Gases, Pressure, laws of pressure

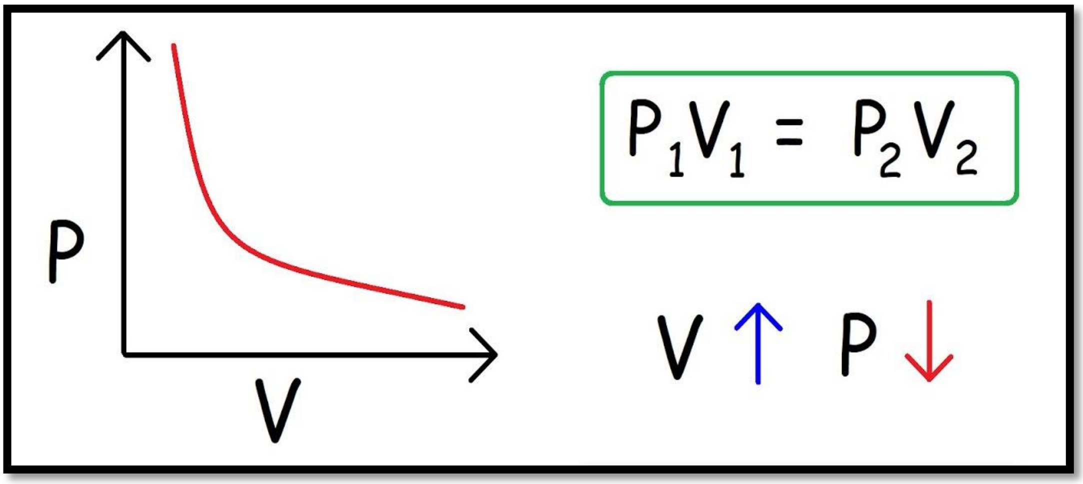
Boyle's law

In 1662 Robert Boyle studied the relationship between volume and pressure of a gas of fixed amount at constant temperature. He observed that volume of a given mass of a gas is inversely proportional to its pressure at a constant temperature. Boyle's law, published in 1662, states that, at constant temperature, the product of the pressure and volume of a given mass of an ideal gas in a closed system is always constant. It can be verified experimentally using a pressure gauge and a variable volume container. It can also be derived from the kinetic theory of gases: if a container, with a fixed number of molecules inside, is reduced in volume, more molecules will strike a given area of the sides of the container per unit time, causing a greater pressure.

A statement of Boyle's law is as follows:

The volume of a given mass of a gas is inversely related to pressure when the temperature is constant.

The concept can be represented with these formulae:



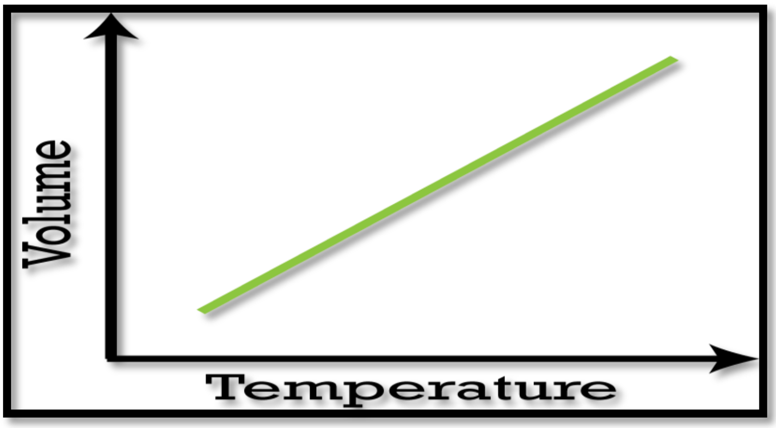
meaning "Volume is inversely proportional to Pressure", or meaning "Pressure is inversely proportional to Volume"

where P is the pressure, and V is the volume of a gas, and k_1 is the constant in this equation.

Charles's law

Charles's law, or the law of volumes, was found in 1787 by Jacques Charles. It states that, for a given mass of an ideal gas at constant pressure, the volume is directly proportional to its absolute temperature, assuming in a closed system. The statement of Charles's law is as follows: the volume (V) of a given mass of a gas, at constant pressure (P), is directly proportional to its temperature (T). As a mathematical equation, Charles's law is written as either :

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



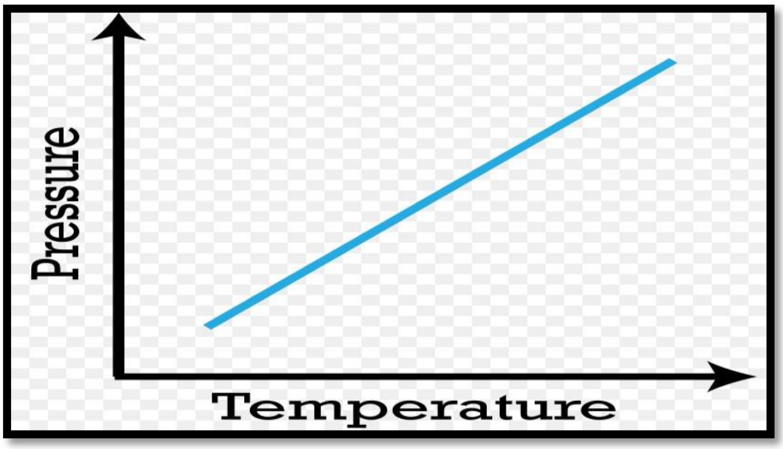
Gay-Lussac's law

Gay-Lussac's law, Amontons' law or the pressure law was found by Joseph Louis Gay-Lussac in 1808. It states that, for a given mass and constant volume of an ideal gas, the pressure exerted on the sides of its container is directly proportional to its absolute temperature.

