Elasticity of Gases Apparatus

P1-2075

CONTENTS:

One wooden base
One wooden top
One small plastic cap
One syringe with piston
One packet of silicone grease

RECOMMENDED ACCESSORIES:

One Ring stand and clamp(s)
One Beaker (250mL)
One Thermometer
Several uniform masses (books or weights)
Ice

ASSEMBLY:

1. Place the large wooden base on a firm surface with the larger hole down.
2. There should be no small plastic cap on the end of the syringe at this point. Pull the plunger completely out of the syringe. Use the silicone rubber grease to lubricate the entire side wall of the black rubber plunger.
3. Press the syringe body into the hole on the top side of the base.

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4. Press the top end of the syringe plunger into the hole in the wooden top. (Thin wooden block.)

5. Reassemble the syringe.

6. Draw a measured volume of air into the syringe and **press the small plastic cap over the nozzle end of the syringe under the large block.**

You are now ready to perform experiments with Boyle's law. To expel air or gas from the syringe, first, remove the small plastic cap from the end of the syringe and push in on the piston. **Be careful not to tear the cap or distort its shape by the careless use of pliers.** Replace the small plastic cap.

Boyle's Law

Given any gas in a state of thermal equilibrium we can measure its pressure *p*, temperature *T*, and volume *V*. Experiment shows that for a constant temperature, the volume of the gas varies with the pressure applied to the gas. Robert Boyle, a British physicist, studied this phenomenon in 1662 and found that there was a specific relationship between pressure and volume and that it was the same for all types of gases. To determine what this relationship is, we will look at the compressibility of gas.

With the assembled apparatus, draw approximately 30cc of air into the cylinder and cap the end. Stack several equal weights carefully on the top block of the apparatus. You can use several copies of the *same* textbook for this. **When stacking weights, keep centered and do not exceed 30 lbs.** Record the volume of the gas as indicated on the scale of the syringe. Before reading the scale on the syringe, tap the table or the top of the apparatus a couple of times to help overcome the static friction between the piston and the syringe walls.

Record the weight and corresponding volume for as many values as possible. After all of the weights are stacked on the apparatus, unstuck them one at a time and record the volumes again. Use this data as trial #2. Plot each of these and the averaged data on graph paper, plotting the number of weights (which is proportional to the pressure) on the independent axis and the volume on the dependent axis.

How does the volume depend on the pressure? Is the plot linear: Try making a new plot with 1/(weight) plotted on the independent axis. Is this plot linear? It should be close to linear with the exception of the points that correspond to one or two weights. Can you explain why these points do not fit the curve? Any plot of data that is a straight line says that the two parameters are directly proportional.

Therefore, the volume is directly proportional to 1/pressure (since pressure equals force times area and the area of the piston is constant). Mathematically, this can be written:

$V \propto \frac{1}{p}$ where $\propto$ means "is proportional to."

This is Boyle's law. Under conditions of constant temperature, volume varies inversely with pressure. Try repeating this experiment using different gases.

Charles' Law:

You have discovered how equal changes in pressure affect equal volumes of gases. Can you predict how equal changes in temperature affect equal volumes of gases?

Heat approximately 200mL of water in a 250mL beaker. A larger beaker may be easier for students to use. Remember it is necessary to have enough water in the beaker to cover the portion of the syringe that holds the trapped volume of air. Bring the water to about 90˚C.

Remove both wooden blocks from the syringe, draw 20cc of air into the syringe then place the cap on the syringe nozzle. Place the thermometer in the beaker of hot water. Hold the syringe by its top and push the portion of the syringe containing the trapped volume of air under the hot water. Wait a few minutes for the air in the cylinder to equilibrate, then measure the volume shown on the syringe scale. When measuring the volume of the trapped air, it is helpful to quickly push the piston down and then release it. The measured volume in this case will be larger. Again, this is due to friction between the piston and cylinder wall. The actual volume will be the average of these two measurements.

Allow the beaker of water to cool by 10˚C and make a new volume measurement. Repeat this procedure of cooling by 10˚C and measuring the volume until you've covered the range from about 60 or 70˚C to 0˚C. From 30˚C and lower it may be necessary to add small pieces of ice to help bring the temperature down, or place the beaker in a container of crushed ice.

Plot your data points on a graph with volume as a function of temperature. Are the results of your experiment consistent with your prediction? Can you summarize the findings of your experiment in a general statement similar to the method used in Boyle's law? Remember, if the plot is linear, it represents a direct proportionality and can be written as

$V \alpha T$ where $\propto$ means "is proportional to."

Ideal Gas Law:

The concept of "proportional to" can be changed to "equal to" by introducing a constant of proportionality.

First, we must combine the two laws by saying that volume is proportional to both the temperature and 1/pressure.

$V \propto T$ and $V \propto \frac{1}{p}$ combine to $V \propto \frac{T}{p}$

Then, we can replace the proportionality with equality and a constant.

$pV = constant \bullet T$ or $\frac{pV}{T}$ is a constant for any particular gas sample

And

$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$ when conditions of the sample change, allowing one to solve for any single unknown.

The constant referred to above is related to the mass of gas in the cylinder and is given a value calculated as the number of moles of gas (n) times the universal gas constant (R), found in most physics textbooks. By making this substitution, we have constructed the ideal gas law:

$$pV = nRT$$

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RELATED PRODUCTS:

Pressure Pumper (P1-2050) and **Pressure Pumper Kit** (P1-2060). Attach this pump to the top of a soda bottle and pump up the pressure on the bottle contents. Kit includes temperature strips and lessons.

Vacuum Pumper and Chamber (P1-2140) and **Vacuum Pumper Set** (P1-2160). This hand-powered vacuum pump works on glass bottles or the specially designed wide-mouth chamber. Test the effect of lowered pressure on objects and liquids.

Cartesian Diver (P1-2000). Use the elastic properties of air for this classic diving demonstration.

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