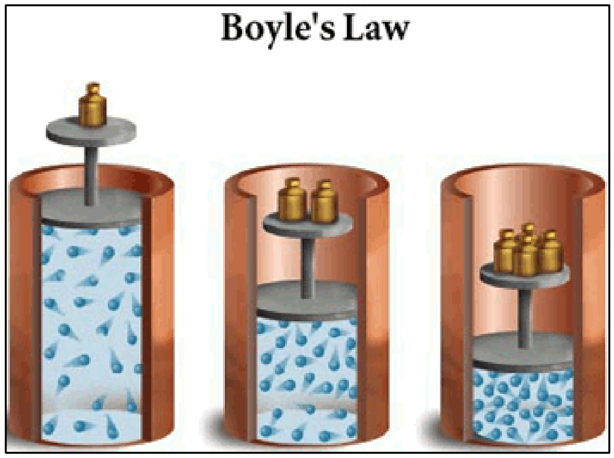
Boyle's Law:

In 1662, Robert Boyle discovered that there existed a relation between the pressure and the volume of a fixed amount of gas at a fixed temperature. In his experiment, he discovered that the product of Pressure & Volume of a fixed amount of gas at a fixed temperature was approximately a constant. So, Boyle's low states that

"At constant temperature, the pressure of a fixed amount (i.e., number of moles n) of gas varies inversely with its volume".



Mathematically

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

$$P = k_1 \frac{1}{V} \Rightarrow PV = k_1 = Constant$$

It means that at constant temperature, product of pressure and volume of a fixed amount of gas is constant.

If a fixed amount of gas at constant temperature T occupying volume V_1 at pressure P_1undergoes expansion, so that volume becomes V_2 and pressure becomes P_2, then according to Boyle's law :

$$\boxed{P_1V_1 = P_2V_2 = Constant \Rightarrow \frac{P_1}{P_2} = \frac{V_1}{V_2}}$$

Boyle's Law

Question:

A gas is present at a pressure of 2 atm. What should be the increase in pressure so that the volume of the gas can be decreased to ¼ th of the initial value, If the temperature is maintained constant?

Solution:

PV = Constant for a given mass of gas at constant pressure

$$P_1V_1 = P_2V_2$$

$P_1 = 2$ atm
$V_1 = V$
$V_2 = V/4$

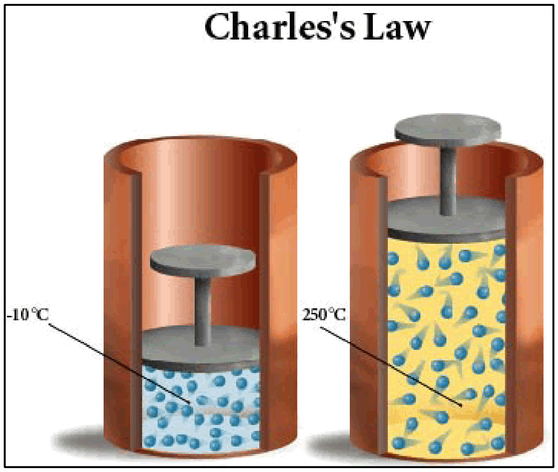
$$2 \times V = P_2 \times V/4$$
$$P_2 = 8\text{atm}$$

Pressure should be increased from 2 to 8 atm.
Total increase = 8-2 = 6 atm

Charles's Law :

In 1787, Jacques Charles discovered that if the pressure is kept constant, the volume of a gas sample increases linearly with the temperature for a fixed amount of gas. This law led to the idea of temperature. The unit of temperature used is Kelvin. Charles's law states that

"At constant pressure, the volume of a given mass of a gas is directly proportional to its absolute temperature"



Mathematically

$$V \alpha T \Rightarrow V = kT$$

or

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

Hence, if at constant pressure the volume of a gas V_1 at temperature T_1 change to V_1 at T_2 we have

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

This equation is known as **Charle's Law equation or formula.**

Question:

Volume of given amount of a gas at 57 °C and constant pressure is 425.8 cm^3. If the temperature is decreased to 37 °C at constant pressure, then what would be the volume of gas?

Solution:

According to Charle's Law

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

Here

V_1 = 425.8 cm^3

V_2 = ?

