The Gaseous State

Lecture Material – Basic Chemistry 1
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Definition

A gas is a substance that is normally in the gaseous state at ordinary temperatures and pressures.

A vapor is the gaseous form of any substance that is liquid or solid at normal temperatures and pressures.

a

The pressure exerted by the gases in the atmosphere can be demonstrated by boiling water in a can and then turning off the heat and sealing the can.

b

As the can cools, the water vapor condenses, lowering the gas pressure inside the can. This causes the can to crumple.

Substances that exist as gases

- Ionic compounds can't be present in gas state under normal condition (25^{o}C, 1atm). But they can be converted to gas at high temperature. Ex: NaCl
- Molecular compounds such as CO, CO_2, HCl, NH_3, CH_4 are gases. The majority of molecular compounds are solid or liquid under room temp. Heating can convert these compounds more easily than ionic compounds.

Some substances found as gases at 25°C, 1 atm:

- Diatomic molecules: H_2, N_2, O_2, F_2 and $Cl_{2.}$
- Allotrope of oxygen: ozon (O_3)
- All the elements in group 8A – the monoatomic gases: He, Ne, Ar, Kr, Xe and Rn.

Gas measurement

- One of the most readily measurable properties of a gas is its pressure → atmospheric pressure.
- It is measured using barometer.

- The standard atmosphere equals to a pressure of 760 mmHg.

  1 mmHg = 1 torr

  1 atm = 760 mmHg

  = 760 torr

  = 14.69 psi

- In SI units, pressure is measured as pascals (Pa) - (N/m^2).

  1 atm = 1.01325×10^5 Pa

The Gas Laws

1. Boyle's Law: the pressure-volume relationship

   " The volume of a fixed amount of gas maintained at constant temperature is inversely proportional to the gas pressure"

   $$V \propto 1/P$$

   $$V = k_1 \times 1/P$$

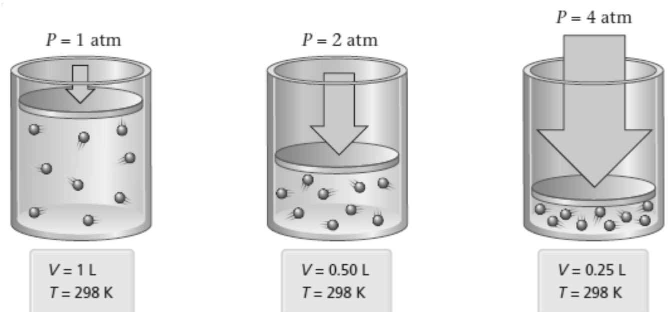
   $$P\,V = k_1$$

   k is proportionality constant.

- To predict how the volume of gas will be affected by a change in pressure, or how the pressure exerted by a gas will be affected by a change in volume:

$$P_1V_1 = k_1 = P_2V_2$$

$$P_1V_1 = P_2V_2$$



Sample question 1

- An inflated baloon has a volume of 0.55 L at sea level (1 atm) and is allowed to rise to a height of 6.5 km, where the pressure is about 0.4 atm. Assuming that the temperature remains constant, what is final volume of the baloon?
- $P_1V_1 = P_2V_2$

  $V_2 = V_1 \times P_1/P_2$

  $= 0.55 \text{ L} \times 1 \text{ atm} / 0.4 \text{ atm}$

  $= 1.4 \text{ L}$

Sample question 2

- A sample of chlorine gas occupies a volume of 946 mL at a pressure of 726 mmHg. Calculate the pressure of the gas if the volume is reduced to 154 mL. Assume that the temperature remains constant!
- $P_1V_1 = P_2V_2$

  $P_2 = P_1 \times V_1/V_2$

  $= 726$ mmHg x 946 mL / 154 mL

  $= 4.46 \times 10^3$ mmHg

2. Charles and Guy-Lussac's Law:

- At a constant pressure, the volume of a gas expands when heated and contracts when cooled.
- *"The fixed volume of a fixed amount of gas maintained at constant pressure is directly proportional to the absolute temperature of the gas".*
- Absolute T: theoretically the lowest attainable T.
- Kelvin (1848): -273.15^{o}C → absolute zero

