Chapter 5 – Gases

Section 1 - Properties, Pressure and Gas Laws

Dr. Sapna Gupta

Introduction and Properties of Gases

Air is one of those substances that no one thinks of until they can see it e.g. as in the whitish air settling over cities in some cases. It is difficult to think of air as matter since most of it is invisible. But air does have molecules, they are just far apart and are always in motion. We may notice it if there is any color or there is some odor.

Here are some properties that make gases different from solids and liquids.

1. They are compressible.
2. Their molecules fill the container since there is so much empty space between the molecules.
3. Pressure, volume, temperature, and amount are related.
4. They have low density.
5. Form a homogeneous mixture.

Kinetic Molecular Theory

This theory is based on the assumption that a gas consists of molecules in constant random motion.

Postulates of the Kinetic Theory

1. Gases are composed of molecules whose sizes are negligible.
2. Molecules move randomly in straight lines in all directions and at various speeds.
3. The forces of attraction or repulsion between two molecules (intermolecular forces) in a gas are very weak or negligible, except when the molecules collide.
4. When molecules collide with each other, the collisions are elastic.
5. The average kinetic energy of a molecule is proportional to the absolute temperature.

Pressure

Pressure is force exerted per unit area. P = Force/Area

The SI unit for pressure is the Pascal, Pa.

Other Units

- atmosphere, atm
- mmHg
- torr
- bar

N/m^2
Pa

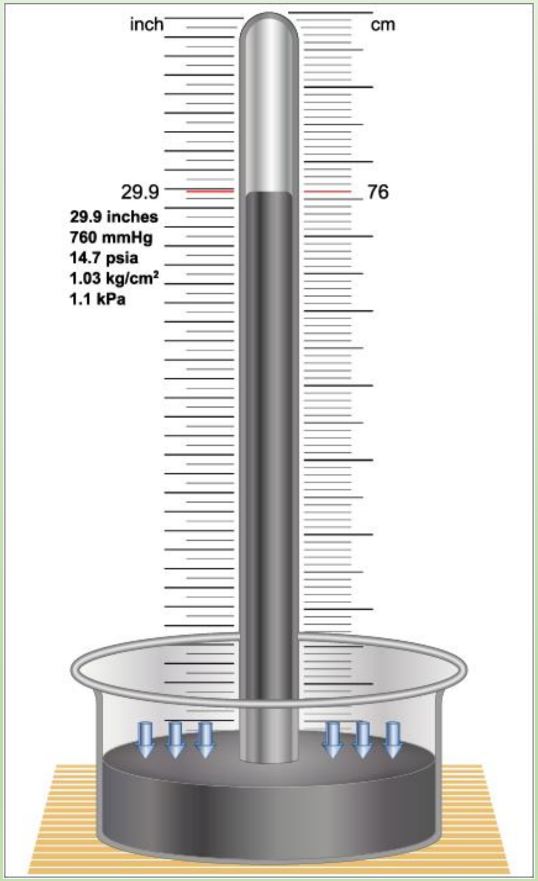
→

1 atm
760 mmHg
760 torr
101,325 Pa
1.01325 bar
14.7 psi

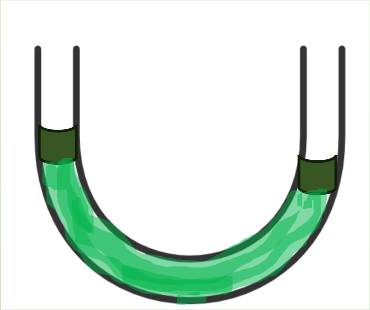
Measurement of Pressure

A **barometer** is a device for measuring the pressure of the atmosphere.

A **manometer** is a device for measuring the pressure of a gas or liquid in a vessel.



Shutterstock Image



Gas Laws

Gas laws are the relationships among four gas parameters.

- Volume (V)
- Pressure (P)
- Temperature (T)
- Amount of a gas, moles (n)

Each gas law is studied by holding two of the above physical properties constant. When pressure and volume relationship is studied, the mols of gas and temperature are kept constant.

