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 ≥ 0 K
- Boyle's Law (1660). The volume of a gas varies inversely with pressure:

  $V = k_B \times \frac{1}{P}$ k_B is Boyle's constant

- Charles' Law (1787). The volume of a gas varies linearly with temperature:

  $V = k_C \times T$ k_C is Charles' constant

- Avogadros' Hypothesis (1812). The volume of a gas varies linearly with the number of moles:

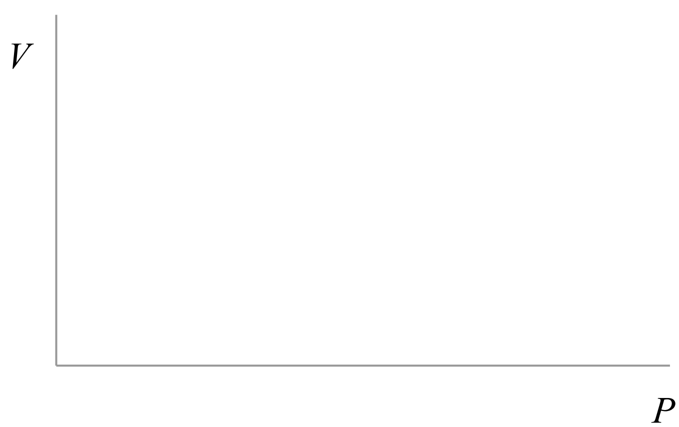
  $V = k_A \times n$ k_A is Avogadro's gas constant

- These are unified in the ideal gas law:

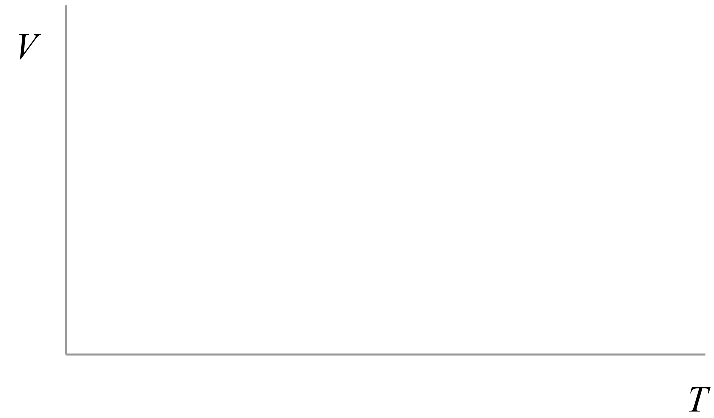
  $PV = nRT$ R is the universal gas constant

Critical thinking questions

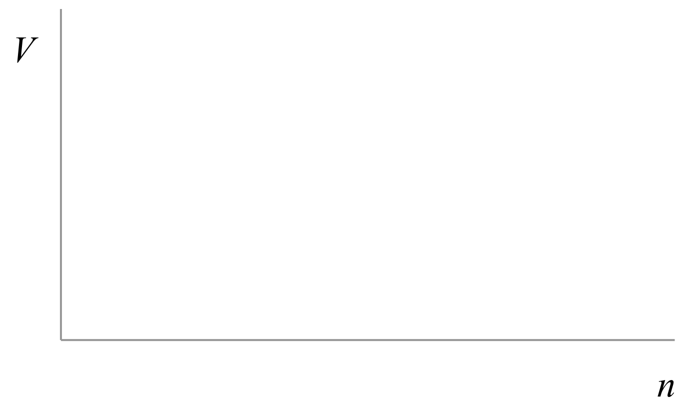
1. *Sketch* on the graph below how the volume of a gas changes as the pressure is increased.



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?

(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 *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 ndividual 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 *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 *volume* is the same at depth as at the surface. It does this by providing air at a *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 O_2 in a diver’s lungs at a depth of 10.0 m?

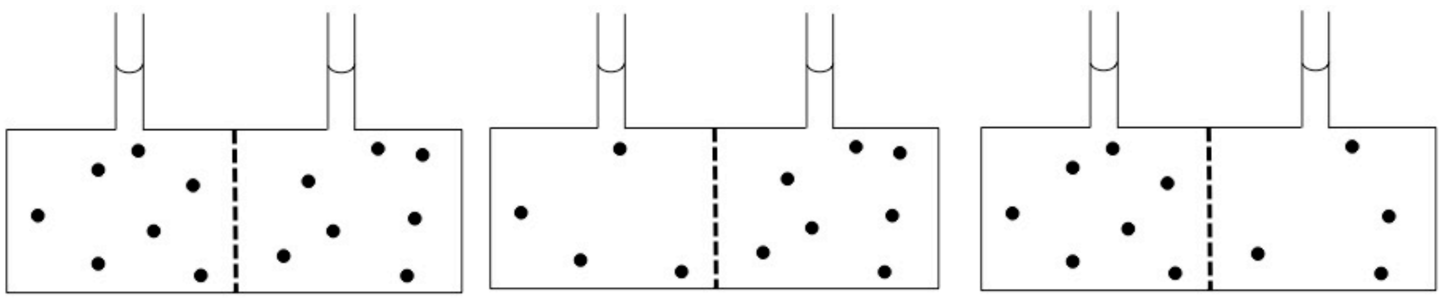
7. Oxygen toxicity occurs when its partial pressure reaches around 1.6 atm*. What depth of water does this correspond to?