$V \propto T$

$V = k_2 \times T$

$V/T = k_2$

$V_1/T_1 = V_2/T_2$

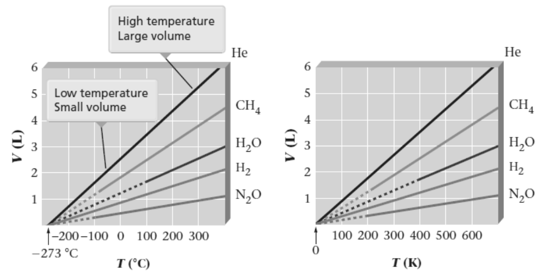


Figure 13.7 Plots of V (L) versus T (°C) for several gases. Note that each sample of gas contains a different number of moles to spread out the plots.

Figure 13.8 Plots of V versus T as in Figure 13.7, except that here the Kelvin scale is used for temperature.

- Kelvin temperature scale:
  Freezing point of water – 273.15 K = 0°C
  Boiling point of water – 373.15 K = 100°C
  T (K) = *t* (°C) + 273.15 °C

Sample question 3

- Argon is an inert gas used in light bulbs. In one experiment, 452 mL of the gas is heated from 22°C to 187°C at constant pressure. What is its final volume?
- V_1 = 452 mL
  T_1 = (22 + 273) K = 295 K
  T_2 = (187 + 273) K = 460 K
- $V_1/T_1 = V_2/T_2$
  V_2 = 452 mL x 460 K/ 295 K
  = 705 mL

Sample question 4

- A sample of carbon monoxide, a poisonous gas, occupies 3.2 L at 125^oC. Calculate the temperature at which the gas will occupy 1.54 L if the pressure remains constant.
- V_1 = 3.2 L
  T_1 = (125 + 273) K = 398 K
  V_2 = 1.54 L
  $T_2 = T_1 \times V_2/V_1$
  = 398 K x 1.54 L/3.2 L
  = 192 K = -81^oC

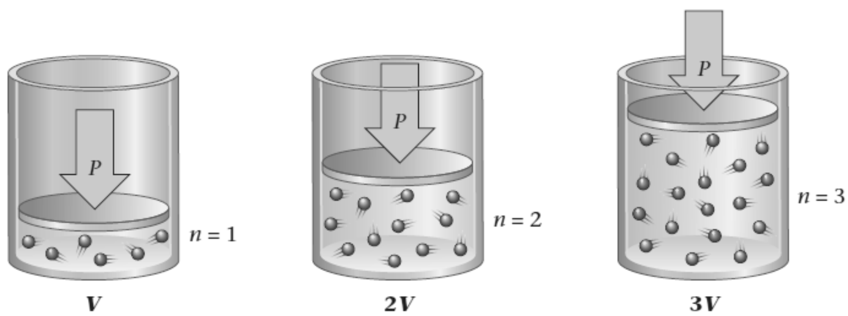
3. Avogadro's Law: The volume-amount relationship

- *"At constant pressure and temperature, the volume of a gas is directly proportional to the number of moles of the gas present"*

$$V \propto n$$

$$V = k_3 \times n$$

- Example: $3H_{2(g)} + N_{2(g)} \rightarrow 2NH_{3(g)}$
  Ratio volume H_2 and N_2 = 3:1
  Ratio product and reactant = 2:4



• Suppose we have a 12.2 L sample containing 0.5 mol oxygen gas at a pressure of 1 atm and a temperature of 25^{o}C. If all of this oxygen is converted to ozone, O_3, at the same temperature and pressure, what will be the volume of the ozone formed?

4. The ideal gas equation

- $V \propto 1/P$
  $V \propto T$
  $V \propto n$
  $V \propto nT/P$
  $V \propto R\, nT/P$
  $P V = n R T$
  R is proportionality constant (the gas constant).
  R = 0.082057 L.atm/K.mol
  R = 8.314 KPa L/ K.mol

- At 0^oC and 1 atm pressure, many real gases behave like an ideal gas.
- Under 0^oC and 1 atm → 1 mol of an ideal gas occupies 22.414 L. ---- STP (Standard Temperature Pressure)

