# 7.3: The temperature-volume relationship

Consider a gas in a cylinder with a piston in Fig. 7.3.1. Increasing temperature increases the average kinetic energy (*KE*) of the gas molecules. The kinetic energy (*KE*) is directly proportional to the velocity of the molecules, i.e., $KE = \frac{1}{2}mv^2$, where *m* is the mass and *v* is the velocity. So, increasing temperature increases the velocity resulting in more frequent and more forceful collisions resulting in increased gas pressure inside the chamber. The gas volume starts to increase causing the pressure to decrease until the pressure inside the chamber is equal to the pressure outside. In other words, increasing temperature increases the volume of the gas if the pressure and amount of gas are not changed.

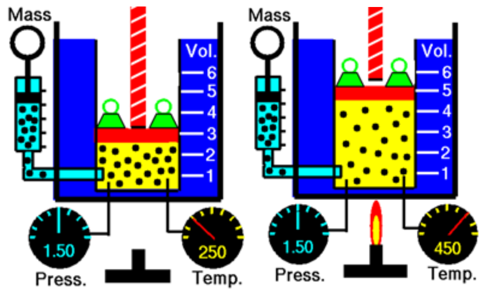


Figure 7.3.1: Increasing temperature increases the volume of the gas i.e., $\frac{V_1}{T_2} = \frac{V_2}{T_2} = \mathrm{k}$. Source: NASA's Glenn Research Center / Public domain.

If two related parameters increase or decrease together, they are directly proportional to each other.

**Charles's law**

Charles's law states that the volume of a given amount of gas is directly proportional to the temperature in the Kelvin scale at constant pressure.

Fig. 7.3.2 demonstrates that the volume of a gas decreases when the gas is cooled down.

Figure 7.3.1: Air balloon (left) shrinks when its temperature is decreased by submerging in liquid nitrogen (middle) and re-expands when returned to room temperature condition (right). Source: Ryan Poling aka expictura on Flickr.https://en.Wikipedia.org/wiki/File:Nitrogen.ogv#file, CC BY 2.0

The mathematical forms of Charles's law are the following.

$$V \propto T$$

, or

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

, or

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

, where k is a constant, *V* is volume, and *T* is the temperature (in kelvin scale) of the gas. Since $\frac{V}{T}$ is a constant, it implies that

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \mathrm{k}$$

where $V_1$ is the initial volume, $T_1$ is the initial temperature in Kelvin, $V_2$ is the final volume, and $T_2$ is the final temperature in Kelvin, provided the amount of gas and pressure do not change. Note that the kelvin scale is used in Charles's law because the kelvin scale does not have negative numbers which means the linear curve starts from the origin without any y-intercept. If the given temperature is not in the kelvin scale, first convert the temperature to the Kelvin scale and then use the gas laws for the calculations.

### ✓ Example 7.3.1

A sample of $CO_2$ occupies 3.23 L volume at 25.0 $^oC$. Calculate the volume of the gas at 50.0 $^oC$ if pressure and amount of gas do not change?

**Solution**

Given: $T_1$ = 25.0 $^oC$ + 273 = 298 K, $T_2$ = 50.0$^oC$ + 273 = 323 K, $V_1$ = 3.23 L, $V_2$ = ?

Formula: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ , rearrange the formula to isolate the desired variable: $V_2 = \frac{V_1 T_2}{T_1}$

Plug in the values in the rearranged formula and calculate: $V_2 = \frac{3.23\text{ L} \times 323\text{ K}}{298\text{ K}} = 3.50\text{ L}$

Charles's law explains the drifting of warm air upward in the atmosphere. As the gas is wormed, its volume increases and its density decreases which makes the gas drift upward. A hot air balloon, shown in Fig. 7.3.3 operates using hot air.


Figure $7.3.3$: A hot air balloon seen from a view directly below. The burner, or flame, is firing into the envelope above. The warm air is less dense than the atmospheric air which makes the balloon rise in the air. Source: Arpingstone at English Wikipedia / Public domain.