CHEM1901/3 Worksheet 8: The Ideal Gas Law: $PV = nRT$

Model 1: The Gas Laws

- $T$ (K) – Kelvin or absolute temperature = $T$ (°C) + 273°. $T$(K) is always $\geq 0$ K
- Boyle’s Law (1660). The volume of a gas varies inversely with pressure:
  \[ V = k_B \times \frac{1}{P} \quad k_B \text{ is Boyle’s constant} \]
- Charles’ Law (1887). The volume of a gas varies linearly with temperature:
  \[ V = k_C \times T \quad k_C \text{ is Charles’ constant} \]
- Avogadro’s Hypothesis (1812). The volume of a gas varies linearly with the number of moles:
  \[ V = k_A \times n \quad k_A \text{ is Avogadro’s gas constant} \]
- These are unified in the ideal gas law:
  \[ PV = nRT \quad R \text{ is the universal gas constant} \]

Critical thinking questions

1. Sketch on the graph below how the volume of a gas changes as the pressure is increased.

2. Sketch on the graph below how the volume of a gas changes as the temperature is increased.
3. Sketch on the graph below how the volume of a gas changes as the number of moles of gas is increased.

4. For each case, rearrange the ideal gas law to show that it is consistent with the given law or hypothesis and obtain an expression for the corresponding constant.

   (a) Boyle’s Law, $k_B$
   (b) Charles’ Law, $k_C$
   (c) Avogadro’s hypothesis, $k_A$

5. One mole of gas occupies 22.414 L at a pressure of 1.000 atm and a temperature of 0 °C (273.15 K). This is known as standard temperature and pressure or STP.

   Use the ideal gas law to work out the value of the universal gas constant, $R$, and its units.

6. The S.I. unit for volume is m$^3$ and for pressure is Pa where 1 m$^3$ = 1000 L and 1 atm = 1.01325×10$^5$ Pa.

   (a) What is the volume occupied by one mole of gas at STP in m$^3$?
The Ideal Gas Law

(b) Use the ideal gas law to work out the value of the universal gas constant, $R$, and its units when volume and pressure are given in S.I. units.

Model 2: Partial Pressures

In a mixture of gases, the \textit{partial pressure} of a gas is the pressure it would have if it alone occupied the volume. The total pressure of a gas mixture is the sum of the partial pressures of each individual gas in the mixture. The partial pressure of a gas A is given by:

$$P_A = n_A \frac{RT}{V}$$

The total pressure of the gases in a mixture is the sum of the partial pressures of each component:

$$P = P_A + P_B + P_C + P_D + ... = \sum_i P_i$$

Critical thinking questions

7. The density of air at 1.000 atm and 25°C is 1.186 g L$^{-1}$.

(a) Assuming that air is 80% nitrogen and 20% oxygen by volume, what are the partial pressures of the two gases?

(b) Calculate the \textit{average} molecular mass of air.

(c) Assuming that air is only made up of nitrogen and oxygen, calculate the % by mass of N$_2$ and O$_2$ in air.

Exercises

These exercises are based on those used in the theory parts of scuba diving courses.

The density of salt water is 1.03 g mL$^{-1}$ which translates to an increase in pressure of 1.00 atm for every 10.0 m of depth below the surface. If the pressure at the surface is 1.00 atm, it will be 2.00 atm at 10.0 m, 3.00 atm at 20.0 m, 4.00 atm at 30.0 m etc. Scuba equipment controls the air flow to the lungs so that their \textit{volume} is the same at depth as at the surface. It does this by providing air at a \textit{pressure} equal to that of the water at that depth.

1. A balloon is inflated at the surface to 6.0 L, the approximate volume of the lungs. What volume would the balloon have at a depth of 15.0 m?

2. At a depth of 30.0 m, the balloon is filled from a cylinder to a volume of 5.0 L and sealed. What volume will the balloon be at the surface?
3. A ‘reverse block’ is a painful effect that occurs when air is trapped inside a cavity (such as in the ears or inside a tooth) during a diver’s ascent. Discuss with your group the cause of the pain.

4. A 12 L air cylinder is filled to a pressure of 200 atm in an air conditioned diving shop at 22 °C. What will be the pressure inside the tank once it has been left in the sun at 35 °C?

5. What happens to the density of the air in a diver’s lungs during descent?

6. What is the partial pressure of O₂ in a diver’s lungs at a depth of 10.0 m?

7. Oxygen toxicity occurs when its partial pressure reaches around 1.6 atm*. What depth of water does this correspond to?

* This figure is dependent on the time spent and the individual physiology and is used here for illustrative purposes only.