answer:
The average kinetic energy of the gases at the same temperature would have the same pressure.