CHEM 3423 001 Spring 2016

Name: KEY
ID:

Final Exam

Answer Sheet: (All problems are multiple choice. List the letter that corresponds to the correct answer. Maximum number of points you can get is 50 pts!)

Conceptual questions (each **1.0 pts**):

1) d
2) d
3) d
4) b
5) c
6) a
7) b
8) c
9) d
10) a
11) b
12) a
13) c
14) b
15) b
16) d
17) d
18) b
19) b
20) c
21) b
22) a

Problems and Calculations (each **2.0 pts**):

1) b
2) E
3) F
4) F
5) E
6) d
7) c
8) d
9) d
10) F
11) E
12) E
13) g
14) E

Bonus question (**1.0 pt**):

1) E

Conceptual Questions:

1. Which of the following properties is extensive?
    - a. Density
    - b. Pressure
    - c. Chemical potential
    - [✓ d.] Energy
    - e. None of above

2. Suppose we decrease the temperature of a gas by a factor 2 ($T_2 = 0.5\ T_1$). What is the relationship between the average speed of molecules?
    - a. $v_2 = 2\ v_1$
    - b. $v_2 = v_1$
    - c. $v_2 = \sqrt{2}v_1$
    - [✓ d.] $v_2 = v_1/\sqrt{2}$
    - e. $v_2 = \frac{1}{2}\ v_1$
    - f. None of above

3. Let P_W be the pressure resulting from a 2 m column of water, and P_H be the pressure resulting from a 2 m column of mercury. Which statement is true?
    - a. $P_w = P_H$
    - b. $P_w > P_H$
    - c. $P_w = \sqrt{P_H}$
    - [✓ d.] $P_w < P_H$
    - e. None of above

4. For an ideal gas, the molar heat capacity at constant volume is
    - a. larger than the molar heat capacity at constant pressure
    - [✓ b.] smaller than the molar heat capacity at constant pressure
    - c. equal to the molar heat capacity at constant pressure
    - d. the negative of the molar heat capacity at constant pressure
    - e. None of above

5. In the van der Wall's equation, the correction for volume accounts for
    - a. The speed of gas molecules
    - b. Attractive interactions between gas molecules
    - [✓ c.] Finite size of gas molecules
    - d. None of above

6. Under constant temperature and constant pressure conditions, a system is said to be in equilibrium when
    - [✓ a.] $\Delta G = 0$
    - b. $\Delta A = 0$
    - c. $\Delta S = 0$
    - d. $\Delta H = 0$
    - e. None of above

7. Which of the following statements is true for a Carnot cycle?
    a. The efficiency of a Carnot Cycle does not depend on temperature
    [✓ b.] All Carnot engine (working between same temperatures) have the same efficiency.
    c. A Carnot engine that includes irreversible processes is more efficient than one build only out of reversible processes
    d. A Carnot engine cannot be used as a refrigerator
    e. None of above

8. The entropy change in a Carnot cycle is
    a. positive
    b. negative
    [✓ c.] zero
    d. depends on temperature ratio
    e. None of above

9. How many different phases can at most co-exist in an one-component system?
    a. 0
    b. 1
    c. 2
    [✓ d.] 3
    e. None of above

10. Which of the following is correct for a completely immiscible 2-component solution?
    [✓ a.] $P = P_A^* + P_B^*$
    b. $P = P_A^* - P_B^*$
    c. $P = x_A P_A^* + x_B P_B^*$
    d. $P = x_A P_A^* - x_B P_B^*$
    e. $P = P_A^* P_B^*$
    f. None of above

11. Determine the number of degrees of freedom for ice in a solution of water and alcohol
    a. 3
    [✓ b.] 2
    c. 1
    d. 0
    e. None of above

12. Consider an ideal solution mixture of components A and B in equilibrium with vapor. B is more volatile than A. Compared to the liquid, the vapor contains
    [✓ a.] Less of component A
    b. Less of component B
    c. Equal amounts of A and B

