Gay-Lussac's Temperature and Volume Changes in a Gas (Charles's Law)
Teacher Activity

Procedure

Advance Preparation

1. Prepare the capillary tubes for the students in advance to ensure that the oil plug is at a good position at room temperature. To get the oil into the tube, first heat the capillary tubes in an oven that is set at about 120°C. Bind the tubes together with string or wire and place in the oven for 30 minutes. Quickly plunge the bundle of tubes, open end down, into a petri dish of #30-weight motor oil for about 15 seconds or until the oil moves into the tube to a height of 1 cm. (Do not use any lighter-weight oil or the column may break up at higher temperatures.) Lay the tubes on paper towels to cool. You may have to try this technique several times to get plugs into every tube at the correct height. The column of trapped air within the tube should be between 5- and 10-cm long once the tube has cooled. (Note: Gay-Lussac used larger glass tubing with mercury plugs: visit the Gay-Lussac museum site to see a schematic of his setup; students might enjoy seeing that what they did in their experiment was originally done by this historical figure some 200 years ago–priceless!)
2. Set up distribution points for hot water and ice. The easiest way to heat water is to use a regular kitchen electric water pot.
3. A data sheet for collecting could be provided for students as a guide.

Data Analysis and Concept Development

Gas Column Temp.	"Degree" or Ruler Reading (Bottom of Plug)	Change in "Degree" (Ruler) Reading of Plug	Change in Gas Column (mm)	Total Length of Gas Column (mm)	Change in Water Temp. (°C)

Safety

- Students should wear safety goggles at all times.
- Students should be aware of and handle carefully the hot water baths.
- Students should be aware of and handle carefully the glass capillary tubes so that they do not splinter in their hands.

Student Skills Required

Students should have basic math skills, including graphing, and should be able to work accurately with an analog thermometer (if used). Students need to understand the concepts of direct and indirect relationships between sets of data, ratios, and the idea of a slope from a graph (a constant).

Student Misconceptions

1. *If a confined volume of gas expands when heated, it means that there are more gas molecules present.*
   Measurements of the mass of gas before and after heating would show no change in mass. Demonstrate by heating a pre-massed flask with a balloon attached; repeat the mass determination immediately after heating the flask to expand the balloon.

2. *If a gas volume expands with a temperature increase, the increase in volume is due to the expansion of the individual gas molecules.*
   Since a volume of gas is mostly empty space, expansion of the individual molecules would not produce the proportional increase in volume that occurs when the Kelvin temperature is doubled: that is, doubling of the temperature causes a doubling of the gas volume. It is also possible to talk about the volume of a mole of any gas and calculate the volume of that same gas if it is changed to a liquid. The volume of a gas in a liquid state would, of course, be different; the liquid would still have some space between the particles, but that space would be significantly reduced.

3. *Gases do not have any weight.*
   Students could determine the mass of gas in a plastic bag or a large balloon by first massing an empty bag or balloon, then filling it with room air (plastic bag) or exhaled air (balloon) and massing again. Discuss with the students the fact that the filled bag or balloon, when placed on a balance, is buoyed up by the volume of air displaced by the bag. This volume of displaced air has a mass. Therefore, the mass of the air in the bag measures less if there is a buoyant effect (objects submerged in water are easier to lift while in the water). For a liter of air displaced, the buoyant effect is relatively small. But there are data that can be used to find a value for the buoyant effect, in grams, that is added to the mass of the bag of air. At standard air pressure and 25°C, a liter of displaced air has a mass of 1.19 grams. This mass of displaced air has to be added to the measured mass of air in the bag. (You would subtract the mass of the empty bag or balloon from the mass of the bag plus air to get the mass of air alone.)

4. *Gases with different particle masses (but the same volume) will produce different volume changes for a given temperature change.*

   Refer to the explanation for Misconception 2.

