The Gas Laws

Any gas can be characterized by four basic physical properties, pressure (P), volume (V), temperature (T), and amount of gas in moles (n). These properties are not independent but are interrelated; changing the one affects other. There are three basic laws governing the behavior of the gas, which describe the relation between only two properties. These are,

- **Boyle's law** – describes the relation between the volume (V) and the pressure (P).
- **Charles's law** – describes the relation between the volume (V) and the temperature (T).
- **Avogadro's law** – describes the relation between the volume (V) and the number of moles (n) of gas.

All the laws in science are based on common experience or common sense. The law should make sense when it is defined.

Boyle's Law (Volume and Pressure relationship)

This law was invented by Robert Boyle (1627-1691) (the photo is taken from http://en.wikipedia.org/wiki/Robert_Boyle), which states that *at a constant temperature, the volume of fixed amount of gas is inversely proportional to the pressure.* The mathematical expression showing the above defined inverse relationship is,

$$V \propto \frac{1}{P}$$

where the symbol $\propto$ is the mathematical symbol used to mean *proportional to*. The above equation is not suitable in its form for any kind of calculations. Hence, the proportionality sign must be removed by introducing the equal sign as

$$V = k \text{ x } \frac{1}{P}$$

where k is a proportionality constant that depends on the nature of the gas. The above equation can be rearranged to yield

$$PV = k = \text{constant}$$

This relationship displays that when the pressure is increased, the volume decreases and vice versa. But the product of P and V is always the same constant. For two different sets of conditions, the above equation takes the following form:

$$P_1V_1 = k = P_2V_2$$

or

$$P_1V_1 = P_2V_2$$

Where P_1 and V_1 are the initial (condition1) pressure and volume of the gas and P_2 and V_2 are the final (condition 2) pressure and volume of the gas.

Example

A gas occupying the volume of 520 ml at a pressure of 1.15 atm is allowed to expand until it reaches the pressure of 0.825 atm. What is its final volume?

Answer

First list the given quantities for two conditions as

condition 1	condition 2
P_1 = 1.05 atm	P_2 = 0.825 atm
V_1 = 520 ml	V_2 = ?

The substitute these values into the equation $P_1V_1 = P_2V_2$ and solve for V_2.

1.05 atm x 520 ml = 0.825 atm x V_2

V_2 = (1.15 atm x 520 ml) / 0.825 atm
= 702.78 ml

Check on your calculation:

How do you know the answer is correct?

Boyle's says that increase in pressure decreases volume or decrease in pressure increases volume. In this problem, the pressure is decreased from 1.05 atm to 0.825 atm. Therefore, the final volume should be greater than the initial volume. The calculated volume (702.78 ml) is indeed greater than the initial volume (520 ml). This tells you that, at least, you are on the right rack. But, it does not guarantee that your answer is correct, that depends upon the way you entered the numbers in your calculator.

Charles's Law (Volume and Temperature relationship)

Charles's law invented by Jacques Alexandre César Charles (1746-1823) (the photo is taken from http://en.wikipedia.org/wiki/Jacques_Charles) states that, *at a constant pressure, the volume of fixed amount of gas is directly proportional to the absolute temperature.* The mathematical expression of this statement is

$$V \alpha T$$

or $$V = k^{'} T$$

or $$\frac{V}{T} = k^{'}$$

According to this law, the volume of the gas increases as the temperature increases, but the ratio of volume to temperature, V/T, is always constant(k').

Like the Boyle's law, the Charles's law can also be applied to two sets of conditions at a constant pressure. The equation applicable to this situation is

$$\frac{V_1}{T_1} = k^{'} = \frac{V_2}{T_2}$$

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

Example

A balloon filled with air has the volume of 250 ml at room temperature 25^0C. What will be the volume of the balloon if it is placed in the refrigerator that operates at 18^0 C?

Answer

condition 1	condition 2
V_1 = 250 ml	V_2 = ?
t_1 = 25^0C	t_2 = 18^0C

Note that symbols t_1 and t_2 are used to indicate the Celsius temperatures. These Celsius temperatures need to be converted into Kelvin before you solve for the final volume.

T_1 = 25 + 273.15 = 298.15 K

T_2 = 18 + 273.13 = 291.15 K

Now you can calculate the final volume by substituting the these values.

$$\frac{250\,\text{ml}}{298.15\,\text{K}} = \frac{V_2}{291.15\,\text{K}}$$

or $$V_2 = 291.15\,\text{K} \times \frac{250\,\text{ml}}{298.15\,\text{K}} = 244.13\,\text{ml}$$

Check

As you can see, the final volume is decreased from 250 ml to 244.13 ml, as it should be according to the Charles's law.

Avogadro's Law (Volume and Amount of gas (in moles) relationship)

Avogadro's law, invented by Lorenzo Romano Amedeo Carlo Avogadro (1776-1856)(the photo is taken from http://en.wikipedia.org/wiki/Amedeo_Avogadro), states that, at a constant pressure and temperature, the volume of the fixed amount of gas is directly proportional to the amount of gas expressed in moles. The mathematical equivalent of this statement is,

$$V \propto n$$

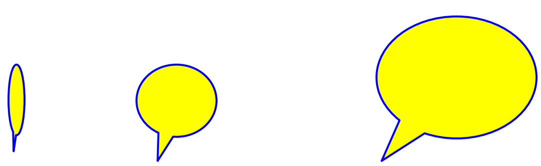
where n is the number of moles of gas. Replacing the proportionality sign with an equal sign assumes the following form.

$$V = k''n$$

or $$\frac{V}{n} = k'' = \text{constant}$$

where k'' is proportionality constant.

You experience Avogadro's law when you inflate the balloon. As you blow more air into the balloon, the volume increases. More blowing means more air inside the balloon (more number of moles of air).



less air   more air   still more air

Like previous two laws, the Avogadro's law can also be extended to two sets of conditions, for which the following equation is written.

$$\frac{V_1}{n_1} = k'' = \frac{V_2}{n_2}$$

or $$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

Example

A helium filled balloon is inflated to 30.0 L with 1.44 moles of the gas. If a balloon needs to be expanded further to 40.0 L, how many additional moles of the gas are required?

Answer

condition 1	condition 2
$V_1 = 30.0$ L	$V_2 = 40.0$ L
$n_1 = 1.44$ mol	$n_2 = ?$

Substituting these values into above equation leads to,

$$\frac{30.0\,\text{L}}{1.44\,\text{mol}} = \frac{40.0\,\text{L}}{n_2}$$

or $$n_2 = 40.0\,\text{L} \text{ x } \frac{1.44\,\text{mol}}{30.0\,\text{L}} = 1.92\,\text{mol}$$

Therefore,

additional moles = 1.92 mol – 1.44 mol = 0.48 mol
