16250 ELASTICITY OF GASES
INSTRUCTOR MATERIAL

SAFETY

Please inform your students of the following safety concerns:

- Using this apparatus involves stacking heavy masses or textbooks on the wooden top attached to the syringe piston. Be sure that all objects on the top are balanced, so that they do not fall on the floor. Stay clear of any area where masses or textbooks may fall.
- Perform all experiments on a level surface.
- When handling hot containers in this experiment, use a thick cloth or potholders to avoid burns.
- Wear appropriate eye protection for this experiment.

REQUIRED ACCESSORIES

- (1) 500 mL Pyrex® Beaker
- (1) Bunsen Burner
- (1) Thermometer
- Large Uniform Masses (books suggested)

PURPOSE

To visually demonstrate the elastic properties of a gas, and to experimentally verify Boyle's Law and Charles' Law.

ASSEMBLY

Follow this assembly procedure when preparing this apparatus for the study of Boyle's Law (Procedure A).

Before assembling this apparatus, pull the piston out of the syringe. Apply water to the outside of the rubber portion of the piston, and place the piston into the body of the syringe.

To trap a particular volume of air in the syringe, push or pull the piston to a volume of your choice. Then, place one of the included plastic caps over the narrow end of the syringe (this end should be sticking out of the base if the apparatus is assembled). Leave the syringe uncapped until you are ready to draw air into it. After you have drawn air into the syringe and capped the syringe, place the end of the syringe with the capped end into the wooden base.

Place the wooden base (the larger of the two included wooden pieces) on a firm surface, with the wider end down. Place the end of the syringe piston into the hole in the wooden top, and push the end of the piston into the slot that is cut into the top.

TIME REQUIREMENTS

- **The initial setup of this apparatus should take no more than 5 minutes.**
- **Procedure A should require no more than 30 minutes to complete.**
- **Procedure B should require no more than 30 minutes to complete.**
- **Time required for class discussion or completion of assessment will vary.**

STANDARDS

The student will show evidence of the following criteria from the National Science Education Standards (NSES) for grades 5-12:

- Grades 5-12 (Content Standard A):
  - **Abilities necessary to do scientific inquiry.**
    (*The student uses this apparatus to conduct scientific inquiry about the elastic nature of gases; addressed in Procedures A and B.*)
  - **Understandings about scientific inquiry.**
    (*The student uses this apparatus to understand the process by which the elastic nature of gases is studied; addressed in Procedures A and B.)*
- **Grades 9-12 (Content Standard B):**
  - **Conservation of Energy and the Increase in Disorder**. Heat consists of random motion and the vibrations of atoms, molecules, and ions. The higher the temperature, the greater the atomic or molecular motion.

(*Addressed in Procedure B; students use this apparatus to observe the effects of a change in temperature on a contained gas.*)

SUGGESTIONS FOR USE

- For suggestions regarding the use of the table on page 9 of the student instructions, see the attached instructions on page 10 of the student instructions.

- While applying lubrication to the piston in the syringe may help with reducing static friction between the piston and the body of the syringe, static friction may still occur. In case the apparatus does not move when adding masses as described in Procedure A, tap the side of the apparatus gently until the apparatus moves due to the force applied by the masses.

PROCEDURE A (BRIEF DESCRIPTION)

Students will use this apparatus and several large uniform masses (textbooks are recommended) to study the relationship between the pressure of a gas and its volume (Boyle's Law). Students will use textbooks to apply a pressure on the air in a syringe, and will record the new volume of the air in the syringe.

ANSWERS (PROCEDURE A)

Q1. How does the amount of effort required to push the syringe change as the volume of the syringe decreases?

As the piston inside the syringe is pushed down, the amount of 'effort' that it takes to compress the air in the syringe should increase.

Q2. What happens to the air inside the syringe after you remove your hand?

After removing your hand, the air will expand in the syringe and the pressure of the air will decrease.

Q3. What happens to the air in the syringe as the masses are added to the apparatus?

As masses are added to the apparatus, the air in the syringe will be compressed, and occupy a smaller volume.

Q4. What happens to the air in the syringe as the masses are removed from the apparatus?

As masses are removed from the apparatus, the air in the syringe will expand and occupy a larger volume.

Q5. From the data you recorded, make a graph that relates the pressure of the air in the syringe to its volume. Is the relationship between the pressure of the air in the syringe and the volume of the air in the syringe linear or non-linear?