Answers to Pre-Lab Questions

1. What do you predict would happen to a confined gas volume if it is heated? Cooled?

The gas volume would not change when heated or cooled if the container is rigid or nonexpandable. If one were to measure the pressure of the gas, it would increase when the gas volume is heated and decrease when the volume is cooled.

2. What if the gas volume is confined to an expandable container? What would happen to the gas volume if it is heated? Cooled?

If the container is expandable, heating or cooling the gas would cause the volume of the container to increase or decrease, respectively.

3. How would the kinetic-molecular theory of gases explain the predicted changes occurring in either question 1 or 2?

If gas particles are heated, it means that they have gained additional kinetic energy, which translates into the particles striking the surface more frequently, causing an expansion in the gas volume or an increase in pressure when the container is nonexpandable (rigid). The opposite is true when a gas is cooled: kinetic energy is reduced, and collisions per unit of time with the container wall also decrease.

4. Would you expect the relationship between temperature and volume changes to be constant?
If the volume changes are directly related to the kinetic energy changes in the gas molecules, then one would expect the volume changes to be proportional to temperature change. Would they be constant? Check the data after doing the laboratory exercise!

Answers to Post-Lab Questions

1. Since we are talking about the volume of the trapped air (gas), how does measuring the length of the three-dimensional tube give us a volume? Do we have to calculate a volume of gas inside the tube? Explain.
Since the volume of the gas trapped in the tube could be calculated knowing the diameter of the tube and its length ($V = \pi \times r^2 \times l$), the only variable in the tube's volume would be length as the trapped air expands or contracts, with the diameter remaining constant. Therefore, the gas volume is proportional to the length of the tube, and the change in volume would be directly related to a change in length. So a unit of length can represent the volume of gas at whatever temperature. There is no need to calculate the volume of gas inside the tube in order to have volume data for each temperature at which it (the length of the tube) is measured.

2. Analyze your temperature and "volume" data. What trend is noticeable?
The data points suggest that as temperature increases, so does volume. As temperature decreases, so does volume. There is a direct relationship.

3. Compare your data with another team. Are the trends the same? Different?
They should be.

4. Graph your data.
The data when graphed should suggest a straight-line relationship.

5. What kind of relationship is suggested by the points on the graph? Is the trend a straight line or some kind of curve?
The relationship should be a straight line.
Is there a way to express the relationship between changes in temperature and corresponding volume change? What is the relationship?
If there is a straight line as best fit for the graphed points, then a slope can be calculated to show a constant, which is the relationship between temperature and corresponding volume.

6. Can you extrapolate about changes in volume of the gas when the temperature goes below zero?
Using the data points and a best-fit line, the line can be extended below 0°C.

7. Does the trend in the graph suggest that there is a temperature at which there is no volume for the gas? **Yes.**
Does this make sense? **Yes.**
What would be the physical state of the gas when it has zero volume?
It is assumed that as temperature decreases, the kinetic energy decreases until the particles are no longer in motion as a gas, hence in a liquid or solid state. It is possible to show with measurements at what temperature a gas becomes a liquid or solid, with the volume representing the gas decreasing dramatically to a zero point.

8. How would you use the graph to determine the temperature at which the volume of the gas is zero? Try it! (Consult with your partners.)
Using the data points, you can extrapolate a straight line until you reach zero volume with a corresponding temperature (ideally at $^{-}273$°C).

9. If your data on the graph suggest a straight-line relationship, then a slope can be calculated. How can you use this slope if the temperature is zero or a negative value (from extrapolation)? How can you change the graph to get away from negative temperature values (and 0°C)?
   If you have a straight-line relationship between temperature and volume on the graph, then the relationship can be expressed by a slope value. However, when you reach 0°C on the graph, the slope value cannot be calculated. To remove both zero and negative temperatures on the graph in order to do slope calculations (which gives a ratio that allows one to calculate a new volume at a new temperature compared with a previously measured volume and temperature), the axis for temperature can be recalibrated starting with the temperature at which the gas volume in your experiment is zero. If this temperature is made zero and all other temperature units above this zero value are given positive values, then any volume will correspond with a positive temperature in the same proportion as previously (the points used on the original graph above 0°C). Because the new temperature scale you established on your graph does not have any negative values, it is an "absolute" scale, the term used in the same way as in matclass (all positive values). And the zero point on this new temperature axis is known as absolute zero.

