EME

BOYLE'S LAW AND ABSOLUTE ZERO

STUDY GUIDE

A. Mason Turner
Orangeburg-Wilkinson SC Senior High School

CO-AUTHOR
"Inquiries in Chemistry" (Allyn & Bacon)

For assistance in developing this Unit, acknowledgment is made to Frank Micciche, Director, Science Instruction Materials Center, Manhasset, New York, Public Schools

www.emescience.com

EME Post Office Box 1949 • Stuart FL 34995

IMPORTANT

1. Before accurate experimental work can be performed with your BOYLE'S LAW UNIT the volume scale must be calibrated. See page 2.
2. If the gauge pressure decreases while the volume remains constant apply a small amount of Stopcock Grease or similar lubricant on the syringe plunger.
3. If your unit has been exposed to low temperatures, remove plunger and clean it with an organic solvent. Then relubricate slightly.

EME MOLECULAR MOTION DEMONSTRATOR

This action overhead projectual clearly presents the abstract concepts of the Kinetic Theory by putting up on the screen a dramatic display of moving spheres that simulate molecular behavior. The MOLECULAR MOTION DEMONSTRATOR consists of a square frame mounted over a glass plate. A motor and solid state controls drive the frame over a range of speeds. All accessories and Experiment Manual are included for 13 experiments:

1. Random Motion of Molecules
2. Three States of Matter
3. Gas Pressure
4. Temperatures of Gases
5. Diffusion of Gases
6. Condensation
7. Brownian Movement
8. Boyle's Law
9. Avogadro's Hypothesis
10. Van der Waals forces
11. Solids and Liquids
12. Changes of State
13. Grahm's Law of Diffusion

To order specify: MMD-1 MOLECULAR MOTION DEMONSTRATOR

EME Corporation
P.O. Box 1949
Stuart FL 34995
800 848-2050

www.emescience.com

OPERATION AND MAINTENCE

The EME Boyle's Law Unit is designed to fit on any overhead projector for simultaneous viewing by the entire class, or it may be used by small groups or individual students without a projector. It consists of an absolute-pressure gauge and a calibrated glass syringe, mounted on a base of acrylic plastic for sturdiness, and excellent projection qualities. The syringe is connected by plastic tubing to a "quick disconnect" fitting on the pressure gauge.

The accessory unit for the Absolute Zero determination consists of a metal sphere, equipped with a handle and five feet of tubing. At one end of the tubing is a male fitting that connects to the "quick disconnect" fitting on the pressure gauge after the syringe fitting has been disconnected.

To operate the quick disconnect fitting, slide the knurled ring at the base of the gauge about 3mm toward the body of the gauge and pull out the male fitting. Release the ring. To connect, again slide the ring toward the gauge, insert the male fitting and release the ring which automatically locks into position. The pressure gauge is set at approximately 14.7. The gauge readings are in absolute pressure so that 14.7 represents atmospheric pressure at sea level. Note that the gauge readings increase counterclockwise. To assure accurate pressure readings:

1. Wait about 5 seconds after setting the desired volume with the plunger before reading the pressure. Usually a slight initial drop in pressure will be noted. This results from the gas returning to room temperature after a slight increase caused by compression.

2. Every third or fourth reading lightly tap the fitting at the base of the gauge with a pencil to relieve any friction effects in the gauge gear system.

3. If the pointer should require adjustment, access to it is obtained through the hole in the base below the gauge. Use a pair of needle-nose pliers to turn the adjustment pin in either direction.

4. If the pointer of the pressure gauge starts to drift when the volume is held constant, the gas is probably leaking around the syringe plunger. Disconnect the syringe from the gauge, remove the plunger, and coat it lightly with stopcock lubricant.

