The Gas Laws

For more than 100 years, the kinetic molecular theory has served as the foundation for explaining the physical behavior of gases. According to this theory, gases are composed of atoms or molecules that are in constant straight-line motion. The molecules of a confined gas collide with the walls of the container, as well as with each other. The collisions are assumed to be perfectly elastic—that is, no energy is gained or lost in the process. When molecules collide with the walls of a container, they exert a force on those walls. The force is directly related to the velocity at which the molecules strike the walls. The combined force of all molecular collisions with the walls divided by the total area that is being struck is the pressure that is exerted by the gas.

In the seventeenth century, Robert Boyle investigated the relationship between the volume of a confined gas and the pressure it exerted upon its container. He found that these variables were related as an inverse function. He expressed this function using the formula $P \times V = k$ (for a constant number of moles at constant temperature). This relationship can be explained in terms of the kinetic molecular theory. As the volume of the gas is decreased, more collisions occur per unit area of the container walls, thus increasing pressure. Similarly, when the volume is increased, fewer collisions occur per unit area, and a subsequent drop in pressure is observed.

More than 100 years later (in 1787), Jacques Charles observed a relationship between the volume of a gas and its temperature. He found that, as a sample of gas was heated, its volume increased. In terms of the kinetic molecular theory, as a gas is heated, its molecules move at a greater velocity and are capable of occupying a larger volume. Charles's work led to the formulation of the absolute temperature scale, a measuring system based on a more direct relationship between molecular motion and temperature.

In this experiment, you will duplicate the results observed by Charles and Boyle. A confined gas volume will be subjected to stresses in pressure and temperature. The resulting changes in volume will be recorded. You will then plot these results and extrapolate the graph to find the volume that corresponds to zero on the absolute temperature scale.

OBJECTIVES

1. to observe the effect of increasing pressure on the volume of a confined gas
2. to observe the effect of increasing temperature on the volume of a confined gas
3. to plot a volume-temperature graph from the collected data and extrapolate the graph to find the volume of a gas at absolute zero

MATERIALS

Apparatus

- gas piston-cylinder assembly with block supports
- 60-cm^3 syringe with end cap
- ruler (mm)
- 5 weights
- 2 utility clamps
- ring stand and ring
- wire gauze
- beaker (600-mL)
- thermometer inserted into rubber stopper
- laboratory balance
- kilogram scale (for class)
- laboratory burner
- barometer (for class)
- safety goggles
- lab apron

PRELAB

Answer questions 1-10 on the Report Sheet.

PROCEDURE

Part I

1. Put on your laboratory apron and safety goggles.
2. Measure the barometric pressure of the room and record this value in Part I of the Report Sheet.
3. Obtain a gas piston-cylinder with block supports. Separate the piston-cylinder component, shown in Figure 7A-1, from the rest of the assembly. Remove the cylinder cap, then separate the piston from the cylinder, and measure the internal diameter of the cylinder. Record the measurement on the Report Sheet.
4. Measure the mass of the piston plus the upper support block. (See Figure 7A-2.) Record this value on the Report Sheet.
5. Reassemble the piston cylinder. Fill the cylinder to a volume of 30 cm^3 with air.
6. Replace the cap and assemble the support system as illustrated in Figure 7A-2. NOTE: Firmly tighten, but do not strip, the wing nuts.
7. Label five weights *A* to *E*. Determine the mass of each weight using the kilogram scale. DO NOT use the laboratory balance. Record these values in Part I of the Report Sheet.
8. Place weight *A* on the upper support block of the gas piston. Record the volume of confined gas in Part I of the Report Sheet.
9. Increase the number of weights, one at a time, and record each subsequent gas volume. Continue until a maximum of five weights have been stacked.

HAZARD

CAUTION: Due to the instability of the stack, one member of the lab team should continually support the bricks.

CAUTION: Thermometers are fragile glass instruments that can break, leaving sharp edges. If the thermometer breaks, call your teacher. Do not touch the mercury or any pieces of glass.

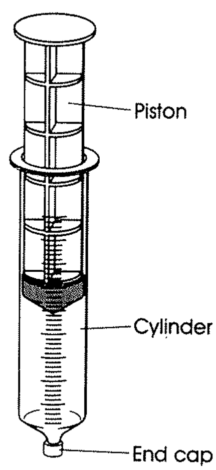

Figure 7A-1

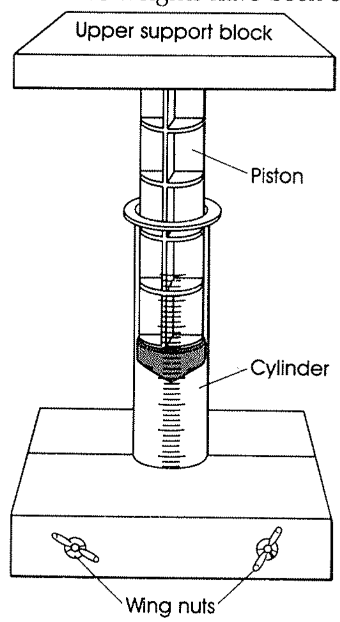

Figure 7A-2 *Assembled gas cylinder-piston system.*

Part II

1. Remove the end cap of 60-cm^3 syringe and fill the cylinder to a volume of 20 cm^3 with air.
2. Replace the cap and secure the syringe within a utility clamp. NOTE: The volume scale should not be obscured by the clamp.
3. Obtain a thermometer inserted into a stopper.

