

Student Activity

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

Companion Web pages: <http://www.chemheritage.org/classroom/chemach/gases/index.html>

Introduction and Historical Context

Lord Kelvin (1824–1907), born William Thomson, was involved in studies of the nature of heat and its measurement. In trying to find a better instrument for measuring temperature that did not use expanding and contracting liquids, he found that using confined gas volumes produced more accurate results. He collected data on temperature and the corresponding pressure of a confined gas. Graphical analysis showed pressure decreased to zero at a temperature of -273.15°C , no matter what gas was used. Kelvin suggested using this temperature as an absolute zero, making all higher temperatures positive and allowing one to relate any pressure (or volume) to this absolute temperature as a ratio. This maneuver allowed for calculations without having any negative values or zero in the temperature data. Eventually the temperature units were named kelvins and the scale was called the Kelvin scale.

Jacques Charles (1746–1823) also worked with volume changes of a gas owing to temperature variations. He originally suggested a direct relationship between these two variables affecting a gas. But his work was not careful enough (the water vapor was not removed), which produced inconsistent results, although a relationship was still proposed between temperature and volume of a gas. Fifteen years later, Joseph Louis Gay-Lussac (1778–1850) provided better data to confirm Charles's ideas. When Gay-Lussac published his work, he referred to Charles (his ballooning friend) and his earlier experimentation. (See reference listings for his original paper, translated from the French.) An English author, Peter Tait, came across Gay-Lussac's reference to Charles and gave priority to Charles, hence the relationship known as Charles's law. Strangely enough, Charles himself thought the volume-temperature relationship to be false! (See reference listing *Creations of Fire*, Cobb and Goldwhite, p. 207.) Later, working with Alexander von Humboldt, Gay-Lussac studied reacting volumes of gases, starting with the hydrogen-oxygen reaction from which Gay-Lussac proposed his law of combining volumes.

The series of biographies in the "Theory and Production of Gases" section of *Chemical Achievers* describes Gay-Lussac's work and that of other scientists who explored the characteristics of gases (<http://www.chemheritage.org/classroom/chemach/gases/index.html>).

Purpose

This lab activity will teach you to determine the mathematical relationship between the volume of a confined gas at different temperatures (with constant pressure).

Safety

- Wear safety goggles at all times.
- Be aware of and handle carefully the hot water baths.
- Be aware of and handle carefully the glass capillary tubes so they do not splinter in your hand.

Materials and Apparatus (for 24 students working in pairs)

Non-consumables

- 12 analog thermometers
- 24 capillary tubes (4-mm tube, 12 to 14 cm in length)
- 12 centimeter rulers
- 24 beakers (400 mL)
- 24 rubber bands (small, to fit around thermometer and capillary tube together)
- Heat source (electric preferred) for large volume of hot water at a distribution point

Consumables (see advanced preparation)

- Ice
- 250 mL of #30 *non*-detergent motor oil (or mineral oil with dye added; also dibutyl pththalate)

Pre-Lab Questions

1. What do you predict would happen to a confined gas volume if it is heated? 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?
3. How would the kinetic-molecular theory of gases explain the predicted changes in either question 1 or 2?
4. Would you expect the relationship between temperature and volume changes to be constant?

Procedure

1. Attach a prepared capillary tube (with liquid plug) to a plastic ruler, using two rubber bands. Adjust the position of the tube so that the trapped air column within the tube will be completely immersed in the beaker of water (water bath). The capillary tube, when placed in the water bath, should not go below the water level since the tube is open at the top.
2. Prepare a 400-cm³ beaker with water that is about half full. Place this beaker on the base of a ring stand. Using a utility clamp and a one-hole stopper, attach your thermometer above the beaker. Test to make sure the thermometer (analog or digital) can be lowered into the beaker so that the recording part of the thermometer (the tip) can be fully immersed.
3. Using the ruler with capillary tube attached, measure the length of the air column trapped by the liquid plug. Note the temperature of the thermometer before it is immersed in the water bath.
4. Add some ice to the water bath and lower the ruler with the capillary tube into the ice-water mix. Allow several minutes for the temperature to stabilize. Record the length of the air column and the temperature of the water bath.
5. Remove the ruler–capillary tube from the water bath and allow it to warm to room temperature. Empty the water bath of its cold water. In the meantime obtain some preheated hot water (the temperature should be above 50°C).
6. Add the hot water to the empty beaker using enough water to allow the air column in the capillary tube to be covered by the water (but make sure the top of the tube is just above water level since the top is open).
7. Adjust the water temperature to around 50°C. Immerse the capillary tube so that the air column below the liquid plug is completely covered by the warm water. Record the temperature of the water and the length of the air column. Repeat these measurements each minute for several minutes.
8. Repeat steps 6 and 7, using hot water that has a temperature around 75°C; record the temperature and the length of the air column. Repeat the measurements each minute for several minutes.
9. Repeat steps 6 and 7, using water that has a temperature between 90°C and 100°C.
10. Remove the ruler with the capillary tube still attached, and place it on several thicknesses of paper towel on the lab bench. Allow the apparatus to cool in the air, recording the air column length and corresponding temperatures for at least 5 measurements as the apparatus cools from about 90°C to room temperature, which was recorded in step 3.

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.
2. Analyze your temperature and “volume” data. What trend is noticeable?

3. Compare your data with another team. Are the trends the same? Different?
4. Graph your data.
5. What kind of relationship is suggested by the points on the graph? Is the trend a straight line or some kind of curve? Is there a way to express the relationship between changes in temperature and corresponding volume change? What is the relationship?
6. Can you extrapolate or talk about changes in volume of the gas when the temperature goes below zero?
7. Does the trend in the graph suggest that a temperature exists at which there is no volume for the gas? Does this make sense? What would be the physical state of the gas when it has zero volume?
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.)
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)?
10. According to your graph, what is the proportional change in volume for every degree-change Celsius?
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?
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)?

Extension Questions

1. Explain why, in terms of graph extrapolation, the temperature at which a gas has zero volume is known as absolute zero. (Hint: What does the word *absolute* mean in mathematical terms?)
2. Would different numbers of moles of a gas sample follow the same graphical line (temperature vs. volume)? Explain.
3. Would the same number of moles of several different gas samples follow the same graphical line (temperature vs. volume)? Explain.
4. According to your graph, in which you are using the absolute temperature scale (also called the Kelvin temperature scale after Lord Kelvin), a temperature change of 1 degree absolute (or Kelvin) is equivalent to a change of how many degrees Celsius? (Refer to your graph with the absolute and Celsius temperature axis; see Post-Lab Question 9.)