5.3 Reactions of Gases (Molar Volumes)

Law of combining volumes: when measured at the same temperature and pressure, volumes of gaseous reactants and products of chemical reactions are always in simple ratios of whole numbers.

Hydrogen (1L) + Chlorine (1L) → hydrogen chloride (2L)

(also known as **Gay-Lussac's law of combining volumes**)

Avogadro's theory: equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.

By using Avogadro's theory, the mole ratios provided by the balanced equation are also the volume ratios.

Sample: A catalytic converter in the exhaust system of a car uses oxygen (from the air) to convert carbon monoxide to carbon dioxide, which is released through the tail pipe. If we assume the same temperature and pressure, what volume of oxygen is required to react with 125 L of carbon monoxide produced during a 100-km trip?

Molar Volume of Gases

$$V_{stp}=22.4L/mol \qquad V_{satp}=24.8L/mol$$

Measuring the volume of a gas is much more convenient than measuring its mass. Molar volume can be used as a conversion factor to convert amount in moles to volume.

Sample: What volume is occupied by 0.024 mol of carbon dioxide gas at SATP?

Sample 2: What amount of oxygen, in moles, is available for a combustion reaction in a volume of 5.6 L at STP?

Molar volume and molar mass can be combined to calculate the volume of gas that is available from a known mass of a substance.

Sample 3: A propane tank for a barbecue contains liquefied propane. If the tank mass drops by 9.1 kg after a month's use, what volume of propane gas at SATP was used for cooking?

Worksheet 5.3 Reactions of Gases (Molar Volumes)

1. If 5.00 L of propane is burned in a gas barbecue, what volume of oxygen, at the same temperature and pressure, is required for complete combustion?

2. In modern automobile catalytic converters, nitrogen monoxide (a pollutant) reacts with hydrogen to produce nitrogen and water vapour (part of the exhaust). The catalytic converter of a car meeting current emission standards removes about 1.2 L of nitrogen monoxide at SATP for every kilometre of driving. What volume of nitrogen gas is formed from 1.2 L of nitrogen monoxide at the same temperature and pressure?

3. The production of sulfuric acid is a very important chemical industry in any developing or developed country. The main reactant required to produce sulfuric acid is sulfur, which can be obtained from a variety of sources.

    (a) One technology for removing hydrogen sulfide from sour natural gas involves converting part of the hydrogen sulfide to sulfur dioxide, which then reacts with the remaining hydrogen sulfide as shown in the reaction equation below. Predict the volume of sulfur dioxide needed to react completely with 248 kL of hydrogen sulfide. The gases are measured at 350°C and 250 kPa.

$$16\ H_2S_{(g)} + 8\ SO_{2(g)} \rightarrow 3\ S_{8(s)} + 16\ H_2O_{(g)}$$
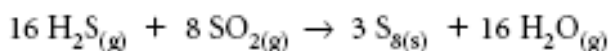
    (b) Solid sulfur is the starting material in the typical manufacture of sulfuric acid. First it is burned to form sulfur dioxide. Predict the volume of oxygen required to produce 250 kL of sulfur dioxide with all gases at 450°C and 200 kPa.

    (c) In the presence of the catalyst $V_2O_{5(s)}$, sulfur dioxide—from the burning of sulfur or directly from the output of a smelter—reacts with oxygen to form sulfur trioxide.

$$2\ SO_{2(g)} + O_{2(g)} \rightarrow 2\ SO_{3(g)}$$
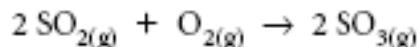
    Predict the volumes of sulfur dioxide and oxygen needed to produce 325kL of sulfur trioxide when all gases are measured at the same temperature and pressure.

4. Sulfur dioxide gas is emitted from marshes, volcanoes, and refineries that process crude oil and natural gas. What amount in moles of sulfur dioxide is contained in 50 mL of the gas at SATP?

5. Neon gas under low pressure emits the red light that glows in advertising signs.
        (a) What volume does 2.25 mol of neon gas occupy at STP before being added to neon tubes in a sign?
        (b) What pressure is reached when the gas is heated to 35°C by the Sun?
        (c) When designing the tube for this application, what specifications for the quality of the tube are necessary? Provide your reasoning.

6. One gram of baking powder produces about 0.13 g of carbon dioxide. What volume is occupied by 0.13 g of carbon dioxide gas at SATP?

7. Volatile liquids vaporize rapidly from opened containers or if spilled. Some vapours, such as those from gasoline, contribute to the formation of smog. What volume at STP is occupied by gasoline vapours from 50.0 g of spilled gasoline (assume octane, $C_8H_{18(l)}$)?

8. Millions of tonnes of nitrogen dioxide are dumped into the atmosphere each year by automobiles and are a major cause of smog formation. What is the volume of 1.00 t (1.00 Mg) of nitrogen dioxide at SATP?

9. Water vapour plays an important role in the weather patterns on Earth. What mass of water must vaporize to produce 1.00 L of water vapour at SATP?