4. Add approximately 400 mL of water at room temperature to a 600-mL beaker.
5. Assemble the apparatus as shown in Figure 7A-3. Lower the syringe far enough into the water so that at least 30 cm^3 of air in the syringe will be below the water surface. Lower the thermometer to a point at which the bulb is about even with, or slightly above, the midpoint of the column of air in the syringe, in order to obtain a temperature that accurately represents that of the contained air. Secure the thermometer in place with a utility clamp placed around the rubber stopper. The syringe and the thermometer should not touch each other, and neither should touch any part of the beaker.
6. Wait several minutes and record the gas volume and solution temperature on the Report Sheet. Gradually heat the water bath.
7. For every 20°C rise in water temperature, record the gas volume and temperature in Part II of the Report Sheet. Continue until the boiling temperature is reached and record the final volume of the air in the cylinder on the Report Sheet.

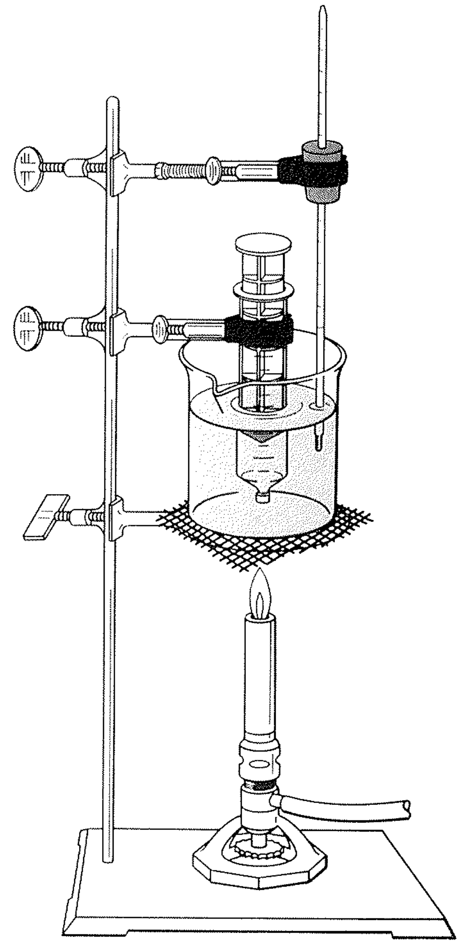

Figure 7A-3

POST LAB DISCUSSION

In Part I, the total force acting upon the confined air volume when no weight is on the block is equal to the sum of the atmospheric pressure and the weight of the upper support block and piston. The downward force (weight) exerted by any object is equal to the product of its mass and the acceleration due to gravity (9.81 m/s^2). To determine the contribution of the block and piston assembly, the weight of this unit must be divided by the surface area in contact with the confined air volume. Since the internal diameter of the cylinder has been measured, the area in contact with the piston may then be derived using the formula, $A = \pi r^2$.

$$\text{System pressure acting upon gas in cylinder (no weight)} = \text{Atmospheric pressure} + \frac{\text{Mass of piston-block assembly} \times 9.81\ m/s^2}{\text{Effective piston area} \times m^2/10^4\ cm^2} \times \frac{10^{-3}\ kPa}{Pa}$$

Once the force exerted by each weight (mass x acceleration due to gravity) is determined, this value must be divided by the surface area in contact with the confined air volume to obtain the weight's effective system pressure. The sum of the appropriate brick pressures is then added to the total "no weight" pressure to obtain the total pressure acting upon the system.

To properly illustrate the relationship between temperature and volume, the Celsius temperatures (t) in Part II must be converted into kelvin temperatures.

$$T = t + 273$$

Once the conversion is complete, the temperature may be plotted against volume. The resulting graph may be extrapolated to find the volume occupied by a gas at zero kelvins. It should be remembered that the gas laws describe the behavior of an ideal gas. Among other things, an ideal gas is assumed to consist of molecules that occupy zero volume, and this will be reflected in the temperature-volume plot.

The Gas Laws

Name____________________
Class __________ Date __________

EXPERIMENT 7A REPORT SHEET

PRELAB QUESTIONS

1. State Boyle's Law in your own words.
2. Give the equation that describes the relationship between temperature and volume.
3. What is meant by the term "elastic collision"?
4. In Part II, at what temperature will the final reading be taken?
5. Why should caution be used when stacking the brick weights?
6. In Step 5 of Part II, why should the thermometer bulb be lowered to a point at which the bulb is even with, or slightly above, the midpoint of the column of air in the syringe?
7. Prior to drawing air into the cylinder in Part I, what must be done?
8. What is meant by the word "extrapolation"?
9. What should you be aware of while securing the 60-cm^3 syringe into a utility clamp?
10. How do you convert Celsius temperatures into kelvin temperatures?