13. Assume two chemical reactions $A + B \Leftrightarrow X + Y$ and $X \Leftrightarrow Z$, characterized by equilibrium constants K_1 and K_2, that are coupled leading to a resulting reaction $A + B \Leftrightarrow Y + Z$. The resulting equilibrium constant K_3 is given by
   a. $K_3 = K_1 + K_2$
   b. $K_3 = K_1 - K_2$
   [✓ c.] $K_3 = K_1 * K_2$
   d. $K_3 = K_1^{-1} + K_2^{-1}$
   e. $K_3 = K_1 / K_2$
   f. None of above

14. For a chemical reaction $A + B \Leftrightarrow C$ we measure an equilibrium constant $K^0 < 1$. Under standard conditions, the reaction will proceed spontaneously from
   a. Left to right ($A + B \Rightarrow C$)
   [✓ b.] Right to left ($C \Rightarrow A + B$)

15. Assume that the enthalpy difference ΔH^0 between products and reactants in a chemical reaction is independent of temperature, and $\Delta H^0 < 0$. How does an equilibrium constant K^0_p (describing the same reaction) change if the temperature is increased?
   a. K^0_p increases
   [✓ b.] K^0_p decreases
   c. K^0_p does not change

16. Assume a reaction $A + B \Rightarrow Z$. Empirically, we find the following relation between the rate of formation of a product Z and the concentrations of two reactants A and B: $v_Z = k_Z [A]^{0.5}[B]^{1.5}$. What would be the order of the reaction?
   a. 0.5
   b. 1
   c. 1.5
   [✓ d.] 2
   e. 2.5
   f. None of above

17. Assume a reaction $A \Leftrightarrow B$, characterized by rate constants k_{AB} and k_{BA}. These two rate constants are related to the equilibrium constant K_c by
   a. $K_c = k_{AB} + k_{BA}$
   b. $K_c = k_{AB} - k_{BA}$
   c. $K_c = k_{AB} * k_{BA}$
   [✓ d.] $K_c = k_{AB}/k_{BA}$
   e. $K_c = k_{BA}/k_{AB}$
   f. None of a) – e)

18. The following reaction describes dissociation of chlorine into atoms: $Cl_2 \Leftrightarrow 2Cl$. If the volume is increased, the degree of dissociation

   a. decreases
   [✓ b.] increases
   c. does not change

19. Assume two first-order reactions characterized by rate constants k_1 and k_2, with $k_2 = 4*k_1$. The half-life of reaction 1 is

   a. Double that of reaction 2
   [✓ b.] Four times that of reaction 2
   c. Half that of reaction 2
   d. A quarter of that of reaction 2
   e. None of above

20. If a reaction has a rate constant of $k = 6.3 \times 10^{-5}$ l/(mol s), the reaction is

   a. Zero order
   b. First order
   [✓ c.] Second order
   d. Cannot be determined based on the given information
   e. None of above

21. In the consecutive reaction $A \overset{k_1}{\rightarrow} X \overset{k_2}{\rightarrow} Z$, where X is an intermediate, the steady state condition applies when

   a. k_1 is much larger than k_2
   [✓ b.] k_2 is much larger than k_1
   c. none of the above

22. In an enzyme-catalyzed reaction, if the concentration of substrate is very large, the reaction is

   [✓ a.] Zero-order in substrate
   b. First-order in substrate
   c. Second order in substrate
   d. Third-order in substrate
   e. None of above

Problems and Calculations:

1. Calculate the pressure of 4 dm³ of a gas weighing 55.0 g at 500 K using the van der Waal's equation (use $a = 0.75$ Pa m^6/mol^2; $b = 0.00005$ m^3/mol). The molar mass of the gas is $M = 35.0$ g/mol
    a. 0.15489 Pa
    b. 1.5489 Pa
    c. 15.489 Pa
    d. 154.89 Pa
    e. 1548.9 Pa
    f. 15.489 kPa
    g. 154.89 kPa
    [✓ h.] 1548.9 kPa
    i. 15489 kPa
    j. none of above

