

How are volume and temperature related?

An interactive investigation of the science of the atmosphere



Overview

Most people don't realize that volume and temperature are related, but they are! They are related according to a law called Charles' Law that states that the volume and temperature of a gas are directly proportional, assuming no other variables change. Charles' Law makes up part of the ideal gas law that describes the state of any gas, including the air.

Necessary materials:

- Balloon
- Gloves
- Helium
- Liquid Nitrogen
- Large bowl to hold the balloon

Theory

When you get really cold, you want to curl into a small ball and when you get hot, you try to spread out as much as you can. Well, gases feel the same way!! When a gas cools, it contracts because it is losing energy and the volume decreases. When the gas warms back up, it gains energy, expands, and fills a larger volume.

This relationship can be described using mathematics as well. Mathematically, Charles' Law states that

$$\frac{V}{T} = k$$

where k is any constant.

The experiment below is very interesting because you will actually see this law at work and how changing temperatures impact the volume of a helium-filled balloon. If regular air is used, as would be the case if someone blew up the balloon normally, the cold temperatures of the liquid nitrogen actually liquefy the air and what you see is a phase change, not Charles' Law, although the effect of a volume change remains the same.

Doing the Experiment

SAFETY NOTE: Liquid nitrogen is very cold!!! Don't allow the students to touch the liquid nitrogen or anything that is frozen by it. Use gloves when handling the balloon. If you do touch some liquid nitrogen, run your skin under warm water.

The experiment goes like this:

- Fill up the balloon with helium and have someone wearing gloves hold it in the bowl.
- Using gloves, pour the liquid nitrogen over the balloon.
- Observe what happens to the size of the balloon.
- Allow the balloon to warm back up and observe its size again.

How do you explain the differences in size? Notice that as the helium in the balloon cools, the balloon becomes less buoyant and no longer wants to float. The process of cooling made the balloon more stable. Think about the real atmosphere for a moment. During the daytime, the sun heats the surface of the Earth, which, in turn, heats the lowest layer of air. As the temperature increases, what happens to the volume? Using the definition of density, $\text{density} = \text{mass}/\text{volume}$, what happens to the density of the air (assuming the mass doesn't change)? As the density changes, will the air become positively or negatively buoyant (does it float or not)? What happens at night when the air cools? How would you make a temperature profile more stable? Less stable?

Summing Up

This exercise is a quick example of how temperature and volume change together and helps to explain one part of the ideal gas law. As the temperature of the helium inside the balloon decreases, the volume also decreases and the balloon shrinks. As the helium begins to warm back up, the helium expands and the balloon grows back to its original size. This experiment can be done repeatedly to show the effect of temperature on volume.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: <http://cmmmap.colostate.edu>

Little Shop of Physics: <http://littleshop.physics.colostate.edu>