1. Super-saturated sugar water is enclosed in a container that is isolated from its surroundings. After a while the sugar water system reaches equilibrium, some particles of sugar are found to precipitate at the bottom of the container.

(a) What phases, and components in each phase, exist within the sugar-water system when equilibrated. *(5%)*

(b) What are the controlled state variables during this process of reaching equilibrium? *(5%)*

(c) What is the conservation equation that governs the energy balance of this system? *(5%)*

(d) Derive the conditions for equilibrium in the sugar-water system among different phases *(10%)*

2. One liter of ideal gas at 100°C is adiabatically expanded in a turbine from a pressure of 20 atm to 2 atm. Although the turbine does operate adiabatically, it's not 100% efficient and only produces 1 KJ of work.

(a) Use the equation of state of ideal gas and thermodynamics 1st law to show that during adiabatic and reversible expansion, $C_P = C_V + nR$, and $TV^{\gamma-1}$=constant.

Here T is temperature, V the volume, n the molar number, R the ideal gas constant, and $\gamma = C_P / C_V$ is the ratio of heat capacity measured at constant pressure and volume conditions, respectively. *(8%)*

(b) What is the final temperature of the gas exiting the turbine, providing $C_V = \frac{5}{2}R$? (8%)

(c) What is the entropy change of the gas due to the turbine inefficiency, providing $C_P = \frac{7}{2}R$? (9%)

3. Hydrogen and bromine chemistry are considered in redox flow batteries for large scale energy storage. A proposed mechanism for the reaction between H_2 and Br_2 is described as the following:

$$Br_2 \rightleftharpoons 2Br^{\cdot}$$
$$H_2 + Br^{\cdot} \rightarrow HBr + H^{\cdot}$$
$$Br_2 + H^{\cdot} \rightarrow HBr + Br^{\cdot}$$
$$HBr + H^{\cdot} \rightarrow H_2 + Br^{\cdot}$$

Use stationary-state approximation by assuming that all radicals are considered short-lived, make necessary assumptions, and note that only the first reaction is reversible.

(a) Find the concentration of free radical $Br^{\cdot}$ in terms of the concentration of steady species. *(5%)*

(b) Find the concentration of free radical $H^{\cdot}$ in terms of the concentration of steady species. *(5%)*

(c) Derive the rate expression for the HBr production. *(5%)*

4. The following data are obtained at 25°C in a constant-volume batch reactor using pure ozone, O_3:

Time, minute	0	2	4	6	8	10	12	14	∞
Partial pressure of O_3, mm Hg	760	600	475	390	320	275	240	215	150

The stoichiometry of the decomposition of ozone is $2O_3 \rightarrow 3O_2$. Find a rate equation which satisfactorily represents this decomposition. *(15%)*

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5. Particles of graphite are burned in a pressurized 20% oxygen stream. Analyze the process on the basis of shrinking-core model. The graphite particles have the following properties:
radius $R = 8\text{mm}$, density $\rho = 2.4\text{gm/cm}^3$, rate constant $k'' = 15\text{cm/sec}$. Reaction temperature = 850°C.

(a) For the high gas velocity used we may assume that the film diffusion does not offer any resistance to transfer and reaction. Draw a schematic diagram of a shrinking graphite particle undergoing such a burning process, and plot the radial concentration distribution of oxygen near the particle with this assumption. *(10%)*

(b) Calculate the time τ required for complete combustion of graphite particles. *(10%)*

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