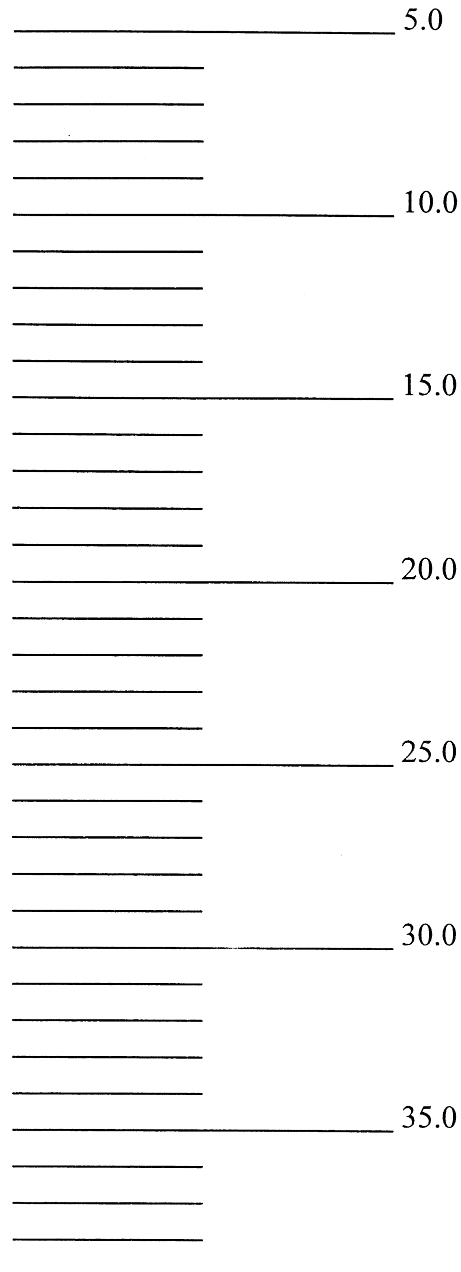
Before using the unit make sure the stage of the overhead projector, the transparent base of the unit and the gauge cover are clean. Proper care of the acrylic components is essential for clear projection and long life. Use only water-soluble ink pens on the base. Clean with a soft, moist cloth. Never use solvent or abrasive cleaners as they will discolor or scratch the acrylic surfaces.

CALIBRATION

To accurately demonstrate Boyle's Law the volume scale on the base must reflect the total volume of gas in the system. This total volume is equal to the volume of the syringe plus the volume of the gauge, tubing and fittings. To obtain the total volume follow this procedure:

1. Disconnect the fitting at the gauge and set the plunger at the 0 cc mark on the syringe. Reconnect the fitting.
2. Record the pressure reading at the 0 cc volume setting.
3. Pull out the plunger until the pressure reading is ½ of the value of the original reading. Record the volume at this pressure. This volume reading equals the volume of the gauge, tubing and fittings.
4. This figure must be added to the volume of the syringe at all plunger settings. Use a marking pen to record the total volume of the system next to the first calibration line on the base, and each succeeding fifth calibration line.

For example, if the volume of the gauge, tubing and fittings is determined to be 5 cc the volume calibrations on the base would be:



Students may now take total volume reading directly from the end of the plunger as projected on the screen.

Experiment 1 GASES AND THE KINETIC THEORY

BACKGROUND

The Kinetic Theory is based on the assumption that all matter is composed of small, invisible particles that are always in motion. Gases are thought to consist of a collection of rapidly moving molecules in helter-skelter (random) motion, colliding with each other and with the walls of their container. Generally, there is thought to be a relatively large amount of space between molecules. The physical behavior of gases is then explained by applying to the rapidly moving molecules the demonstrated theories of motion and collision which apply to larger visible objects. A nearly quantitative explanation of many properties of gases can be given by using such a particle model for matter. One property of gases that supports the Kinetic Theory is their ability to be compressed and expanded.

PROCEDURE I

For this experiment the plunger and the inside of the syringe should be cleaned of all lubricant. An organic solvent such as alcohol or acetone may be used.

Disconnect the syringe from the gauge and set the plunger at 20 cc. Hold your thumb tightly over the end of the tubing fitting to seal it and use your other hand to push the plunger in enough to decrease the volume to about 10 cc. This illustrates the ability of a gas to be compressed. Then release the plunger suddenly. Students will see that the plunger returns approximately to its original position. Ask students to explain this in terms of the moving-particle (Kinetic) theory.

DISCUSSION I

The compressibility of a gas supports the Kinetic Theory assumption that gas molecules are relatively far apart. As the volume of the gas was decreased the molecules crowded together more and more. Since the amount of space available for the movement of the gas molecules was greatly decreased, they collided more and more with the inside walls of the syringe and the front of the plunger, producing an increase in pressure inside the syringe. The increased pressure pushed out the plunger as soon as it was released.