OBSERVATIONS AND DATA

Part I

1. Barometric pressure (convert to kPa)
2. Internal diameter of cylinder (cm)
3. Internal radius of cylinder (diameter/2)
4. Area of cylinder/piston interface (cm^2)
5. Mass of piston-block assembly (kg)
6. Weight of piston-block assembly ($kg\cdot m/s^2$)

7. Pressure exerted by piston-block assembly (convert to kPa) ______________________

8. Sum of barometric and piston-block pressure (kPa) ______________________

9. WEIGHT	MASS (kg)	WEIGHT ($kg \cdot m/s^2$)	PRESSURE (kPa)
A			
B			
C			
D			
E			

10. NUMBER OF WEIGHTS	VOLUME OF CONFINED AIR (cm^3)	TOTAL PRESSURE (kPa)	$k = PV$
0			
1			
2			
3			
4			
5			

Part II

TEMPERATURE (°C)	VOLUME OF CONFINED AIR (cm^3)	TEMPERATURE (K)

CONCLUSIONS

1. Plot the system pressure against the volume of contained gas (from the data table in Part I, item 10 of the Report Sheet) on the grid provided.
2. What type of relationship does this graph illustrate? Explain. ______________________

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3. On the grid provided, plot the kelvin temperature against the volume of confined gas (from the data table in Part II of the Report Sheet).
4. What type of relationship does this graph illustrate? Explain. ______________________

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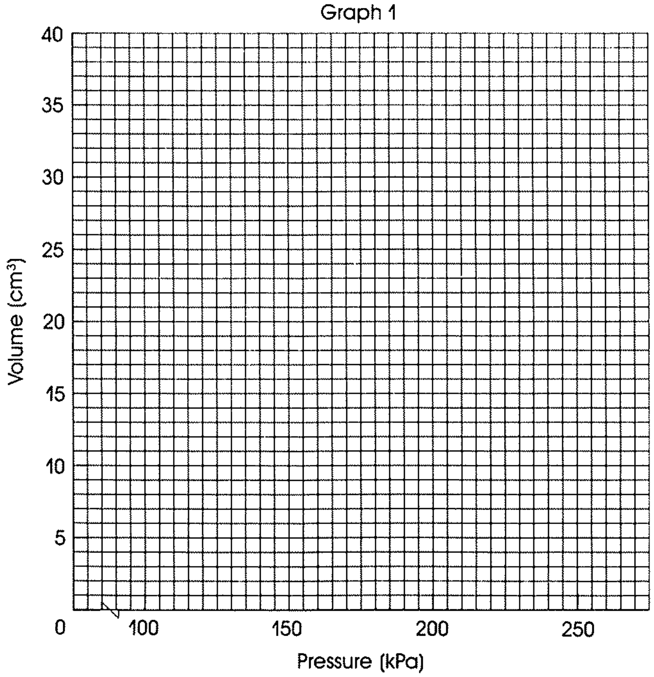
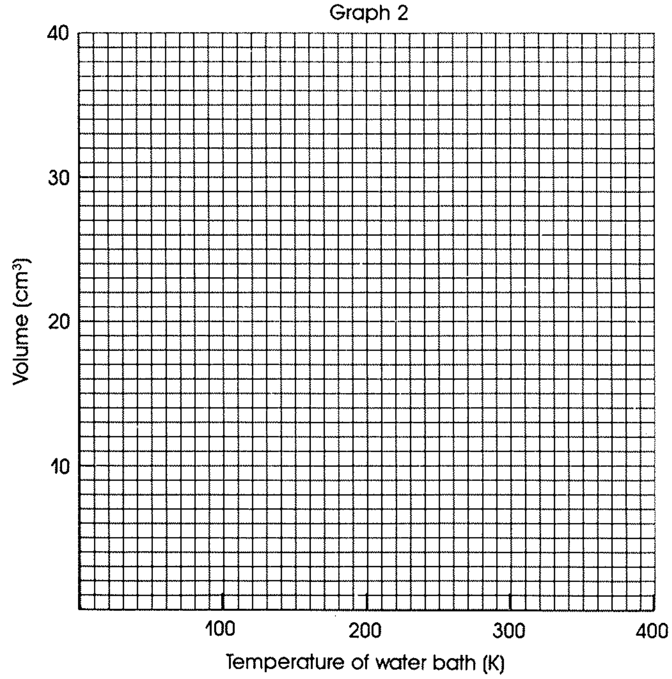
Graph 1



Graph 2



5. Extrapolate the graph to find the volume at zero kelvins. ______________ cm^3

6. Why must the zero-kelvin value be obtained by extrapolation instead of direct observation?

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SYNTHESIS

1. If a helium-filled balloon is released at the Earth's surface, what is its eventual fate? Why? ___

2. Aerosol spray cans should never be thrown into fires or disposed of in incinerators. Explain.