Charles' Law

Strand	Phases of Matter and Kinetic Molecular Theory	
Topic	Investigating Charles' law (volume-temperature relationships)	
Primary SOL	CH.5	The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include a) pressure, temperature, and volume.
Related SOL	CH.1	The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include a) designated laboratory techniques; b) safe use of chemicals and equipment; e) accurate recording, organization, and analysis of data through repeated trials; f) mathematical and procedural error analysis; g) mathematical manipulations including SI units, scientific notation, linear equations, graphing, ratio and proportion, significant digits, and dimensional analysis; h) use of appropriate technology including computers, graphing calculators, and probeware for gathering data, communicating results, and using simulations to model concepts.

Background Information

Among the important gas laws are Charles' law, Boyle's law, and Avogadro's law.

- **Charles' law** describes the directly proportional relationship between temperature and the volume of a gas.
- **Boyle's law** describes the inversely proportional relationship between the absolute pressure and the volume of a gas.
- **Avogadro's law** states that under the same condition of temperature and pressure, equal volumes of all gases contain the same number of molecules.

The three laws together make up the **ideal gas law**.

Materials

- Ring stands
- Rings and wire gauze
- Bunsen burners
- Tubs of cool water
- Goggles
- Protective gloves
- Empty soda cans
- Water
- Graduated cylinders

- Beaker tongs
- Beakers large enough to provide water baths for Erlenmeyer flasks
- 125 mL Erlenmeyer flasks
- Hot plates
- One-hole stoppers to fit Erlenmeyer flasks
- Short glass tubes to fit in stoppers
- Temperature probes or thermometers
- Large graduated cylinders

Vocabulary

atmospheric pressure, Kelvin temperature, molar volume, pressure

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

Introductory Activity

The following is a brief investigative activity to get students thinking about the relationship between temperature and volume.

1. Have each lab team set up a ring stand with a ring and wire gauze. Direct them to place a Bunsen burner under the wire gauze. Also, have them place a tub of cool water near the ring-stand-burner setup.
2. Have students don safety equipment, such as goggles and protective gloves. Have each team place an empty soda can containing 10 mL of water on the wire gauze and then light the burner. While the water in the can is heating, ask students the following questions:
   - What is happening to the water in the can? What phase change is occurring?
   - What would occur if you were to seal the can and drop the temperature outside the can quickly? Why?
3. After the water in the cans begins to boil, releasing steam, direct each team to use a pair of beaker tongs and protective gloves to pick up the can and very quickly in one fast motion, turn the can upside down in the tub of cool water, being sure the top of the can is completely submerged so the hole in the top is under water. (The can will collapse with a sudden thud.)
4. Hold a class discussion on what occurred before, during, and after the cans were submerged.

Quantitative Activity for Demonstrating Charles' Law

In the following investigation, students heat the air inside a flask and then cool the flask in a tub of cool water, which in turn cools the air inside the flask. As the air cools, it decreases in volume, and water is drawn into the flask to replace the air-volume decrease. The amount of water drawn in equals the decrease in air volume that resulted from the decrease in temperature.

1. Have each lab team place a beaker one-third filled with water on a hot plate (or on a ring stand with a ring and wire gauze over a Bunsen burner). Direct them to fit a one-hole stopper with a short glass tube and fit the stopper into a 125 mL Erlenmeyer flask. Instruct them to support the Erlenmeyer flask in the beaker so that the flask is completely submerged in the water with the tube sticking out of the water.

2. Have each team heat the water in the beaker to the boiling point and then measure and record the water temperature, using a temperature probe or thermometer. Have them allow the Erlenmeyer flask to sit in the boiling water for several minutes to ensure temperature equilibrium between the water and the air in the flask.
3. Direct each team to use a pair of beaker tongs and protective gloves to remove the flask very quickly in one fast motion, turn it upside down, and submerge it in the tub of room-temperature water. As the air in the flask cools, it will decrease in volume, and water will enter the flask through the tube to replace it.
4. Once the air in the flask has cooled completely, have each team measure and record the water temperature, which is now also the temperature of the air in the flask. Direct each team to equalize the pressure in the flask by moving the flask up and down to a point where the water level inside is the same as the water level outside.
5. Direct teams in how to remove the flasks from the tubs and turn them upright again without losing any of the water in them. Have each team pour the water from their flask into a graduated cylinder to measure its volume, which is the same as the decrease in air volume.
6. Instruct students to plot on a graph the volume of the air at boiling temperature and the volume of the air at room temperature.

Assessment

- **Questions**
  - Would you expect the two measurements of volume and temperature to predict a straight-line graph?
  - If the graph is a straight line, what would be the expected change in volume in an ice bath (0° C)?
  - If we were to place a container of a gas in an alcohol-dry-ice bath, how could we measure the volume change? What would happen to the pressure if the volume were to remain the same by using a stopper without a hole or by inserting some type of pressure gauge in the hole?
  - If 2.5 moles of fluorine are at a temperature of 25°C and are under 275.2 kPa of pressure, what is the volume?
  - A container of oxygen at −25°C and under 8.54 atm of pressure takes up 225.0 L of space. What is the mass of oxygen?
  - At −35°C, 55 g of sulfur dioxide occupies a container that is 3.250 L in volume. What is the pressure of the gas, in torr?
  - At 825 mm Hg, a 26 g sample of carbon dioxide has a volume of 2,655 mL. What is the temperature of the sample in degrees Celsius? In degrees Kelvin?
  - At 155°C and under a pressure of 4.65 atm, a 329 g sample of an unknown noble gas occupies 62.08 L of space. What is the gas?
- **Journal/Writing Prompts**
  - Charles' law says that as temperature decreases, the volume of gases decreases. Boyle's law says that as pressure decreases, the volume of gases increases. A weather balloons is filled with helium, which is lighter (less dense) than air; thus, the balloon rises in air. Then, when it eventually loses its helium, it returns to Earth. Explain what

you think happens when a weather balloon rises in the atmosphere. Does it become larger or smaller?
- The ideal gas law contains a series of assumptions about the kinetic nature of gases. Included is the concept that collisions between particles are seen to be elastic—in other words, the atoms or molecules merely bounce off each other in different directions. Explain what happens to the atoms or molecules as they begin to approach condensation.

Extensions and Connections (for all students)

- Have students explain how the gas laws help describe our breathing at different altitudes.
- Charles' law says that gases increase in volume as temperature increases. Boyle's law says gases decrease in volume as pressure increases. Charles' law is related to the average kinetic energy of the atoms or molecules. With this information, have students explain the difficulties involved in producing a controlled fusion reaction with isotopes of hydrogen.

Strategies for Differentiation

- Have students draw what happens to a balloon when it is cooled. Then, have students actually cool an inflated balloon to test their drawn assumptions. Finally, have students show in a drawing what is happening to the molecules inside the balloon.
- Have students heat a used soda can with no more than 5 mL of water inside until steam appears. After steam appears, have students use beaker tongs to invert the can into a cold water bath. Have them draw what happens to the can and the molecules inside the can.