16250 ELASTICITY OF GASES
STUDENT NAME:______________________________

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.

SAFETY

Please pay attention to 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.

INTRODUCTION

Robert Boyle (1627 – 1691), an Irish chemist, made several contributions to physics and chemistry; the most notable of which is Boyle's Law, which details the relationship between the pressure of a gas and the volume it inhabits. Boyle's other contributions to physics includes the study of sound, specific gravities and other properties of chemicals. Jacques Charles (1746 – 1823), a French physicist, developed the proportional relationship between volume and temperature in 1787. This relationship is known most commonly as Charles' Law. Joseph Louis Gay-Lussac referenced Charles and published a theory based on Charles' work in 1802. Charles' Law is sometimes also known as the Law of Charles and Gay-Lussac.

The most prevalent example of a gas on Earth is its atmosphere, the body of gases that surrounds us and fills our lungs. The air around us, when drawn into a container, will take the shape of that container, and will exhibit particular properties when contained. These properties are outlined by relationships such as the Ideal Gas Law, which relates the pressure, temperature, and volume of a gas in a single equation of state.

Measurements of the properties of the air around us, and gases in use, are essential for so many different applications. The tires on a car, for instance, are inflated to roughly 30 or 35 pounds per square inch; a pressure gauge is necessary to inflate tires properly, and is a practical application of the proportional relationship between pressure and volume. Pressure gauges also help to provide SCUBA divers with air at a breathable pressure.

Barometers are another form of pressure gauge, used to measure atmospheric air pressure. Aboard ships, barometers measure atmospheric air pressure with particular units so that sailors can compare local air pressures to a previously determined atmospheric standard at sea level. Barometers and thermometers provide sailors at sea with insight about possible weather patterns that may affect their voyage at sea. Sailors on quartermaster watch aboard some vessels are required by the Coast Guard manually record the current temperature and pressure of the air around them every hour.

CONCEPTS

IDEAL GAS LAWS

Both Boyle's Law and Charles' Law are derived by placing specific conditions on the Ideal Gas Law, which relates, in one formula, the relationship between the temperature, pressure, and volume of an ideal gas. This relationship is given by the following equation:

$$PV = nRT$$

where ‘P’ is the pressure of an ideal gas sample (measured in kilopascals, as a general standard), ‘V’ is the volume of that sample (measured in liters or cubic centimeters), ‘T’ is the temperature of that sample (measured in Kelvin), and ‘n’ is the number of moles contained in the sample. ‘R’ is the Universal Gas Constant, equal to 8.3145 joules per mole-Kelvin (J/mol-K). The equation that mathematically articulates the Ideal Gas Law is an *equation of state*, which, in this particular case, describes the state of a gas under a set of given initial conditions.

PRESSURE

Pressure is defined as an applied force per unit area, and is given by the following general formula:

$$P = F/A$$

where ‘P’ is the pressure resulting from a force ‘F’, applied over an area ‘A’. The SI unit for pressure is the pascal (Pa), or a Newton per square meter. Because a pascal is a relatively small unit, pressures in SI measurements are normally reported in kilopascals (kPa). Although this unit is standard for SI use, several other measures of pressure exist in relation to several different standards.

Below is a table interrelating common units of pressure. To find the value of a particular unit of pressure in comparison to another, locate the unit in the left-most column; in line with the unit that you want to convert are five conversion factors. Multiply the value of the pressure you have recorded by the conversion factor, and the value is converted to the unit respective to the conversion factor. For example, to convert kilopascals to pounds per square inch (psi), find the value at the intersection of the ‘1 kPa’ row and ‘pounds/square inch’ column. You will find a conversion factor of 6.894757 pounds per square inch per kilopascal.

	kilopascals (kPa)	pounds/square inch (psi)	atmospheres (atm)	millibar (mbar)	millimeters of mercury (mmHg)
1 kPa	1	6.894757	0.00966924	10	7.50061
1 psi	0.145038	1	0.068046	0.0145038	51.7149
1 atm	101.32535	14.695949	1	1013.25	760
1 mbar	0.1	68.94757	0.0009869	1	.750061
1 mmHg	.133322	0.019337	.0013158	1.33322	1

TEMPERATURE

The temperature of a particular substance is a measure of the average kinetic energy of the atoms or molecules that make up that substance. Traditionally, we measure temperatures in degrees Centigrade (a scale based on the boiling and freezing points of water), or in degrees Fahrenheit (a scale proposed by physicist Gabriel Fahrenheit). Temperatures in degrees Centigrade or Fahrenheit are related by the following formulas:

$$C = (5/9)(F + 32)$$
$$F = (9/5)C + 32$$

where ‘F’ is degrees Fahrenheit and ‘C’ is degrees Centigrade.
Scientific measurements of temperature, however, are traditionally not taken in either of these temperature scales. Instead, temperature measurements are taken in degrees **Kelvin**, which is related to the temperature at which no energy can be extracted from a substance (**absolute zero**). This temperature is theoretical, and is derived from mathematical predictions based on many concepts, such as the inversely proportional relationship between pressure and temperature, kinetic theory, and quantum mechanics. Absolute zero is zero degrees Kelvin, and degrees Kelvin can be related to degrees Centigrade with the following formula:

$$K = C + 273.15$$

where ‘K’ is degrees Kelvin, and ‘C’ is degrees Centigrade.

Boyle's and Charles' Laws.

