Measuring gases

The following dot points from the VCE Chemistry Study Design 2023-2026 are covered in this text.

Measuring gases

- CO_2, CH_4 and H_2O as three of the major gases that contribute to the natural and enhanced greenhouse effects due to their ability to absorb infrared radiation
- the definitions of gas pressure and standard laboratory conditions (SLC) at 25 °C and 100 kPa
- calculations using the ideal gas equation ($pV = nRT$), limited to the units kPa, Pa, atm, mL, L ,°C, and K (including unit conversions)
- the use of stoichiometry to solve calculations related to chemical reactions involving gases (including moles, mass and volume of gases)
- calculations of the molar volume or molar mass of a gas produced by a chemical reaction

Helpful links

- Greenhouse gases
- Sources of GHGs
- Using and manipulating the ideal gas equation (PV=nRT)

Transformation of Solar Energy and the Greenhouse Effect

Energy from the Sun reaches Earth primarily as high energy, short wavelength, electromagnetic radiation. This radiation includes ultraviolet (UV) and visible light. This UV radiation passes through the Earth's atmosphere with relatively little absorption by atmospheric gases. When it reaches the Earth's surface, it is absorbed by land and ocean mass and transformed into infrared radiation. This causes the surface to heat up.

Figure 1 – Simulating the greenhouse effect in a passenger car

As the surface temperature increases, the absorbed energy is re-emitted as low energy, long wavelength infrared (IR) radiation. This change in wavelength occurs because warmer objects emit radiation at longer wavelengths than the Sun. It is this outgoing infrared radiation, not incoming UV radiation, that plays a key role in climate regulation. You may have experienced this phenomenon sitting in a car on a cold Winter's day with the glass windows closed. High energy UV radiation penetrates the glass windows and heats up the dashboard and any other internal surface directly exposed to sunlight. As the surface warms up it emits relatively low energy IR radiation that is unable to escape and ultimately warms the internal atmosphere of the car.

Certain atmospheric gases, known as greenhouse gases (GHGs), including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2) and water vapour (H_2O), have molecular properties that allow them to interact with and strongly absorb infrared radiation. These molecules possess bond vibrations whose frequencies closely match the frequencies of infrared radiation. As a result, they are able to absorb IR radiation efficiently.

When greenhouse gas molecules absorb infrared radiation, their bonds vibrate more vigorously, increasing the internal energy of the molecule. The absorbed energy is emitted as infrared radiation in all directions. Some of this emitted IR radiation returns towards Earth’s surface, reducing the rate at which energy escapes to space. This process retains heat within the atmosphere, increasing the average temperature of Earth and giving rise to the natural greenhouse effect.

Human activities, particularly the burning of fossil fuels and deforestation, have increased the concentration of greenhouse gases in the atmosphere. This intensifies the absorption of infrared radiation, leading to the enhanced greenhouse effect and contributing to climate change.

Using the Ideal Gas Equation to quantify the properties of gases.

The behaviour of gases under many conditions can be described using the ideal gas equation:

$$pV = nRT$$

where:

- p= pressure of the gas (in kPa)
- V= volume of the gas (in litres)
- n= amount of gas (in moles)
- R= gas constant (commonly given as a value of 8.31)
- T= temperature (in Kelvin)

Rearrangements of the Ideal Gas Equation

The ideal gas equation can be rearranged to solve for many unknown variables

- **Pressure:**

$$p = \frac{nRT}{V}$$

- **Volume:**

$$V = \frac{nRT}{p}$$

- **Number of moles:**

$$n = \frac{pV}{RT}$$

- **Temperature:**

$$T = \frac{pV}{nR}$$

- **Molar mass:**

$$M = \frac{mRT}{pV}$$

- **Density:**

$$d = \frac{Mp}{RT}$$

These rearrangements allow calculations involving changes in pressure, volume, temperature, or amount of gas, even density (*d)* and molar mass (*M)* can be calculated, provided the other variables are known.

Another important bit of information that will be very handy in these calculations is the molar volume of an ideal gas at SLC (25°C and 100kPa), given at 24.8 L mol^{-}.

Before attempting the assessment below view the attached video, for more clarity on how to attempt these questions.

1. Short wave (UV) energy originating from the Sun is ultimately transformed into a form of energy that is trapped by greenhouse gases in the Earth's atmosphere.

a. Name three greenhouse gases that contribute significantly to climate change

____ *1 mark*

b. Describe the type of energy and how it is absorbed by these gases in the atmosphere, which contributes to climate change.

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____ *3 marks*

2. Define gas pressure.

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____ *2 marks*

3. What is the volume occupied by the following gases at SLC?

a. 5.00 grams of nitrogen gas (N_2) *2 marks*

b. 1.80 grams of water vapour (H_2O) *2 marks*

4. Using the ideal gas equation, calculate the amount, in mol, of gas present in a 2.50 L container at 100 kPa and 35 °C. *2 marks*

5. A gas mixture is composed of 0.140 grams of N_2 and 0.640 grams of O_2. What is the total volume, in litres, occupied by this mixture when stored at 25°C and at a pressure of 100 kPa? *4 marks*

6. Magnesium reacts with hydrochloric acid according to the equation:

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

The gas produced is trapped in a gas syringe, as shown in fig. 2. Calculate the number of grams of magnesium metal that reacted, if 20.0 mL of gas is produced. *3 marks*

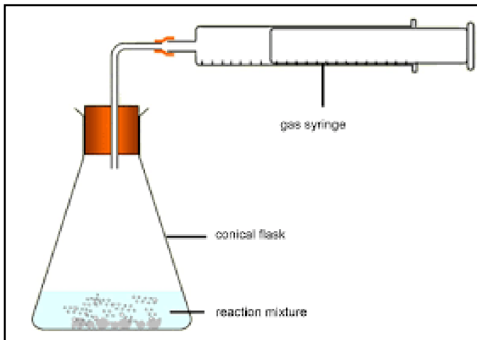

Figure 2 – Gas produced at SLC.

7. An unknown mass of CO_2 gas was placed in a 21.1 L vessel and sealed at a temperature of 30.0 °C and 110 kPa pressure. Calculate the mass of CO_2 in grams. *2 marks*

8. Calcium carbonate ($CaCO_3$) decomposes when heated to form CO_2 according to the chemical equation below.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

A mass of 2.48 kg of Calcium carbonate was heated and completely decomposed. The carbon dioxide produced was stored in a 300 litre sealed vessel at a pressure of 400 kPa. Calculate the temperature, in °C, of the gas. *3 marks*

9. Ammonia gas is formed according to the chemical equation given below.

$$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$$

The following volumes of each reactant were mixed at SLC in a 300 litre sealed reaction vessel, 4.96 litres of N_2 and 9.92 litres of H_2. The mixture was allowed to react at a temperature of 390 °C.

a. Which reactant is in excess? *2 marks*

b. What is the amount, in mol, of excess reactant left unreacted? *2 marks*

c. What is the amount, in mol, of product formed? *2 marks*

d. Calculate the pressure, in kPa, exerted on the walls of the reaction vessel after the reaction is complete? *2 marks*

10. An industrial process released 4523 L of exhaust gas into the atmosphere at SLC.
A 2.00 L sample of this exhaust gas was analysed and found to contain 4.40×10^{-4} g of CO_2.

a. Calculate the concentration of CO_2 in the exhaust gas, in ppm.
Show all calculations in the space provided below. *4 marks*

b. Calculate the total volume, in litres, of CO_2 in the 4523 litres of exhaust. *2 marks*