9.3: The Temperature-Volume Relationship: Charles’s Law

A fun laboratory demonstration in which a fully inflated balloon is placed in liquid nitrogen (at a temperature of –196 ˚C) and it shrinks to about 1/1000th of its former size. If the balloon is carefully removed and allowed to warm to room temperature, it will again be fully inflated.

This is a simple demonstration of the effect of temperature on the volume of a gas. In 1787, Jacques Charles performed a systematic study of the effect of temperature on gases. Charles took samples of gases at various temperatures, but at the same pressure, and measured their volumes.

The first thing to note is that the plot is *linear*. When the pressure is constant, volume is a direct linear function of temperature. This is stated as **Charles’s law.**

Charles’s law

The volume (V) of an ideal gas varies *directly* with the temperature of the gas (T) when the pressure (P) and the number of moles (n) of the gas are constant.

We can express this mathematically as:

$$V \propto T \quad at\ constant\ P\ and\ n$$

$$V = constant(T)\ or\ \frac{V}{T} = constant$$

The data for three different samples of the same gas is as follows: 0.25 moles, 0.50 moles and 0.75 moles. All of these samples behave as predicted by Charles’s law (the plots are all linear), but , if you extrapolate each of the lines back to the *y*-axis (the temperature axis), all three lines intersect at the same point! This point, with a temperature of –273.15 ˚C, is the theoretical point where the samples would have “zero volume”. This temperature, -273.15 ˚C, is called **absolute zero**. An even more intriguing thing is that the value of absolute zero is independent of the nature of the gas that is used. Hydrogen, oxygen, helium, argon, (or whatever), all gases show the same behavior and *all* intersect at the same point.

The temperature of this intersection point is taken as “zero” on the Kelvin temperature scale. The abbreviation used in the Kelvin scale is **K** (no degree sign) and there are *never* negative values in degrees Kelvin. The size of the degree increment in Kelvin is identical to that in Centigrade and Kelvin and centigrade scales are related by the simple conversion:

$$Kelvin = Centigrade + 273.15$$

Note

Please note that whenever you work gas law problems where temperature is one variable, you MUST use the Kelvin scale.

Just like we did for pressure-volume problems, we can use Charles’s law to predict what will happen to the volume of a sample of gas as we change the temperature. Because V/T is a constant for any given sample of gas (at constant P), we can again imagine two states; an initial state with a certain temperature and volume (V_1/T_1), and a final state with different values for pressure and volume ([V_2/T_2). Because V/T is always a constant, we can equate the two states and write:

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

Example 9.3.1:

We have a container with a piston that we can use to adjust the pressure on the gas inside. You are told that, initially, the temperature of the gas in the container is 175 K and the volume is 1.50 L. The temperature is changed to 76 K and the piston is then adjusted so that the pressure is identical to the pressure in the initial state; what is the final volume?

Solution

We substitute into our Charles’s law equation:

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

$$\frac{1.50\ L}{175\ K} = \frac{V_2}{76\ K}$$

$$V_2 = \left(\frac{(76\ K)(1.50\ L)}{175\ K}\right) = 0.65\ L$$

? Exercise 9.3.1

1. A container with a piston contains a sample of gas. Initially, the pressure in the container is exactly 1 atm, the temperature is 14.0 ˚C and the volume is 997 mL.
   The temperature is raised to 100.0 ˚C and the piston is adjusted so that the pressure is again exactly 1 atm What is the final volume?
2. A 50.0 mL sample of gas at 26.4˚ C, is heated at constant pressure until its volume is 62.4 mL . What is the final temperature of the gas? A sample container of carbon monoxide occupies a volume of 435 mL at a temperature of 298 K. What would its temperature be if the pressure remained constant and the volume was changed to 265 mL? (182 K)