Boyle's Law

The volume of a sample of gas is inversely proportional to pressure at constant temperature. (one increases if the other decreases and *vice versa*)

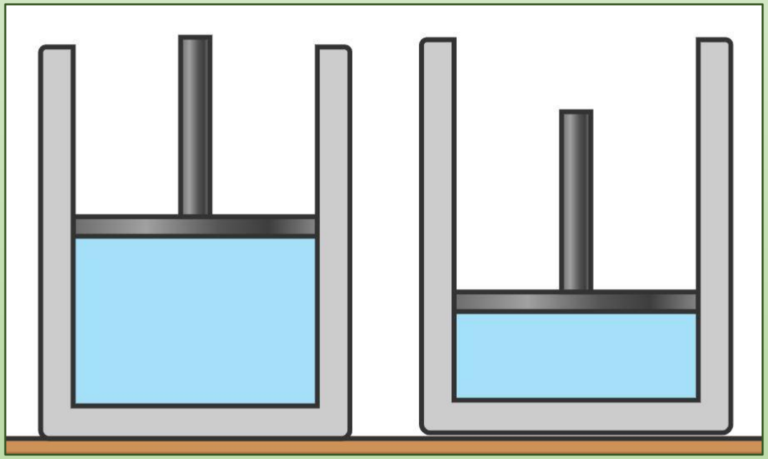
$$V \propto \frac{1}{P}$$

PV = constant

$P_1V_1=P_2V_2$

A sample of a gas at $0^{o}C$ is placed in 2.0 L container at a pressure of 1.0 atm.

When the volume of the gas is reduced to 1.0 L the pressure on the gas is doubled to 2.0 atm.



1.0 atm

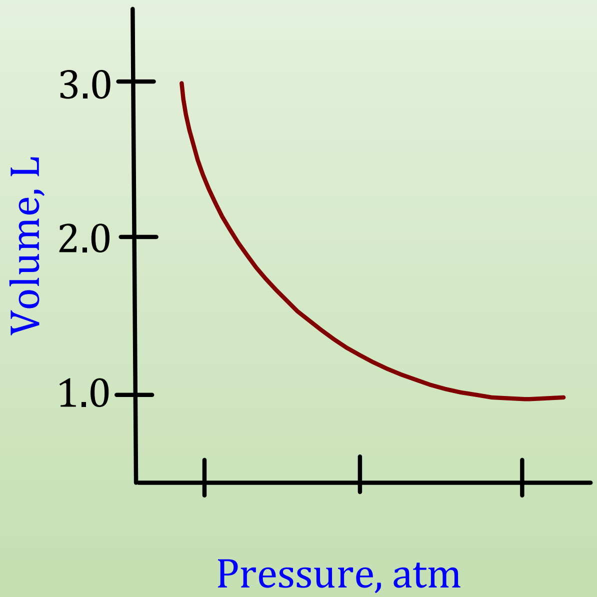
2.0L

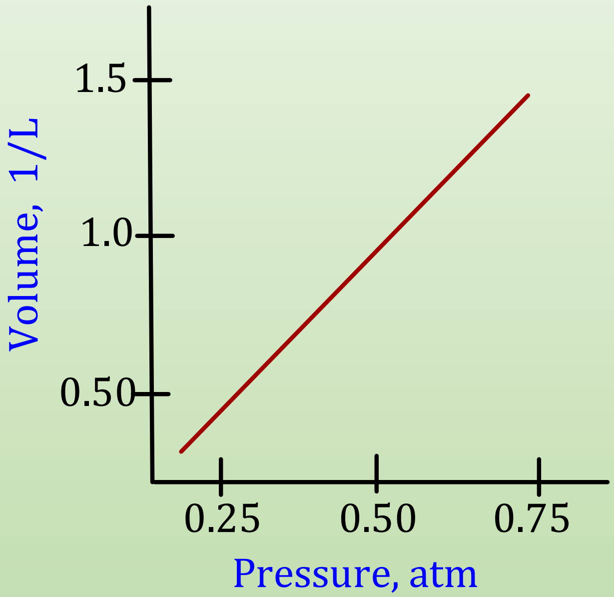
2.0 atm

1.0L

Boyle's Law Contd….

Graphical representation





Solved Problem: Boyle's Law

A volume of oxygen gas occupies 38.7 mL at 751 mmHg and 21°C. What is the volume if the pressure changes to 359 mmHg while the temperature remains constant?

$P_1V_1 = P_2V_2$

V_i = 38.7 mL
P_i = 751 mmHg
T_i = 21°C

V_f = ?
P_f = 359 mmHg
T_f = 21°C

$$V_f = \frac{P_i V_i}{P_f}$$

$$V_f = \frac{(38.7\ \text{mL})(751\ \text{mmHg})}{(359\ \text{mmHg})} = \boxed{81.0\ \text{mL}}$$

Charles's Law

The volume of a sample of gas at constant pressure is directly proportional to the absolute temperature (K).

