

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%)

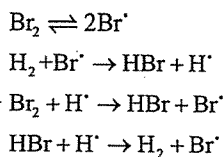
2. One liter of ideal gas at 100°C is adiabatically expanded in a turbine from a pressure of 20 atm to 2 atm. Although the turbine does operate adiabatically, it's not 100% efficient and only produces 1 KJ of work.

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

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:



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	$\infty$
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%)

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 =  $850^\circ\text{C}$ .
- (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  $\tau$  required for complete combustion of graphite particles. (10%)

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