As a mathematical equation, Gay-Lussac's law is written as either:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

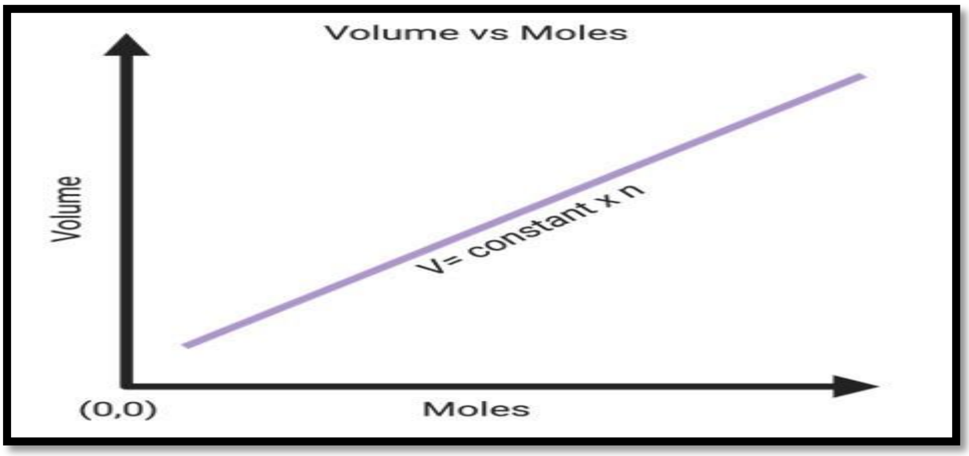
where *P* is the pressure, *T* is the absolute temperature, and *k* is another proportionality constant.



Avogadro's law

Avogadro's law (hypothesized in 1811) states that at a constant temperature and pressure, the volume occupied by an ideal gas is directly proportional to the number of molecules of the gas present in the container. This gives rise to the molar volume of a gas, which at STP (273.15 K, 1 atm) is about 22.4 L. The relation is given by :

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



where *n* is equal to the number of molecules of gas (or the number of moles of gas).

Combined and ideal gas laws

The Combined gas law or General Gas Equation is obtained by combining Boyle's Law, Charles's law, and Gay-Lussac's Law. It shows the relationship between the pressure, volume, and temperature for a fixed mass (quantity) of gas:

This can also be written as:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

With the addition of Avogadro's law, the combined gas law develops into the ideal gas law:

$$PV = nRT$$

where

P is pressure

V is volume

n is the number of moles

R is the universal gas constant

T is temperature (K)

This law has the following important consequences:

If temperature and pressure are kept constant, then the volume of the gas is directly proportional to the number of molecules of gas.

If the temperature and volume remain constant, then the pressure of the gas changes is directly proportional to the number of molecules of gas present.

If the number of gas molecules and the temperature remain constant, then the pressure is inversely proportional to the volume.

If the temperature changes and the number of gas molecules are kept constant, then either pressure or volume (or both) will change in direct proportion to the temperature.

Example

An amount of gas has a pressure of 350 KPa, a volume of 0.03 m^3 and a temperature of 35°C. If R = 0.29 kJ/kg .K, calculate the mass of the gas and the final temperature if the final pressure is 1.05 MPa and the volume remains constant?

Solution:

The absolute temperature: $T_1 = 35 + 273 = 308$ K Applying the equation of state for the initial conditions: $P_1V_1 = mRT_1$

$= 350 \times 0.03 = m \times 0.29 \times 308 \rightarrow m = 350 \times 0.03 / (0.29 \times 308)$

$\boldsymbol{m = 0.12\ \text{kg}}$

Applying the equation of state between two conditions at constant volume:

$P_1 / T_1 = P_2 / T_2$

$= 350 / 308 = (1.05 \times 10^3 / T_2) \rightarrow T_2 = (1.05 \times 10^3 \times 308) / 350$

$\boldsymbol{T_2 = 924\ \text{K}}$

Example

A tank has a volume of 0.5 m^3 and contains 10 kg of an ideal gas having a molecular weight of 24. The temperature is 25°C. What is the pressure of the gas?

Solution:

The absolute temperature:

$T = 25 + 273 = 298$ K

$R = R_o / M = (8.314 / 24) = 0.35$ kJ/kg. K

Applying the equation of state:

$PV = mRT$

$P \times 0.5 = 10 \times 0.35 \times 298 \rightarrow \quad P = (10 \times 0.35 \times 298) / 0.5$

$\boldsymbol{P = 2086\ \text{kPa}}$.