Model 3: Osmotic pressure

A semi-permeable barrier blocks the passage of many (but not all) molecules and ions. The solvent (often water) can diffuse through it but many charged and large molecules cannot.

The concentration of the solutions on either side of a membrane is not at equilibrium, where the concentration is the same on both sides of the membrane. To achieve equilibrium, the solvent passes through the membrane to dilute the more concentrated side, but the solute molecules cannot pass through to increase the concentration of the more dilute side.

The figures below represent two solutions separated by a semipermeable membrane (the dashed line). The dots represent solute molecules with the number of dots representing the concentration of solute. The two halves of the container are open to the atmosphere, as represented by the open tubes, with liquid half-way up.



Critical thinking questions

1. When the concentration of solute is the same on both sides of the membrane, the water flows through the membrane at the same rate from both sides. Draw arrows on the other two figures to represent the flow of water across the membrane.
2. Indicate water levels in the three tubes after water has flowed across the membrane for some time.
3. Which side of the solution is at higher pressure? (Hint: consider the weight of the water above each side)

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

The pressure that must be applied to the solution to stop the processes described above is called the *osmotic pressure*, π. For dilute solutions, it is given by:

$\pi = cRT$ where $R = 8.314\ \text{J K}^{-1}\ \text{mol}^{-1}$

c is the concentration of *all* impermeable species in solution. As salts dissociate into ions in solution, the concentrations of all of the ions must be added together.

4. If 0.35 mol of NaCl and 0.15 mol of KCl are added to 1.00 L of water, calculate:

   (i) $[Na^+(aq)]$

   (ii) $[K^+(aq)]$

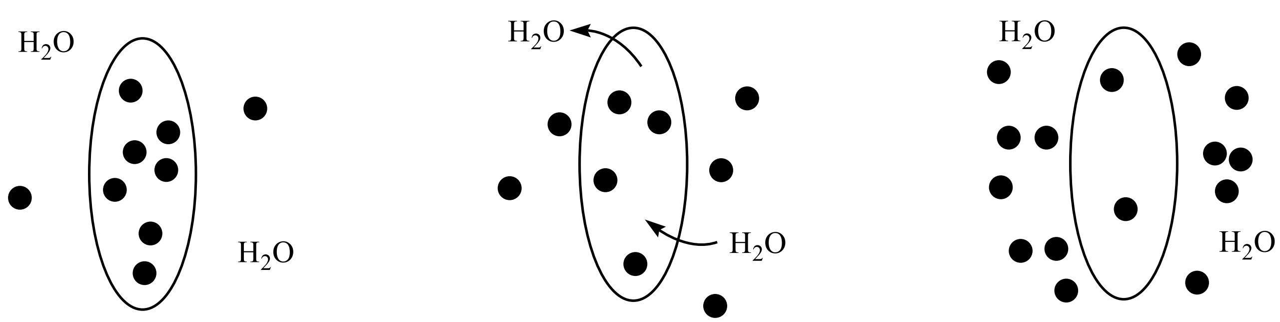
   (iii) $[Cl^-(aq)]$

5. What is the overall concentration of ions in this solution? Convert this value into mol m^{-3}. (*Hint:* there are 1000 litres in a m^3).

6. Calculate the osmotic pressure for this solution at 298 K.

Model 4: Osmotic pressure in biology

The cell membrane is a semi-permeable barrier to the passage of many (but not all) molecules and ions. The schemes below show 3 cells with solute particles shown as black dots. The first picture represents a cell which has *higher* levels of solute relative to the medium it is in. The second represents a cell which has the *same* levels of solute as the medium. The third represents a cell which has *lower* levels of solute than the medium.



(i) Hypotonic medium (ii) Isotonic medium (iii) Hypertonic medium

Critical thinking questions

1. In an isotonic medium, water flows in and out at the same rate. Draw arrows on the other two pictures to indicate the direction in which water flows.

2. Describe what you think will happen to the size of the cell in each of the mediums.

   (i)

   (ii)

   (iii)

3. Animal cells do not have cell walls. Using your answer to Q2, describe what might occur if pure water is accidentally injected into a blood vessel.