DISCUSSION II

This time the volume has been increased allowing more space for the movement of the gas molecules. Thus, there will be fewer molecule-to-wall collisions resulting in a decrease in pressure inside the syringe. When the plunger is released the higher pressure outside will push it in until the pressures inside and out are equalized.

Experiment 2 BOYLE'S LAW

BACKGROUND

Boyle's Law deals with the quantitative relationship between the pressure and the volume of a gas when the temperature remains unchanged. It is usually stated as: Pressure times Volume equals a constant ($PV = k$), or: the pressure of a gas varies inversely with its volume provided the temperature remains unchanged ($P = 1/V$).

A good example of Boyle's Law is the breathing process. When a person exhales, the ribs move inward and the diaphragm moves up. This decreases the volume inside the lungs and causes the air molecules in the lungs to move closer together since less room is available. When the air molecules move closer together the pressure inside the lungs increases. The air pressure outside the lungs is now less than inside so air rushes out of the lungs until the pressure is equalized. Inhaling reverses the process.

Basic Presentation

Disconnect the syringe from the gauge, set the plunger at 20 cc and re-connect. Push in plunger, stopping at 3 or 4 different convenient volume settings, and have students record the pressure and volume at each setting. Release the plunger. Ask students: "What happens to the pressure of a confined gas as its volume is decreased?" Their pressure readings will tell them that the pressure increases as the volume decreases.

Next, increase the volume by pulling the plunger out, stopping at 2 or 3 convenient volume settings. Again have students record each pair of volume and pressure readings. Now ask: "What happens to the pressure of a confined gas as its volume increases?" This time their readings will show that pressure decreases as the volume increases. Try to draw out of the students the generalization that "as one goes up the other goes down". This rough and qualitative rule will provide an excellent foundation for a mathematical treatment of Boyle's Law.

Advanced Presentation

Disconnect the syringe from the gauge, set the plunger at 20 cc and re-connect. Each student should set up a data table similar to the one projected on screen. Move the plunger to the following volume settings: 20.0 cc, 15.0 cc, 10.0 cc, 7.5 cc, 20.0 cc, 25.0 cc, 30.0 cc, 35. 0 cc

20.0 cc. The original volume setting (20 cc) is used three times to illustrate the possibility of uncertainty in measurement and as a check for leaks in the system. Have the students record the volume and pressure at each setting. Readings of volume and pressure should be estimated to the nearest tenth of a unit.

Repeat the measurements for any other gases available. This helps to emphasize the generality of Boyle's Law for all gases.

Before drawing any other gas into the syringe disconnect the fitting from the gauge and push the plunger in all the way. Natural (burner) gas is usually available. It is mostly methane. Hydrogen and oxygen can be generated by electrolysis of water. After a minimum of 20 cc of gas is generated, connect a piece of rubber tubing from the top outlet of the electrolysis unit to the fitting on the end of the syringe fitting. Open the top valve on the electrolysis unit and draw the collected volume of the hydrogen or oxygen into the syringe. Close the electrolysis valve. Squeeze or bend the tubing to prevent loss of the gas. Remove rubber tubing and connect syringe fitting to the gauge.

Students should note that all the gases tested can be compressed and expanded and that their volume-pressure measurements closely agree. Treatment of the data depends on the mathematical ability of the class and the time available. Two different approaches are given. The teacher can select the one most suitable.

1. Brief Approach

Ask students if they can find any pattern in their data table. Most will notice that as the pressure goes up the volume goes down and, conversely, as the volume goes up the pressure goes down. Press them to be more specific. For instance, have them compare the pressure readings at one volume and then at one-half the volume, for example 20 cc and 10 cc. Some will realize that the pressure doubles when the volume is halved. Ask them if this is true throughout the range of volumes recorded. Point out the pressures may not exactly double as the volumes halve and ask why. Students should realize that it is not always possible to obtain exact measurements. Problems in setting and reading volumes, and reading pressures require about ± .7 leeway in comparing the pressures of doubled volumes.