T_1 =273+ 57 = 330 K

T_2 =273+ 37 = 331 K

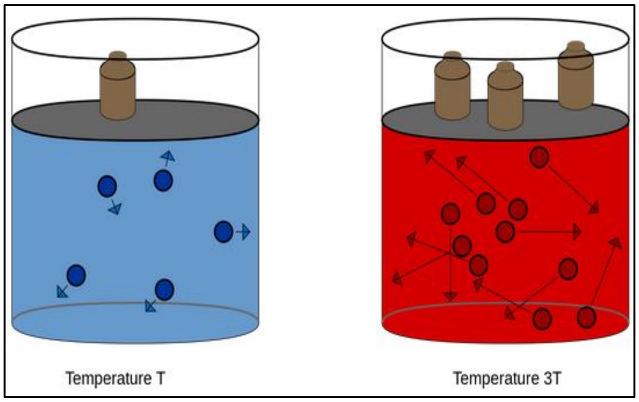
So,

$$V_2 = \frac{425.8 \times 310}{300} = 440\ cm^3$$

*Note/ In **Charle's Law equation** units of Temperature should be in kelvins*

Gay-Lussac's Law or Amonation's Law :

This law states that "*at constant volume, the pressure of a given mass of a gas is directly proportional to its absolute temperature".*



Mathematically

$P \alpha T$ (at constant volume)

$$\Rightarrow P = kT \Rightarrow \frac{P}{T} = k = constant$$

Where,

***P* = Pressure of Gas**

***T*= Absolute Temperature**

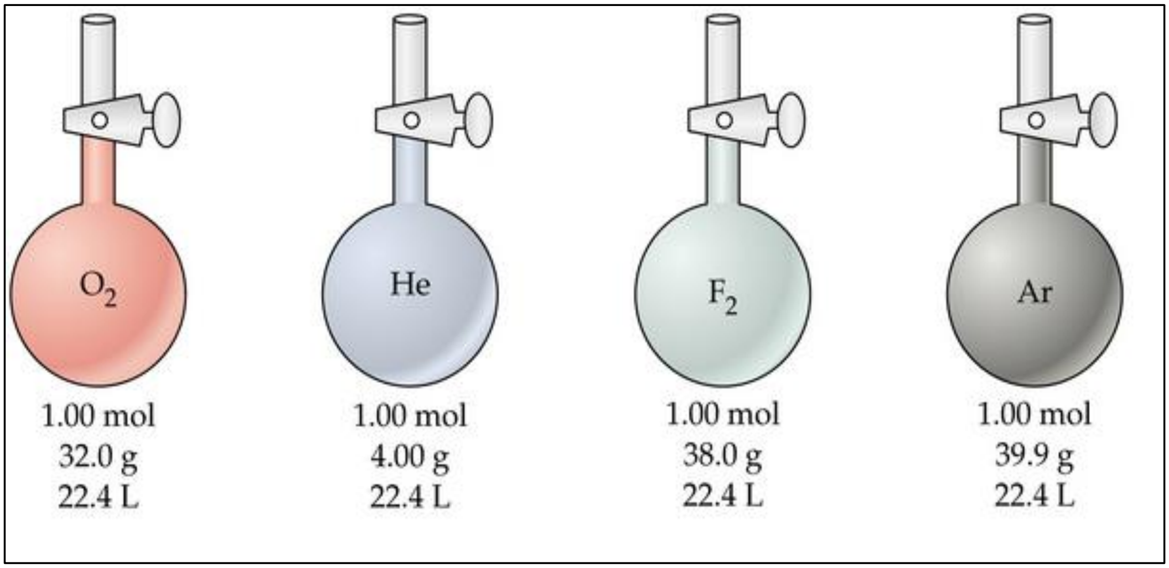
If the pressure and temperature of a gas changes from P_1 & T_1 to P_2 & T_2 , volume remaining constant , we have

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

4. Avogadro's Law

In 1812, Amadeo Avogadro stated that

"Samples of different gases which contain the same number of molecules (any complexity, size, shape) occupy the same volume at the same temperature and pressure".



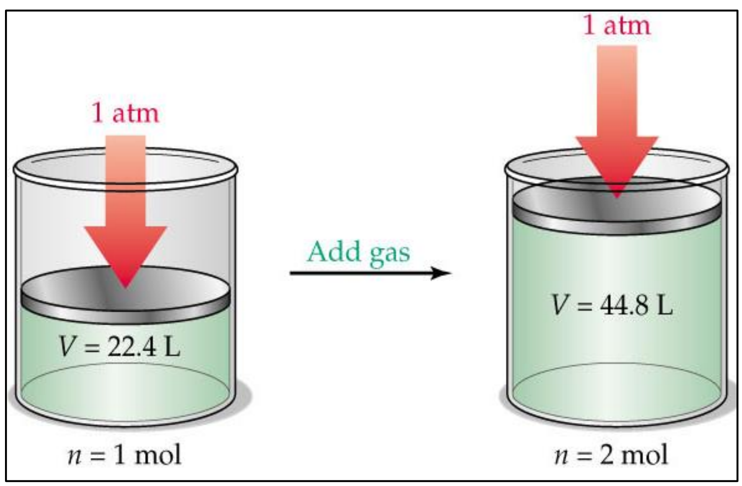
It follows from Avogadro's hypothesis that $V \propto n$ (when T and P are constant).