The relationship between the pressure of air in the syringe and the volume of the air in the syringe is non-linear, since the two quantities are inversely proportional.

Q6. Multiply your individual measurements for the pressure applied to the piston by the average of the volume measurements for that particular pressure. Record this product in the 'PV' column in your data table. Does your data support Boyle's Law? How can you tell?

When multiplying pressure and volume in this experiments, students should notice that the product remains relatively constant throughout the experiment. This supports Boyle's Law: pressure and volume are inversely proportional, and the product of pressure and volume in an initial and final state are equal.

ANSWERS (ASSESSMENT A)

1. An ideal gas is contained in a 50 cubic centimeters syringe at 120 kPa; temperature is allowed to remain constant. The volume of the syringe is reduced by 10 cubic centimeters. Find the final pressure of the gas in the syringe in atmospheres.

For this problem, let P_i = 120 kPa, P_f = x, V_i = 50 cc, and V_f = 40 cc. Apply the Boyle's Law equation detailed in the Concepts section:

$$(120\ kPa)/(x\ kPa) = (40\ cc)/(50\ cc)$$
$$(120\ kPa)/(x) = .8$$
$$x = 150\ kPa$$

To convert the answer to atmospheres, use the conversion factor that is given in the table on page 4:

$$x_{atmospheres} = (0.00966924) x_{kilopascals}$$
$$x_{atmospheres} = 1.45\ atm$$

2. A small box is partially closed, and contains 100 cubic centimeters of air at 175 kPa. The box is then opened, and now contains the same amount of air, at the same temperature, in a volume of 250 cubic centimeters. Find the final air pressure of the air in the box.

For this problem, let P_i = 175 kPa, P_f = x, V_i = 100 cc, and V_f = 250 cc. Apply the Boyle's Law equation detailed in the Concepts section:

$$(175\ kPa)/(x\ kPa) = (250\ cc)/(100\ cc)$$
$$(175\ kPa)/(x) = 2.5$$
$$x = 70\ kPa$$

PROCEDURE B (BRIEF DESCRIPTION)

Using the syringe included in this apparatus, students will study the relationship between the temperature and volume of a gas. Students will use a beaker filled with hot water to heat a certain volume of air in the syringe, and will allow the air to cool; meanwhile, students will take measurements of the volume that the air occupies.

ANSWERS (PROCEDURE B)

Q1. What happens to the air in the syringe as it is heated?
As the air in the syringe is heated, it should expand and occupy a larger volume in the syringe.

Q2. What happens to the air in the syringe as it cools?
As the air in the syringe cools, it should condense and occupy a smaller volume in the syringe.

Q3. Based on your observations, what can you say about the molecular motion of the air molecules in the syringe? How does the molecular motion relate to the volume of the space that the air occupies?

Because the temperature of a substance is a measure of the average kinetic energy of molecules in that substance, it is also reflects the speed at which particles in the substance move or vibrate. Therefore, as the temperature of the air in the syringe increases, the kinetic energy of the molecules in the air also increases. This increase in kinetic energy is accommodated by an increase in the volume of the syringe; the faster movement of the molecules forces the syringe to expand.

ANSWERS (ASSESSMENT B)

1. A balloon is filled with 2.4 liters of air at 170 kPa and at 300° K. The balloon is then thrown into a freezer, with an air temperature of 275° K. Assuming the pressure of the air remains constant, what is the volume of the balloon after it is ‘frozen’?

For this problem, V_i = 2.4 L, V_f = x, T_i = 300° K and T_f = 275° K. From these values, the unknown volume after ‘freezing’ can be calculated using the Charles’ Law equation in the Concepts section:

$$(2.4\ L)/(300°\ K) = (x\ L)/(275°\ K)$$

$$x = 2.2\ L$$

2. Suppose the air inside the same balloon (2.4 L at 300°K) is heated with a Bunsen burner. If the balloon has a maximum capacity of 3.5 liters before it bursts, at what temperature will the balloon burst? Assume that pressure remains constant, and that the balloon will not melt as a result of the heat from the Bunsen burner.

For this problem, V_i = 2.4 L, V_f = 3.5 L, T_i = 300° K, and T_f = x° K. From these values, the unknown temperature can be calculated using the Charles’ Law equation in the Concepts section:

$$(2.4\ L)/(300°\ K) = (3.5\ L)/(x°\ K)$$

$$x = 437.5°\ K$$