

## PROPERTIES OF GASES QUESTION SHEET

- An ideal gas at  $10\text{ }^\circ\text{C}$  and a pressure of  $100\text{ kPa}$  occupies a volume of  $2.5\text{ m}^3$ .
  - How many moles of gas are present?
  - If the pressure is now raised to  $300\text{ kPa}$  and the temperature raised to  $30\text{ }^\circ\text{C}$ , what volume will the gas now occupy?
  - The best vacuum that can be attained in the laboratory corresponds to a pressure of about  $10^{-18}\text{ atm}$ , or  $1.01 \times 10^{-13}\text{ Pa}$ . How many molecules are there per cubic centimetre in such a vacuum at  $298\text{ K}$ ?
- The average velocity of the molecules in a gas must be zero if the gas as a whole is not in translational motion. Explain how it can be that the average speed is not zero.
- The equation of state for a non-ideal gas is often written as a virial expansion, the first two terms of which are:

$$pV_m = RT(1 + B'p)$$

The second virial coefficient,  $B'$ , takes the form  $B' = a - b e^{c/T}$

- What is the physical origin of the second virial coefficient (i.e. why do real gases deviate from ideal behaviour)?
  - The Boyle temperature is the temperature at which  $B' = 0$ . What is the physical significance of this temperature?
  - For  $\text{N}_2$ , the coefficients in the above expression for  $B'$  take the values  $a = 185.4$ ,  $b = 141.8$ ,  $c = 88.7\text{ K}$ . Calculate the Boyle temperature for  $\text{N}_2$ .
- A gas can transmit only those sound waves whose wavelength is long compared with the mean free path. What is the reason for this? Describe a situation where this limitation might be important.
    - At what frequency would the wavelength of sound in air be equal to the mean free path in oxygen at  $1.0\text{ atm}$  pressure and  $0\text{ }^\circ\text{C}$ . (Take the diameter of the oxygen molecule to be  $3.0 \times 10^{-10}\text{ m}$ ).
  - The sun may be treated as a huge ball of hot ideal gas. The corona (the sun's atmosphere) has a temperature and pressure of  $2.0 \times 10^6\text{ K}$  and  $0.030\text{ Pa}$ , respectively. Calculate the rms speed of free electrons ( $m_e = 9.1 \times 10^{-31}\text{ kg}$ ) in the corona.

- Plot the Maxwell-Boltzmann distribution of molecular speeds for  $\text{N}_2$  molecules at a temperature of  $500\text{ K}$ .
  - What is the most probable speed of the  $\text{N}_2$  molecules?
  - Write down an expression, in the form of an integral, that describes the probability of finding a particle with a speed lying between the two limits  $v_1$  and  $v_2$ .
  - The fraction of particles with velocities between zero and the rms speed is not equal to the fraction of particles with velocities between zero and the mean speed. Why are these fractions not equal?
- An effusion cell has a circular orifice  $1\text{ mm}$  in diameter. If the molar mass of the solid in the cell is  $260\text{ g mol}^{-1}$  and its vapour pressure is  $0.835\text{ Pa}$  at  $400\text{ K}$ , by how much will the mass of the solid decrease over a period of two hours?
- In a double-glazed window the panes of glass are separated by  $5\text{ cm}$ . What is the rate of transfer of heat by conduction from the warm room ( $25\text{ }^\circ\text{C}$ ) to the cold exterior ( $-10\text{ }^\circ\text{C}$ ) through a window of area  $1.0\text{ m}^2$ ? What power of heater is required to make up for the loss of heat? (The coefficient of thermal conductivity for air is  $\kappa = 0.025\text{ W m}^{-1}\text{ K}^{-1}$ ).
- An electric light bulb contains argon at  $50\text{ Torr}$  and has a tungsten filament of radius  $0.10\text{ mm}$  and length  $5.0\text{ cm}$ . When operating, the gas close to the filament surface has a temperature of around  $1000\text{ }^\circ\text{C}$ . How many collisions are made with the filament per second?
- Collision densities for a binary gas mixture can be calculated using

$$Z_{XY} = \sigma \left( \frac{8k_B T}{\pi \mu} \right)^{1/2} N_A^2 [X][Y]$$

where  $\mu$  is the reduced mass. The reaction  $\text{H}_2 + \text{I}_2 \rightarrow 2\text{HI}$  depends on collisions between a variety of species in the reaction mixture. Assuming  $\sigma(\text{H}_2) = 0.27\text{ nm}^2$  and  $\sigma(\text{I}_2) = 1.2\text{ nm}^2$ , for a gas containing partial pressures of  $0.50\text{ atm}$  each of  $\text{H}_2$  and  $\text{I}_2$  at  $400\text{ K}$ , calculate the collision densities for the encounters of: (i)  $\text{H}_2 + \text{H}_2$ ; (ii)  $\text{I}_2 + \text{I}_2$ ; and (iii)  $\text{H}_2 + \text{I}_2$ .