Mathematically

$$V \propto n \Rightarrow V = kn$$

$$\Rightarrow \frac{V}{n} = k = Constant$$

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



Since volume of a gas is directly proportional to the number of moles; **one mole of each gas at standard temperature and pressure (STP) will have same volume.** Standard temperature and pressure means 273.15 K (0°C) temperature and 1 bar (i.e., exactly 10^5 pascal) pressure.

Ex// If 4.00 L of gas at 1.22 atm is changed to 876 torr at constant temperature, what the final volume?

Ex// if 0.979 L of gas at 0°C is changed to 737 mL at constant pressure. What the final temperature?

H.W)
EX// A 20 L cylinder containing 6 atm of gas at 27 °C. What would the pressure of the gas be if the gas was heated to 77 °C
EX// A 6.0 L sample at 25 °C and 2.00 atm of pressure contains 0.5 moles of a gas. If an additional 0.25 moles of gas at the same pressure and temperature are added, what is the final total volume of the gas?

Q) Helium occupies 3.8 L at -45°C. What volume will it occupy at 45°C?

Q) A gas at STP is cooled to -185°C. What pressure in atmospheres will it have at this temperature (volume remains constant)?

Q) At 27°C, fluorine occupies a volume of 0.500 L. To what temperature in degrees Celsius should it be lowered to bring the volume to 200.0 mL?

Combined Gas Equation

The Boyle's and Charles' law can be combined to give a relationship between the three variables P, V and T.

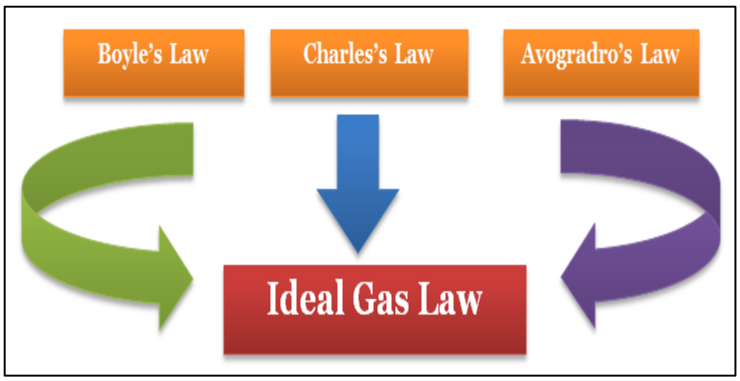
Let a certain amount of a gas in a vessel have a volume V_1, pressure P_1 and temperature T_1.

On changing the temperature and pressure to T_2 and P_2 respectively, the gas occupies a volume V_2.

Then we can write

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

Ideal Gas Equation



A gas that would obey Boyle's , Charle's law and Avogadro's law under the conditions of temperature and pressure is called an ideal gas.

Here, we combine four measurable variables P, V, T and n to give a single equation.

$V \propto n$ [P, T constant]	Avogadro's law
$V \propto T$ [n, P constant]	Charle's law
$V \propto 1/P$ [n, T constant]	Boyle's law

The combined gas law can be written as

$V \propto nT / p$

or $pV \propto nT$

[$pV = nRT$] Ideal Gas Equation

This is called **ideal gas equation**

where R is the constant of proportionality or universal gas constant

The value of R was found out to be

Values of R
$0.082057\ L\ atm\ mol^{-1}\ K^{-1}$
$62.364\ L\ Torr\ mol^{-1}\ K^{-1}$
$8.3145\ m^3\ Pa\ mol^{-1}\ K^{-1}$
$8.3145\ J\ mol^{-1}\ K^{-1*}$
$2\ cal\ mol^{-1}\ K^{-1}$

Ex// calculate the value of gas constant (R) if 1.00 mol of gas that occupies 22.4L at **STP.**

Ans. STP means 1.00 atm and 273 K (0°C). Thus,

$$R = \frac{PV}{nT} = \frac{(1.00\ \text{atm})(22.4\ \text{L})}{(1.00\ \text{mol})(273\ \text{K})} = 0.0821\ \text{L·atm/(mol·K)}$$

Relation between molar mass and density (From ideal gas equation)
$n = \frac{w}{M}$ $p = \frac{nRT}{V}$ $p = \frac{wRT}{MV} = \frac{\rho RT}{M}$

- Ideal gas equation is a relation between four variables and it describes the state of any gas, therefore, it is also called **equation of state**.
- Ideal gas is a hypothetical concept. Real gases behave ideally only under certain conditions (i.e. high temperature and low pressure).

EX// A 3.0 L flask at 30.0°C contains 0.250 mole of Cl_2 gas.
a. What is the pressure in the flask?
b. What is the mass of the gas in the flask?
c. What is the density of the chlorine gas in this flask?

H.W// A 5.0 L flask at 60.0°C contains 0.055 mole of oxygen gas.
a. What is the pressure in the flask?
b. What is the mass of the gas in the flask? if known the molar mass of oxygen is 32 gm/mole.
c. What is the density of the oxygen gas in this flask?