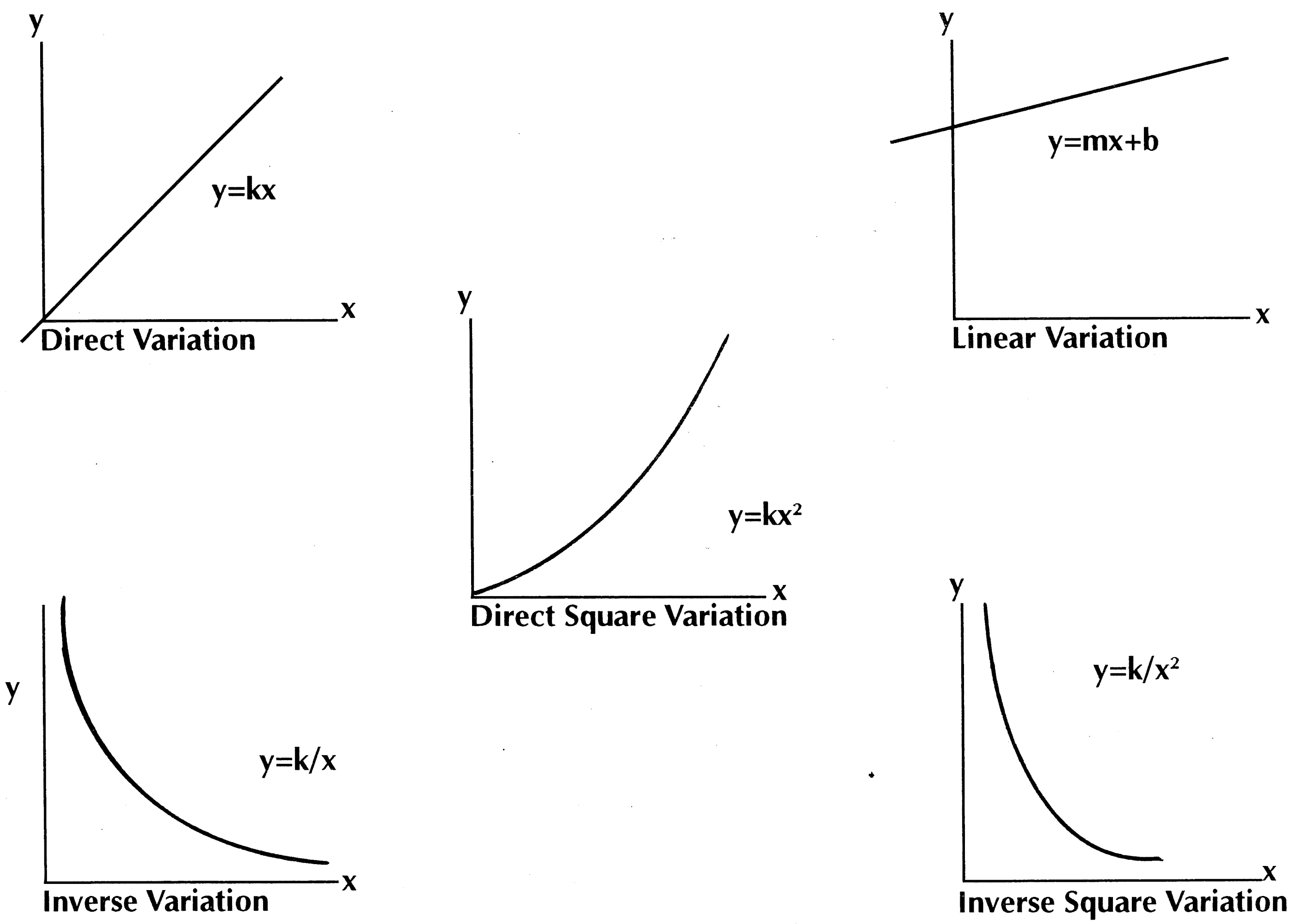
Tell the class that the type of variation where one variable doubles as the other is halved, or one triples as the other is divided by three, is called **inverse variation**. Have them check their data table for the pressure when the volume triples (10.0 cc to 30.0 cc) and as the volume quadruples (7.5 cc to 30.0 cc). Then ask how many would agree with this summary statement: **The volume of a given mass of gas varies inversely with its pressure if the temperature remains constant**. Robert Boyle, a British scientist, discovered this relationship for gases. Hence, it is know as Boyle's Law.

