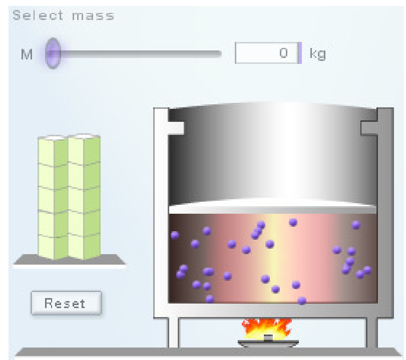
Teacher Guide: Boyle's Law and Charles' Law

Learning Objectives
Students will…

- Observe the motion of gas molecules in a closed container.
- Define pressure.
- Discover how the pressure relates to the volume of a gas at a constant temperature (Boyle's law).
- Discover how the temperature relates to the volume of a gas under constant pressure (Charles' law).

Vocabulary
absolute zero, Boyle's law, Charles' law, Kelvin scale, pressure

Lesson Overview
Boyle's law and Charles' law describe how pressure and temperature affect a gas. Unlike a liquid, the volume of a gas changes greatly in response to temperature and/or pressure changes.



In the *Boyle's Law and Charles' Law* Gizmo™, students can change either the temperature or pressure of a container of gas. The resulting gas volume can then be observed.

The Student Exploration sheet contains two activities:

- Activity A – Students determine the relationship between gas volume and pressure at constant temperature (Boyle's law).
- Activity B – Students determine the relationship between gas volume and temperature at constant pressure (Charles' law).

Suggested Lesson Sequence

1. **Pre-Gizmo activity** (10 – 15 minutes)
   You can introduce the gas laws by showing two real-world situations.

   Show your students a picture of a hot-air balloon, and ask them why the hot-air balloon can fly. What is happening to the air molecules that cause the balloon to float in the air? (Note: To give your students a hint, you can show a picture of the hot-air balloon before it is filled with hot air.)

   Next, show your students a picture of a helium tank and a pile of balloons. (See the **Selected Web Resources** below.) Ask your students to explain how such a small tank could contain enough gas to fill so many balloons.

2. **Prior to using the Gizmo** (10 – 15 minutes)
Before students are at the computers, pass out the Student Exploration sheets and ask students to complete the Prior Knowledge Questions. Discuss student answers as a class, but do not provide correct answers at this point. Afterwards, if possible, use a projector to introduce the Gizmo and demonstrate its basic operations. Demonstrate how to take a screenshot and paste the image into a blank document.

3. **Gizmo activities** (15 – 20 minutes per activity)
Assign students to computers. Students can work individually or in small groups. Ask students to work through the activities in the Student Exploration using the Gizmo. Alternatively, you can use a projector and do the Exploration as a teacher-led activity.

4. **Discussion questions** (15 – 30 minutes)
As students are working or just after they are done, discuss the following questions:
   - How would the volume of a gas change if the pressure was multiplied by five?
   - Can you write an expression to describe how changes in pressure affect the volume of a gas? [Example: $V = k \div P$, where k is a proportionality constant.]
   - How would the volume of a gas change if the temperature was divided by 5?
   - Can you write an expression to describe how changes in temperature affect volume? [Example: $V = k \times T$, where k is a proportionality constant.]
   - The Gizmo is not completely realistic because it doesn't include atmospheric pressure. How would the results change if atmospheric pressure was included?

5. **Follow-up activity: Cartesian divers** (15 – 30 minutes)
There are a multitude of demonstrations that illustrate how temperature and pressure affect the volume of a gas. (See the **Selected Web Resources**.) An intriguing example is the Cartesian diver. To make a simple Cartesian diver, wrap several lengths of wire around the neck of an eyedropper. Place the eyedropper in water—it should barely float.

   Next, fill a 2-liter soda bottle to the very top with water. Add the Cartesian diver, and screw the cap on tight. Squeeze the bottle, and the diver will sink to the bottom. Release the bottle, and the diver will come back to the top. The reason for this behavior is the small air bubble trapped in the bulb of the eyedropper. Squeezing the bottle increases the pressure on the air bubble and compresses the bubble. This has the effect of increasing the density of the eyedropper, and it sinks. When you release the bottle, the air bubble returns to its former size and the eyedropper rises.

   Cartesian divers can be made from everything from drinking straws to ketchup packets. If you like, hold a Cartesian diver contest in your class to see if your students can invent their own working Cartesian divers.

Scientific Background

Gases are composed of a sea of colliding molecules. The *temperature* of the gas is a measure of the average velocity of the molecules. As the molecules speed up, the temperature increases. As the molecules slow down, the temperature decreases. The lowest possible temperature is *absolute zero* (-273.15 °C), when all molecular motion ceases. The Kelvin scale measures temperature from absolute zero, so 0 K is absolute zero and 273.15 K is 0 °C.

If a gas is held in a container, it will expand to fill the entire container. As the molecules of the gas collide with the walls of the container, the gas exerts *pressure* on the container. Pressure is a measure of force exerted on a unit of area. The SI unit of pressure is the pascal (Pa), where 1 Pa = 1 newton per square meter (1 N/m^2).

The *ideal gas law* quantifies the relationship between the volume, pressure, and temperature of a gas:

$$pV = nRT$$

In this equation p stands for pressure, V for volume, n for the number of gas molecules, R for the ideal gas constant, and T for temperature. The gas constant R is 8.314 when p is measured in pascals, V in cubic meters, n in moles, and T in degrees Kelvin.

Boyle's law and Charles' law are both contained in the ideal gas law. If pressure is doubled and temperature held constant, then the volume must be halved for the equation to hold. If the temperature is doubled under constant pressure, then the volume must double as well.

An interesting aspect of the ideal gas law is that it does not depend on the type of gas. At the same temperature and pressure, a mole of oxygen occupies the same space as a mole of hydrogen, helium, nitrogen, or carbon dioxide.

Health connection: "The bends"

Have you ever felt and observed an unopened bottle of soda or seltzer? The bottle is hard, and few or no bubbles can be seen in the soda. When you unscrew the cap, thousands of bubbles appear in the soda and you can get soaked if you're not careful! *Henry's law* states that the amount of gas dissolved in a liquid increases as pressure is increased. When the pressure is released, the gas forms bubbles and quickly leaves the liquid.

When human divers are deep in the ocean, their bodies are under an enormous amount of pressure from the water. As a result, many gases such as nitrogen dissolve into the blood. If the diver ascends too quickly, bubbles can form in the blood and cause *decompression sickness*, or "the bends." The bubbles can block blood vessels, inflame tissues, and cause swelling, pain, and even death. To prevent decompression sickness, divers must closely monitor how much time they spend at depth, and ascend slowly to let the gas leave their blood gradually, similar to opening a bottle of soda slowly to allow the bubbles to escape without an explosion.

Selected Web Resources

Helium tanks: http://www.target.com/Disposable-Helium-Tank/dp/B000PGQ63O
Pressure and temperature demonstrations: http://www.arborsci.com/CoolStuff/cool8.htm
(Note: Some of these demonstrations illustrate phase changes rather than gas laws.)
Cartesian diver: http://www.stevespanglerscience.com/experiment/00000089
Ideal gas law: http://library.thinkquest.org/12596/ideal.html
Ideal gas law problems: http://www.wisc-online.com/objects/index_tj.asp?objID=GCH5804
Decompression sickness: http://www.merck.com/mmhe/sec24/ch295/ch295c.html

Related Gizmo:
Temperature and Particle Motion: http://www.explorelearning.com/gizmo/id?555