Properties of Gases Problems

1. An office window measures 3.4 m by 2.1 m. As a result of the passage of a storm, the outside air pressure drops to 0.96 atm, but inside the pressure is held at 1.0 atm. What net force pushes out on the window?

2. The human lungs can operate against a pressure differential of up to one twentieth of an atmosphere. If a diver uses a snorkel for breathing, how far below water level can he swim?

3. Where does the average speed of air molecules in still air at room temperature fit into the following sequence?
   $2\ ms^{-1}$ (walking speed)
   $30\ ms^{-1}$ (fast car)
   $500\ ms^{-1}$ (concorde)
   $1.1x10^4\ ms^{-1}$ (escape velocity from earth)
   $3x10^8\ ms^{-1}$ (speed of light)?

4. The average velocity of the molecules in a gas must be zero if the gas as a whole and the container are not in translational motion. Explain how it can be that the average *speed* is not zero.

5. The equation of state for a non-ideal gas is often written in terms of a *virial* expansion, the first two terms of which are:

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

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

   (a) What is the physical origin of the second virial coefficient i.e. why do real gases deviate from ideal behaviour?

   (b) The Boyle temperature is the temperature at which $B' = 0$. What is the physical significance of this temperature?

   (c) For N_2, the coefficients in the above expression for B' take the values $a = 185.4$, $b = 141.8$, $c = 88.7$. Calculate the Boyle temperature for N_2.

6. (a) A gas can transmit only those sound waves whose wavelength is long compared with the mean free path. Can you explain this? Describe a situation for which this limitation might be important.

   (b) At what frequency would the wavelength of sound in air be equal to the mean free path in oxygen at 1.0 atm pressure and 0 °C. Take the diameter of the oxygen molecule to be $3.0x10^{-10}$ m.

7. The best vacuum that can be attained in the laboratory corresponds to a pressure of about 10^{-18} atm, or $1.01\text{x}10^{-13}$ Pa. How many molecules are there per cubic centimetre in such a vacuum at 298 K?

8. An ideal gas at 10 °C and a pressure of 100 kPa occupies a volume of 2.5 m^3.

   (a) How many moles of gas are present?

   (b) If the pressure is now raised to 300 kPa and the temperature raised to 30 °C, what volume will the gas now occupy?

9. (a) The lowest temperature in outer space is 2.7 K. What is the rms speed of hydrogen molecules at this temperature?

   (b) The sun may be treated as a huge ball of hot ideal gas. The glow surrounding the sun is the corona – the sun's atmosphere – and has a temperature and pressure of $2.0\text{x}10^6$ K and 0.030 Pa, respectively. Calculate the rms speed of free electrons (mass $9.1\text{x}10^{-31}$ kg) in the corona.

10. A group of particles has the following speed distribution, where N_i represents the number of particles with speed v_i.

v_i / cm s^{-1}	1	2	3	4	5
N_i	2	4	6	8	2

Determine:
   (a) the average speed;
   (b) the root-mean-square speed;
   (c) the most probable speed (from the five speeds shown).

11. (a) Plot the Maxwell-Boltzmann distribution of molecular speeds for N_2 molecules at a temperature of 500 K.
   (b) What is the most probable speed of the N_2 molecules?
   (c) 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.
   (d) This integral cannot be solved analytically. Use the rectangle rule or trapezium rule to determine the fraction of molecules with speeds
   (i) greater than and less than the rms speed.
   (ii) greater than and less than the mean speed.
   (e) Why are the fractions in (ii) not equal?

12. An effusion cell has a circular orifice 1 mm in diameter. If the molar mass of the solid in the cell is 260 g mol^{-1} and its vapour pressure is 0.835 Pa at 400 K, by how much will the mass of the solid decrease over a period of two hours?

13. In a double-glazed window, the panes of glass are separated by 5 cm. What is the rate of transfer of heat by conduction from the warm room (25 °C) to the cold exterior (-10 °C) through a window of area 1.0 m^2? What power of heater is required to make up for the loss of heat?

[The coefficient of thermal conductivity for air is $\kappa = 0.025\ Wm^{-1}K^{-1}$.]

14. An electric light bulb contains argon at 50 Torr and has a tungsten filament of radius 0.10 mm and length 5.0 cm. When operating, the gas close to the filament surface has a temperature of around 1000 °C. How many collisions are made with the filament per second?

15. The reaction $H_2 + I_2 \rightarrow 2HI$ depends on collisions between a variety of species in the reaction mixture. For a gas containing partial pressures of 0.50 atm each of H_2 and I_2 at 400 K, calculate the collision densities for the encounters of

    (a) $H_2 + H_2$
    (b) $I_2 + I_2$
    (c) $H_2 + I_2$

    [Use $\sigma(H_2) = 0.27\ nm^2$ and $\sigma(I_2) = 1.2\ nm^2$.]