52.10: Gases

The study of the physics of gases can be fairly involved, and is usually studied as part of thermodynamics, or the study of heat. In this section, we'll cover a few basic properties of gases.

A gas is a state of matter in which the atoms or molecules making up the gas are not attached to one another, so that they are free to move about independently. The air we breath is an example of a gas; it consists primarily of 78% nitrogen molecules $(\mathrm{N_2})$ and 21% oxygen molecules $(\mathrm{O_2})$; the remainder is argon and a few other gases.

Studies of gases in the 18th and 19th centuries revealed a few basic properties of a gas of volume V and (absolute) temperature [1]T, under a pressure P :

$$P \propto \frac{1}{V} \text{ (Boyle's law)} \tag{52.10.1}$$

$$P \propto T \text{ (Amonton's law)} \tag{52.10.2}$$

$$V \propto T \text{ (Charles's law)} \tag{52.10.3}$$

where in each case, the unnamed variable (T, V, and P, respectively) is assumed to be held constant. These three equations can be combined into one, called the ideal gas law that relates the pressure P, volume V, and temperature T of an ideal gas:

$$PV = nRT \tag{52.10.4}$$

Here n is the number of moles of gas atoms or molecules present, and R is a constant called the (molar) gas constant; it is equal to exactly

$$R = 8.31446261815324 \quad \mathrm{J\ mol^{-1}\ K^{-1}} \tag{52.10.5}$$

The ideal gas law is sometimes expressed in the equivalent form

$$PV = Nk_BT \tag{52.10.6}$$

where N is the total number of atoms or molecules of gas present, and k_B is Boltzmann's constant; it is equal to exactly

$$k_B = 1.380649 \times 10^{-23}\ \mathrm{J/K} \tag{52.10.7}$$

The ideal gas law is an equation of state for the gas; it assumes the gas is "ideal" — that is, the atoms making up the gas are of negligible size, and that the atoms to not interact with each other chemically (only through collisions). Other equations of state may be used, such as the van der Waals equation of state, that takes into account the finite size of the atoms or molecules making up the gas, and the intermolecular forces between nearby molecules:

$$\left[P + a\left(\frac{n}{V}\right)^2\right]\left(\frac{V}{n} - b\right) = RT \tag{52.10.8}$$

If the coefficients a and b describing these effects are known, then the van der Waals equation may be a more realistic equation of state than the ideal gas law.

{[1] Temperature must be in kelvins (K) for SI or CGS units, or in degrees Rankine ($^\circ\mathrm{R}$) in English units. Fahrenheit ($^\circ\mathrm{F}$) and Celsius $(^\circ\mathrm{C})$ are not absolute temperature scales, and may not be used here.