Boyle's Law states that the pressure of a gas is inversely proportional to its volume when the gas remains at a uniform temperature. Mathematically, this relationship is expressed in the following formula:

$$P_i/P_f = V_f/V_i$$

where 'P_i' and 'P_f' are the initial and final pressures of a gas after a particular operation, and 'V_i' and 'V_f' are the initial and final volumes of that gas after the operation. This formula can also be expressed as:

$$P_iV_i = P_fV_f.$$

Charles' Law states that the volume of a gas is inversely proportional to its temperature when pressure is allowed to remain constant. Demonstration of this relationship requires a container which can change as the temperature of the gas inside rises or falls. Mathematically, this relationship is expressed in the following formula:

$$V_i/T_i = V_f/T_f$$

where 'V_i' and 'V_f' are the initial and final volumes of a gas after a particular operation, and 'T_i' and 'T_f' are the initial and final temperatures of that gas after the operation.

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.

SAFETY

Please observe 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.

PROCEDURE A (BOYLE'S LAW)

Before beginning this experiment, measure the masses you intend to use. Also, measure the area of the larger opening in the syringe. With the syringe uncapped, draw 50 cubic centimeters (cc) of air into the syringe. Place the cap on the syringe, and assemble the apparatus according to the Assembly instructions. Place the assembled apparatus on a level table.

Before taking any data, press down on the wooden top of the syringe and hold the piston in place. **(Warning: for this part of the experiment, only displace the piston to 25 cc or so. Pushing down too hard can damage the apparatus.)**

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

After pushing on the wooden top, remove your hand from the wooden top and observe the behavior of the apparatus.

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

Compress the air inside of the syringe by stacking several uniform masses, one at a time, on the wooden top of the apparatus. As you stack the masses, record the volume of the air inside the syringe, and use the data table on page 10 to relate the pressure applied by the masses on the apparatus to the volume of the air inside the syringe.

(Suggestion: while stacking masses on this apparatus, you may notice that the syringe does not move immediately, due to static friction. To overcome this static friction, gently tap the wooden top, until the piston begins to move downward. Eventually, the piston will no longer move when the apparatus is tapped. After finding a true value for the volume of the gas contained in the syringe, record your results.)

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

After stacking a suitable number of masses on top of the apparatus, remove them one by one and record the volume of the air inside the syringe. Make another column in your table for data from this second run. Repeat this procedure several times, and take the average of all data that relates to one mass.

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

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?

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?

ASSESSMENT A
Assume all gases are ideal gases.

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.

2. You have a box with a door that separates two compartments. The door is shut, and one compartment contains 100 cubic centimeters of air at 175 kPa. The door 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.

PROCEDURE B (CHARLES' LAW)

With the wooden blocks removed, draw 20 cc of air into the syringe and then cap the syringe. Heat 300 mL of water in a 500 mL Pyrex® beaker to 90° C with a Bunsen burner. Place the syringe in the beaker, and be sure to completely submerge the volume of air in the syringe. Give the piston a quick push so that static friction is broken, and allow the air in the syringe to equilibrate. Record the volume of the air in the syringe. Then, give the piston a quick pull, allow the air in the syringe to equilibrate and record the volume of the air in the syringe.

Q1. What happens to the air in the syringe as it is heated?

Q2. What happens to the air in the syringe as it cools?

Repeat this procedure as the water in the beaker cools. Make recordings of the volume of the air in the syringe when the water in the beaker cools by 5° C. To obtain temperatures less than 30° C, empty the water from the beaker, fill it with ice, and repeat this procedure.

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?

ASSESSMENT B

Assume all gases are ideal gases.

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'?

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.

SUGGESTIONS FOR USING THE FOLLOWING DATA TABLE

- To find the area through which force on the enclosed air is applied, measure the inner diameter of the syringe (in meters), and use the formula for the area of a circle.

- In the 'mass' cells, record the value of the total mass stacked on the top of the apparatus in kilograms. Include the mass of the piston and the wooden top in every measurement.

- If unequal masses are used, measure the masses individually, and mark them. Then, find the total mass on the apparatus by adding the values of all masses on the apparatus. For example, if two masses are on the apparatus, one with a mass of 1 kg and one with a mass of 2 kg, you would record a mass of 3 kg in the cell that is under the 'mass' column, and in the '2 mass' row.

- To find the force applied to the apparatus by the masses, multiply the amount of mass stacked on the apparatus by 9.8. This will give you the force applied to the apparatus in the correct units (Newtons).

- To find the pressure of the air inside the syringe, divide the force applied by the masses stacked on the apparatus (in the 'force' column) by the area of the syringe. This result will be in pascals (Pa); divide this result by 1000 to obtain a result in kilopascals (kPa).

- Before stacking masses on top of the apparatus, record the initial volume of the air in the syringe.

- When performing this experiment, add one mass at a time to the top of the stack, and record the new volume of the air in the syringe after adding the mass. Repeat this procedure until no more mass can be added without risking damage to the apparatus; four or five 2 kilogram masses can be stacked on the top of the apparatus before reaching this point. After reaching this point, remove one mass at a time from the top of the apparatus, and record the new volume of the air in the syringe each time.

DATA TABLE FOR RECORDING PRESSURES AND VOLUMES

# of Masses on Apparatus	Area of Syringe (m^2)	Mass (kg)	Force applied (N)	Pressure Applied (kPa)	Volume (stacking masses) (cm^3)	Volume (removing masses) (cm^3)	PV
Initial State							
1							
2							
3							
4							
5							
6							