Sample question 5

- Sulfur hexafluoride (SF_6) is a colorless, odorless, very unreactive gas. Calculate the pressure (atm) exerted by 1.82 moles of the gas in a steel vessel of volume 5.43 L at 69.5^oC.
- P = nRT/V

$$= \frac{(1.82\ \text{mol})\ (0.0821\ \text{L. atm/ K.mol})\ (69.5+273)\text{K}}{5.43\ \text{L}}$$

$= 9.42$ atm

Sample question 6

- A small bubble rises from the bottom of a lake, where the temperature and pressure are 8^oC and 6.4 atm, to the water's surface, where the temperature is 25^oC and pressure is 1 atm. Calculate the final volume (mL) of the bubble if its initial volume was 2.1mL!
- $V_2 = V_1 \times P_1/P_2 \times T_2/T_1$

$$= 2.1.\ \text{mL} \times \frac{6.4\ \text{atm}}{1.0\ \text{atm}} \times \frac{(25 + 273)\ \text{K}}{(8 + 273)\ \text{K}}$$

$= 14$ mL

Density calculations

- $PV = nRT$
- n = mass (m) / molecular mass (M)
- $n = PV/RT$
- $m/M.V = P/RT$
- $d = m/V = PM/RT$

Sample question 7

- Calculate the density of ammonia (NH_3) in grams per liter at 752 mmHg and 55^{o}C!
- P = 752 mmHg x 1 atm / 760 mmHg
- $d = PM/RT$

$$= \frac{(752/760)\ \text{atm}\ (17.03\ \text{g/mol})}{(0.0821\ \text{L.atm/K.mol})\ (328\ \text{K})}$$

$= 0.626$ g/L

Dalton's Law – Partial Pressure

- Describing the pressure, volume and temperature relationship of a sample of air, which contains several gases.
- *" The total pressure of a mixture of gases is just the sum of pressure that each gas would exert if it were present alone"*.

- Gas A and B

$P_A = n_A RT / V$
$P_B = n_B RT / V$
$P_T = P_A + P_B$
$= nRT / V$
$n = n_A + n_B$

$$\frac{P_A}{P_T} = \frac{n_A RT/V}{(n_A + n_B) RT/V}$$

$P_A/P_T = n_A/(n_A+n_B) = X_A$
$P_A = P_T . X_A$
$P_i = X_i . P_T$

X_A : mole fraction

The Kinetic Molecular Theory of Gases

- A relatively simple model that attempts to explain the behavior of an ideal gas is the **kinetic molecular theory.**
- This model is based on speculations about the behavior of the individual particles (atoms or molecules) in a gas

Postulates of the Kinetic Molecular Theory of Gases

1. Gases consist of tiny particles (atoms or molecules).
2. These particles are so small, compared with the distances between them, that the volume (size) of the individual particles can be assumed to be negligible (zero).
3. The particles are in constant random motion, colliding with the walls of the container. These collisions with the walls cause the pressure exerted by the gas.
4. The particles are assumed not to attract or to repel each other.
5. The average kinetic energy of the gas particles is directly proportional to the Kelvin temperature of the gas.

- The kinetic energy is the energy associated with the motion of a particle.
- Kinetic energy (*KE*) is given by the equation

$$KE = \frac{1}{2} mv^2,$$

  where m is the mass of the particle and v is the velocity (speed) of the particle.
- The greater the mass or velocity of a particle, the greater its kinetic energy.
- If a gas is heated to higher temperatures, the average speed of the particles increases; therefore, their kinetic energy increases.

Gas Stoichiometry

- We have looked at stoichiometry: 1) using masses & molar masses, & 2) concentrations.
- Stoichiometry can be used for gas reactions.
- We need to consider mole ratios when examining reactions quantitatively

Sample question 8

- Calculate the volume of oxygen gas produced at 1.00 atm and 25 °C by the complete decomposition of 10.5 g of potassium chlorate.

$$2KClO_{3(s)} \rightarrow 2KCl_{(s)} + 3O_{2(g)}$$

Sample question 9

- Quicklime, CaO, is produced by heating calcium carbonate, $CaCO_3$. Calculate the volume of CO_2 produced at STP from the decomposition of 152 g of $CaCO_3$ according to the reaction

$$CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$$

THANK YOU…