2. Graphing Approach

Each student should record on a data table the volume and pressure readings from the screen. The data may be graphed by the instructor or have each student graph the data as a homework assignment. Use rectangular coordinate graph paper with volume on the x axis and pressure on the y axis. The resulting graph will be a gentle curve known as a hyperbola.

Ask students to compare their graphs to the set of graphs shown below. The graphs may be duplicated and passed out to each student, drawn on the board or drawn on a transparency and projected. Most students will select the Inverse Variation graph as the one most similar to their own.

TYPES OF VARIATION: THEIR GRAPHS AND EQUATIONS



However, some may argue for the Inverse Square Variation. Point out the equation for Inverse Variation: xy = k (k standing for a constant). Have students substitute v for x and p for y so the equation reads: vp = k.

If students are uncertain whether the P times V products are close enough to each other to be called a constant, point out that uncertainties in measurement could result in as much as ± 5% variation in the P times V products from the average P times V product. Have them average the products, calculate 5% of this average, and confirm that each P times V product falls within ± 5% of the average. This check will confirm the inverse relationship between pressure and volume for gases within the uncertainty of measurement. Below is an example of a completed data table.

V	P	P x V
37.5	11.4	428
34.5	12.0	414
32.5	13.0	423
29.5	14.0	413
27.5	15.0	413
25.5	16.0	408
22.5	18.5	416
20.5	20.5	420
18.5	23.0	426
16.5	26.0	429
14.5	30.0	435
12.5	35.0	438

Average P X V product is 422. Readings are with ± 3.6%.

In summary, we have found a mathematical relationship between the pressure and volume of gases called inverse variation. In the form of an equation the relationship is stated as: PV = k (pressure times volume equals a constant) when the temperature remains the same. It is called Boyle's Law.

Experiment 3 ABSOLUTE ZERO DETERMINATION

BACKGROUND

Absolute zero is believed to be the lowest temperature possible to achieve. On the celsius scale absolute zero equals – 273.15°. Theoretically, at this temperature all molecular motion would cease. Although temperatures have been attained down to within one hundred-thousandth of absolute zero, it has not been possible to penetrate below this barrier. This tends to support acceptance of absolute zero as the lowest limit of coldness.

PROCEDURE

Connect the fitting from the metal sphere to the pressure gauge and place the projectual on the overhead projector. Mask out the words BOYLE'S LAW on the base with a piece of paper before turning on the projector. Obtain four 1500 mL beakers or four other containers, each large enough for the metal sphere to fit into easily. Fill one container ¾ full of water and heat to boiling. Fill the second container with water from the cold water faucet. The third should be ¾ full with a mixture of cold water and ice, with salt or calcium chloride. Leave the fourth empty. Place celsius thermometers into the heated and the ice-water containers.

Remove the container of boiling water from the heat source and have the cold-water and empty containers nearby. Immerse the sphere in the hot water and record the pressure at its peak. Take the temperature at the same time the pressure is recorded. Next, remove about 100 mL of the hot water and pour it down the sink or into the empty container. Replace the hot water with an equal amount of cold (not ice-salt) water. Immerse the sphere again and take pressure and temperature measurements.

If time permits take another five or six sets of readings allowing the temperature to drop about 10° C between readings. Finally, immerse the sphere into the water-ice-salt mixture and record the temperature and pressure.

If time is limited take a minimum of three readings: one near boiling, one about 40° C and one in the ice water.

IMPORTANT: Do not allow the plastic tubing to come into contact with the heat source.

PRESENTATION OF DATA

When the pressure and temperature data are graphed absolute zero in degrees Celsius can be determined by extrapolation. The graph may be plotted on the board by the teacher or on an overhead transparency, or each student may plot his own graph in class, if time permits, or as a homework assignment.

The graph should be drawn so that one-fourth of the x (temperature) axis is positive and three-fourths is negative. The x axis is then scaled from - 300° C at the origin to + 100° C. The y axis is scaled from zero at the origin to + 25. Plot the temperature/pressure points and connect them with a straight line. Then extend (extrapolate) the line down until it intersects the x axis (where the pressure on the y axis equals zero). The intersection of the line and the x axis should be within ± 25° C of the accepted value of absolute zero - 273° C. See graph below.