10. According to your graph, what is the proportional change in volume for every degree-change Celsius?
   1/273.

11. If you renumber the units on the Celsius temperature axis, starting with absolute zero, what is the range of absolute units from absolute zero to the equivalent of 0°C?
   The range is 273 units.

12. How could you mathematically convert any Celsius temperature value to an absolute temperature value (consult your graph with both the Celsius and absolute temperature units).
   Using a few temperature points on the graph, going from zero absolute (–273^{o}C) to an absolute temperature corresponding to 0^{o}C, there is a change of 273 degrees. Going from 0^{o}C to 100^{o}C means going from 273 absolute to 373 absolute. So adding 273 to any Celsius temperature gives an absolute temperature. In reverse, subtracting 273 from an absolute temperature gives a Celsius temperature. In chemistry parlance the word *Kelvin* is substituted for absolute since a physicist of the mid-19th century, William Thomson (later known as Lord Kelvin), worked with the same temperature and volume data for gases as you have done. And he first suggested extrapolating the data back to a zero pressure (as opposed to volume) and making all temperature values positive or absolute. He also suggested that the data and extrapolated line on this graph with an absolute temperature axis would apply to the expansion of an ideal gas–an imaginary model gas in which there is no attraction or repulsion between gas particles. The gas particles do not occupy any volume themselves!

Assessment

1. Using the methods in this lab for collecting data, provide new data from which students would determine variable volumes at various temperatures; determine the slope of the line from the data points.
2. From the slope of the line, have students determine a new volume at a specific temperature, preferably in the negative range, Celsius. (The key point is for students to first convert temperature to the Kelvin scale.)
3. Absolute zero implies the absence of any thermal activity (molecular motion). Students could investigate the implications of this on particle motion within the atom. In addition, research into the world of superconductivity is related to finding ways to reduce random motion of electrons within the atoms of superconductive materials. The chemical

composition of these materials and the rationale for such is worth investigating, as is the application of superconductivity (example: maglev trains).

Additional Teacher Resources

1. A Web site for the Gay-Lussac museum at his country home includes, among other things, photos of some of Gay-Lussac's equipment (choice of English language for tour) and a diagram of his equipment for measuring temperature-volume data (http://apella .ac-l imoges .fr/musee-gaylussac/Gay-Lussac-en . htm).
2. Charles's law (Gay-Lussac setup) can be done on a macro scale, using a 125-mL Erlenmeyer flask, with a water manometer attachment (rubber tubing attaching a vertical glass tube [clamped] to the flask). The flask is immersed in a water bath that can be heated and cooled. Add a water "bubble" marker within the tube to show expansion and contraction of the flask air volume. The volume of air in the flask is determined by filling the flask, then emptying it into a graduated cylinder. The flask used in the experiment must be dry. Changes in the volume of the air in the flask are indicated by the change in the position of the water marker within the glass tube as done in the micro-scale experiment.

References

1. Good history of chemistry book: Cathy Cobb and Harold Goldwhite, *Creations of Fire (Chemistry's Lively History from Alchemy to the Atomic Age* (New York: Plenum Press, 1995). Includes references to Jacques Charles and Lord Kelvin in their work related to Gay-Lussac.
2. An original paper of Gay-Lussac describing his procedures for collecting data on expanding gases (translated from the French) can be found at the following Web site, which has many articles on the history of science and its participants (http://web.lemoyne.edu/~giunta/gaygas.html)
3. A short article about the many scientific activities of Gay-Lussac in the context of the early 19th century can be found in the Spring 2007 issue of *Chemical Heritage* magazine, pp. 40−41.