Constants to be used: Gas constant \( R = 8.314 \text{ JK}^{-1}\text{mol}^{-1} \)

1. (10%) (a) Calculate the root-mean-square speed of \( \text{O}_2 \) molecules at the standard temperature. (b) The collision cross-section between two \( \text{O}_2 \) molecules is \( 0.4 \times 10^{-18} \text{ m}^2 \). Estimate the mean free path of \( \text{O}_2 \) molecules in a oxygen gas at the standard ambient temperature and pressure.

2. (10%) In van der Waals equation of state given in the following:

\[
(p + \frac{an^2}{V^2})(V(nb)) = nRT,
\]

there are two parameters \( a \) and \( b \). Give physical explanations for the two terms containing the two parameters.

3. (10%) An ideal gas makes an extremely slow adiabatic expansion from pressure \( P_i \) and volume \( V_i \), to pressure \( P_f \) and volume \( V_f \). Show that the work done by the gas during the expansion is

\[
W = \frac{1}{\gamma - 1}(P_iV_i - P_fV_f),
\]

where \( \gamma = C_p/C_v \), the ratio of the molar specific heats at constant pressure and at constant volume.

4. (10%) An ideal gas of \( n \) moles expands isothermally and reversibly from volume \( V_i \) to \( V_f \). What is the change in entropy of the gas in this expansion?

5. (15%) A gas of diatomic molecules \( \text{A}_2 \) is 25% dissociated at \( T=1300\text{K} \) and \( P=1\text{bar} \) in the equilibrium \( \text{A}_2 (g) \leftrightarrow 2 \text{ A (g)} \). Calculate (a) equilibrium constant \( K \), (b) the standard reaction Gibb energy \( \Delta_r G^\circ \), and (c) equilibrium constant \( K \) at \( T=100{\degree} \text{C} \) given that the standard reaction enthalpy \( \Delta_r H^\circ =37.2 \text{ kJmol}^{-1} \) over the temperature range.
6. (10%) A reaction \(2A \rightarrow P\) has a second-order rate law with rate constant \(k = 1.5 \text{ mL mol}^{-1}\text{s}^{-1}\). Calculate the time required for the concentration of A to change from 0.25 molL\(^{-1}\) to 0.025 molL\(^{-1}\).

7. (10%) A rate constant is \(1.6 \times 10^{-4} \text{ L mol}^{-1}\text{s}^{-1}\) at 25°C and \(2.5 \times 10^{-3} \text{ L mol}^{-1}\text{s}^{-1}\) at 37°C. Evaluate the Arrhenius parameters of the reaction.

8. (15%) For a particle of mass \(m\) in a one-dimensional infinite square well between \(x=0\) and \(x=L\), what are the energies and the normalized wave functions for the first three levels? What is the probability of finding the particle between \(x=L/4\) and \(x=3L/4\) in the ground state?

9. (10%) The Hamiltonian of a spherical rotor is

\[
H = \frac{J^2}{2I},
\]

where \(J\) is the angular momentum and \(I\) is the moment of inertia. What are the energy levels of the rotor? If \(P_0\) and \(P_1\) are the probabilities for finding the rotor in the ground and the first-excited states, respectively, find the expression for the ratio \(P_1/P_0\) at temperature \(T\).