$$V \propto T$$

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

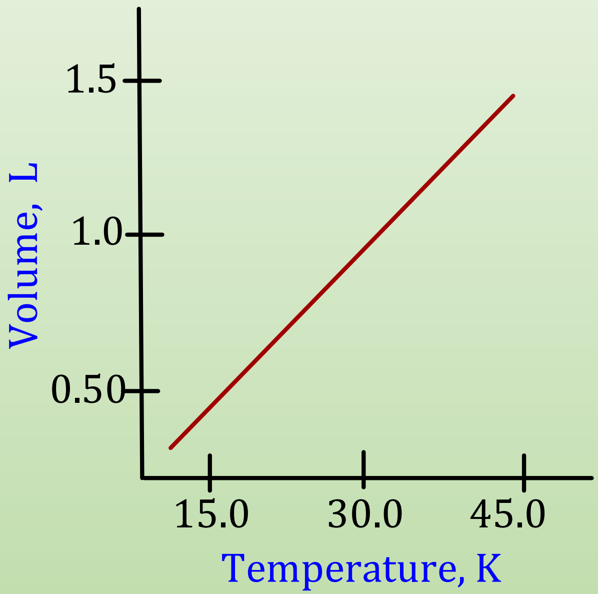
$$\frac{V_i}{T_i} = \frac{V_f}{T_f}$$

The temperature always has to be converted into Kelvin before carrying out temperature related calculations. K = °C + 273.

The temperature -273.15°C is called **absolute zero.** It is the temperature at which the volume of a gas is hypothetically zero.

Charles's Law contd….

Graphical Representation



Solved Problem: Charle's Law

You prepared carbon dioxide by adding HCl(*aq*) to marble chips, $CaCO_3$. According to your calculations, you should obtain 79.4 mL of CO_2 at 0°C and 760 mmHg. How many milliliters of gas would you obtain at 27°C?

$$\frac{V_i}{T_i} = \frac{V_f}{T_f}$$

V_i = 79.4 mL
P_i = 760 mmHg
T_i = 0°C + 273 = 273 K

V_f = ?
P_f = 760 mmHg
T_f = 27°C + 273 = 300. K

$$V_f = \frac{T_f V_i}{T_i}$$

$$V_f = \frac{(300.\ K)(79.4\ mL)}{(273\ K)} = 87.3\ mL$$

Avogadro's Law

The volume of a gas sample is directly proportional to the number of moles in the sample at constant pressure and temperature.

$$V \ \alpha \ n$$

$$\frac{V}{n} = constant$$

$$\frac{V_i}{n_i} = \frac{V_f}{n_f}$$

$$3H_2 \quad + \quad N_2 \longrightarrow 2NH_3$$

3 molecules + 1 molecule ⟶ 2 molecules

3 moles + 1 mole ⟶ 2 moles

3 volumes + 1 volume ⟶ 2 volumes

Solved Problem: Avogadro's Law

A 39.2 g sample of hydrogen chloride gas occupies 30.4 L. How much volume will 39.2 g of carbon dioxide occupy?

$$\frac{V_i}{n_i} = \frac{V_f}{n_f}$$

$V_i = 30.4$ L

$$n_i = 39.2 \text{ g x } \frac{1 \text{ mol}}{36.5 \text{ g HCl}} = 1.07397 \text{mol HCl}$$

$V_f = ?$

$$n_f = 39.2 \text{ g x } \frac{1 \text{ mol}}{44 \text{ g } CO_2} = 0.8909 \text{ mol } CO_2$$

$$V_f = \frac{n_f V_i}{n_i}$$

$$V_f = \frac{(0.8909\ mol\ CO_2)(30.4\ L\ HCl)}{(1.07397\ mol\ HCl)} = 25.2 \text{ L}$$

Dalton's Law of Partial Pressure

- Dalton found that in a mixture of unreactive gases, each gas acts as if it were the only gas in the mixture as far as pressure is concerned.
- The sum of the partial pressures of all the different gases in a mixture is equal to the total pressure of the mixture:

$$P = P_A + P_B + P_C + \ldots$$

Partial Pressure

The pressure exerted by a particular gas in a mixture, e.g. in a mixture of nitrogen and oxygen will be addition of the pressure of the two gases.

$$P_{total} = P_{N_2} + P_{O_2}$$

For example, if there is a mixture of nitrogen and oxygen at a total pressure of 1.20 atm, what is the partial pressure of nitrogen if the pressure of oxygen is 0.62 atm?

Answer: $P_{total} = P_{N_2} + P_{O_2}$

$$P_{N_2} = P_{total} - P_{O_2} = 1.20 - 0.62 = 0.58 \text{ atm}$$

Key Points

- Properties of gases
- The kinetic molecular theory
- Gas pressure
  - Units
  - Calculation
  - Measurement
- The gas laws
  - Boyle's law
  - Charles' law
  - Avogadro's law
  - Dalton's law