1. Consider a fertilized hen egg in an incubator at a constant temperature and pressure environment. In a few weeks, the egg will hatch into a chick.
   (a) In the fertilized egg, hen proteins are formed into a highly ordered chick. Does this violate the Second Law of Thermodynamics? Why? (5%)
   (b) Does the free energy of the system (the egg) increase, decrease or remain the same? Why? (5%)

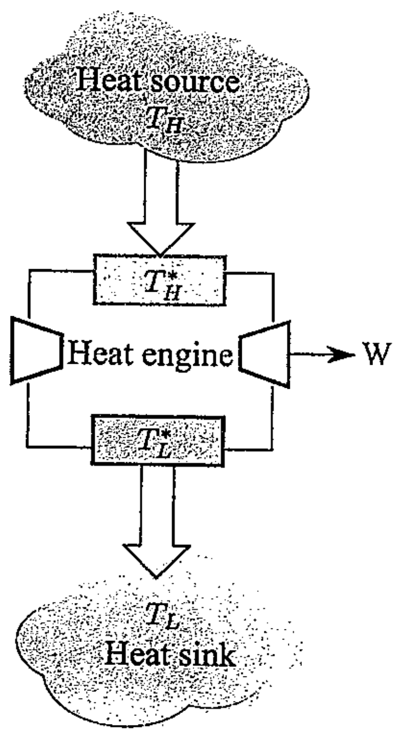
2. On the planet Taurus II, ammonia plays a role similar to that of water on Earth. Ammonia has the following properties: Normal (1bar) boiling point is -33.4°C where its enthalpy of vaporization is 23.34 kJ/mol. Normal freezing point is -77.7°C.
   (a) Estimate the temperature at which the vapor pressure of $NH_3(l)$ is 8 kPa. (10%)
   (b) Calculate the entropy of vaporization of NH_3 at its normal boiling point. (5%)

3. The Carnot engine is assumed to be in thermal equilibrium with the source and the sink during the heat addition and heat rejection processes. In other words, $T_H^* = T_H$ and $T_L^* = T_L$ so that there is no external irreversibility. The thermal efficiency of the Carnot engine is $\eta_C = 1 - T_L / T_H$. In reality, there must remain some temperature difference between two heat transfer media in order to have an acceptable heat transfer rate through a finite heat exchanger surface area. The heat transfer rates can be expressed as

$$\dot{Q}_H = (hA)_H (T_H - T_H^*)$$
$$\dot{Q}_L = (hA)_L (T_L^* - T_L)$$

where h and A are the heat transfer coefficient and heat transfer surface area, respectively. When the values of h, A, T_H, and T_L are fixed, (a) show that the power output will be a maximum when $\frac{T_L^*}{T_H^*} = \left(\frac{T_L}{T_H}\right)^{1/2}$. (13%)

(b) Also show that the maximum net power $\dot{W}_{C,\max} = \frac{(hA)_H T_H}{1 + (hA)_H / (hA)_L}\left[1 - \left(\frac{T_L}{T_H}\right)^{1/2}\right]^2$ (12%)



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4. Consider an isothermal gas-phase isomerization reaction A→B. The reciprocal of chemical reaction rate ($1/-r_A$) was determined in a laboratory as a function of conversion (X), as listed in the following table. The temperature was 500K (440 °F), the total pressure was 830 kPa (8.2 atm), and the initial charge to the reactor was pure A. The volumetric flow rate of A is 0.01 m^3/s, and the entering concentration of A is 40 mol/m^3.

X	0	0.1	0.2	0.4	0.6	0.7	0.8
$1/-r_A$ ($m^3 \cdot s/mol$)	2.22	2.70	3.33	5.13	8.85	12.7	20

(a) Justify why the Levenspiel plot suggests that $-1/r_A$ is proportional to $1/(1-X)$. (5%)
(b) Estimate the difference in the reactor volume between a CSTR and a PFR required for achieving a conversion of 80%. (10%)

5. The isomerization of butane $n\text{-}C_4H_{10} \leftrightarrow i\text{-}C_4H_{10}$ was carried out adiabatically in the liquid phase. The rate data for this reversible reaction are given below (for an entering molar flow rate F_{A0} of n-butane of 50 kmol/hr). Assume that three reactors in series (CSTR1-PFR-CSTR2) are used to achieve a final conversion of X = 0.65, while the conversion values at the exits of the first CSTR and PFR are 0.2 and 0.6, respectively.

X	0	0.2	0.4	0.6	0.65
$-r_A$ ($mol/m^3 \cdot s$)	39	53	59	38	25
$[F_{A0}/-r_A]$ (m^3)	1.28	0.94	0.85	1.32	2.0

(a) Estimate the volume of each of the reactors, i.e., V_{CSTR1}=? V_{PFR}=? V_{CSTR2}=? (9%)
(b) Assume that the entering concentration of n-butane is 0.1 mol/dm^3, estimate the space time for each of the reactors according to (a). (6%)

6. When a competitive inhibitor I is present, the enzyme kinetics is changed and undergoes the following reaction mechanism.

$$\text{E (enzyme)} + \text{S (substrate)} \rightarrow \text{E}\cdot\text{S},\ k_1$$
$$\text{E}\cdot\text{S} \rightarrow \text{E} + \text{S},\ k_2$$
$$\text{E}\cdot\text{S} \rightarrow \text{P} + \text{E},\ k_3$$
$$\text{I} + \text{E} \rightarrow \text{E}\cdot\text{I (inactive)},\ k_4$$
$$\text{E}\cdot\text{I} \rightarrow \text{E} + \text{I},\ k_5$$

(a) Show that the rate law for the enzyme reaction in the presence of a competitive inhibitor can be described by the following equation. (10%)

$$r_P = -r_S = \frac{V_{max}[S]}{[S] + K_M\left(1 + {[I]}/{[K_I]}\right)}$$

(b) On the derivation of the above rate law, did you use pseudo-steady-state hypothesis (PSSH), rate-determining-step (RDS) assumption, or both? (4%)
(c) Draw the $1/-r_S$ vs. $1/[S]$ plots (the Lineweaver-Burk plot) for the cases of (i) no inhibitor, (ii) low-concentration inhibitor, and (iii) high-concentration inhibitor. (6%)

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