IDEAL GAS LAW, CALORIMETRY AND STARS

1) The Ideal Gas Law: \( PV = nRT \)

An ideal gas is made up of particles that:

a) Are so small that their sizes are negligible compared to the average distances between them
b) Are in constant, random motion, colliding with each other and the walls of a container
c) Experience no intermolecular forces
d) Have an average kinetic energy that is proportional to the absolute temperature

All ideal gases obey the following equation:

\[
PV = nRT
\]

What does each symbol in this equation mean? What are the SI units of each symbol?

In actuality, some gases deviate from ideal gas behaviour – why could this be?

1. Boyle’s Law: sketch on the graph how the volume \((V)\) of a gas changes as the pressure \((P)\) is increased (with a constant temperature, \(T\), and a constant number of moles of gas, \(n\)).

2. Charles’ Law: sketch on the graph how the volume \((V)\) of a gas changes as the temperature \((T)\) is increased (with a constant pressure, \(P\), and a constant number of moles of gas, \(n\)).

3. Avogadro’s Law: sketch on the graph how the volume \((V)\) of a gas changes as the number of moles of gas \((n)\) is increased (with a constant temperature, \(T\), and pressure, \(P\)).
4. 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.

5. The S.I. unit for volume is \( \text{m}^3 \) and for pressure is \( \text{Pa} \) where 1 \( \text{m}^3 = 1000 \text{ L} \) and 1 atm = \( 1.01325 \times 10^5 \text{ Pa} \).

   (a) What is the volume occupied by one mole of gas at STP in \( \text{m}^3 \)?
   
   (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.

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 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:

\[
P = P_A + P_B + P_C + ... = \sum_i P_i
\]

6. The density of air at 1.000 atm and 25°C is 1.186 g \( \text{L}^{-1} \).

   (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 \( \text{N}_2 \) and \( \text{O}_2 \) in air.

7. The density of salt water is 1.03 g \( \text{mL}^{-1} \), 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.

   a) 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?

   b) 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?
c) A 12 L air cylinder is filled to a pressure of \(2.00 \times 10^2\) 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?

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

e) What is the partial pressure of \(O_2\) in a diver’s lungs at a depth of 10.0 m?

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

3) Calorimetry

Calorimetry is the science of measuring the heat produced or absorbed by chemical reactions. A calorimeter is used to quantify the amount of heat released or absorbed. A calorimeter containing a known volume of a substance (e.g. water) with a known specific heat capacity can be constructed, and in a perfectly insulated system, the heat absorbed or lost by this substance will reflect the heat lost or absorbed by the reaction of interest.

The equation below can be solved for such a system:

\[
\Delta q = mc\Delta T
\]

...Equation 1

What does each symbol in this equation mean? What are the SI units of each symbol?

8. A calorimeter containing 300.0 mL of water at 25 °C was calibrated as follows. A 1000.0 W heating coil was run for 10.0 s, after which time the temperature had increased by 7.5 °C. Calculate the heat capacity of the empty calorimeter. The specific heat of water is 4.184 J K\(^{-1}\) g\(^{-1}\).

9. If 15.0 g of sodium nitrite was dissolved into this calorimeter, and the temperature of the solution was found to decrease by 2.6 °C, calculate the enthalpy of solution of sodium nitrite.
4) Stars (Stefan-Boltzmann Law)

The Stefan-Boltzmann law states that the total energy radiated per unit surface area of a black body per unit time is directly proportional to the fourth power of the black body’s temperature. If a star, such as the sun, is considered to be a black body:

\[ q = 4\pi r^2 \times 5.67 \times 10^{-8} \times T^4 \]

What does each symbol in this equation mean? What are the SI units of each symbol? (the Boltzmann constant has units of Js^{-1}m^{-2}K^{-4})

If this is the energy released by a black body at its surface, the amount of energy received by some other celestial body at a distance \( d \) km from the black body is:

\[ \text{Flux} = \frac{q_{\text{out}}}{4\pi d^2} \]

Albedo is a measure of the reflectivity of a surface. A perfect white surface has an albedo of 100% and a perfect black surface an albedo of 0%. Thus, a percentage albedo is the percentage of incident radiation that is reflected by a surface.

Assuming that a celestial body is in thermal equilibrium (i.e. energy in = energy out):

\[ E_{\text{in}} = \pi r^2 \times \text{flux} \times \% \text{ radiation absorbed} \]
\[ E_{\text{out}} = q = 4\pi r^2 \times 5.67 \times 10^{-8} \times T^4 \]

10. The diameter of Saturn’s moon, Titan, is 5150 km and it orbits at an average of \( 1.427 \times 10^9 \) km from the sun, or 9.54 times farther than the Earth. Its mean surface temperature is 94 K, it has an albedo of 0.09, and it has an atmosphere comprised of methane, nitrogen, ethane, argon and a trace of ammonia. The temperature of the sun is 5780 K and its radius is \( 6.96 \times 10^8 \) m. Determine the magnitude (in K) of the greenhouse effect on Titan’s atmosphere.