$$\left(P+\frac{an^2}{V}\right)(V-nb)=nRT$$

$$P=\frac{nRT}{V-nb}-\frac{an^2}{V^2} \qquad n=\frac{m}{M}=1.57$$

$$=\left(\frac{1.57\cdot 8.3145\cdot 500}{4\cdot 10^{-3}-1.57\cdot 5\cdot 10^{-5}}-\frac{0.75\cdot 1.57^2}{4.4\cdot 10^{-6}}\right)\text{Pa}$$

$$=\left(\frac{6526.88}{0.0039215}-\frac{1.848675}{1.6\cdot 10^{-5}}\right)\text{Pa}$$

$$=(1.6644-0.1155)\,10^6\ \text{Pa}$$

$$=1.5489\cdot 10^6\ \text{Pa}$$

$$=1548.9\ \text{KPa}$$

2. Hydrogen gas has a molecular collision diameter d of 0.258 nm. Calculate the mean free path λ of hydrogen at T= 700 K and P = 500 kPa.
   a. 4.95 x 10^{-8} m
   b. 4.95 x 10^{-9} m
   c. 2.23 x 10^{-8} m
   d. 2.20 x 10^{-7} m
   [✓ e.] 6.54 x 10^{-8} m
   f. 6.54 x 10^{-9} m
   g. 3.13 x 10^{-8} m
   h. 3.13 x 10^{-7} m
   i. 3.13 x 10^{-9} m
   j. none of above

$$\lambda = \frac{V}{\sqrt{2}\,\pi\, d_1^2\, N} \qquad \frac{V}{N} = \frac{RT}{LP}$$

$$= \frac{RT}{\sqrt{2}\,\pi\, L P d^2}$$

$$= \frac{8.3145 \cdot 700}{1.4142 \cdot 3.1416 \cdot 6.022 \cdot 10^{23} \cdot 500 \cdot 10^{3} \cdot 0.06656 \cdot 10^{-18}}$$

$$= \frac{5820.15}{890.4078 \cdot 10^{+8}}$$

$$= 6.5365 \cdot 10^{-8}\ m$$

3. Initially, one mol of O_2 is contained in a 3-liter vessel, and 5 mol of N_2 are in a 4-liter vessel. The two vessels are connected by a tube with a stopcock. If the stopcock is opened and the gases mix, what is the change in entropy?
    a. -49.94 J/K
    b. -41.47 J/K
    c. -38.62 J/K
    d. -30.31 J/ K
    e. 17.866 J/K
    [✓ f.] 30.31 J/K
    g. 38.62 J/K
    h. 41.47 J/K
    i. 49.94 J/K
    j. none of above

$$\Delta S = R\left(n_1 \ln\frac{V_1+V_2}{V_1} + n_2 \ln\frac{V_1+V_2}{V_2}\right)$$

$$= 8.3145\left(1 \ln\frac{3+4}{3} + 5 \ln\frac{3+4}{4}\right)$$

$$= 8.3145\left(\ln\frac{7}{3} + 5 \cdot \ln\frac{7}{4}\right)$$

$$= 8.3145\left(\ln 2.333 + 5 \ln 1.75\right)$$

$$= 8.3145\left(0.8473 + 5 \cdot 0.5596\right)$$

$$= 8.3145 \cdot 3.6454$$

$$= 30.31 \ J/K$$

4. At what temperature T and pressure P will H_2 be in a corresponding state with CH_4 at 500 K and 3.5 bar pressure? The critical temperatures are $T_c = 33.2$ K for H_2 and $T_c=190.6$ K for CH_4; the critical pressures $P_c= 13.0$ bar for H_2 and $P_c=46.0$ bar for CH_4.
    - a. P = 145.7 bar ; T = 52.66 K
    - b. P = 2.05 bar; T = 0.011 K
    - c. P = 9.89 bar; T = 87.09 K
    - d. P = 0.003 bar; T = 0.079 K
    - e. P = 2.05 bar; T = 104.52 K
    - [✓ f.] P = 0.989 bar; T = 87.09 K
    - g. P = 145.7 bar; T = 104.52 K
    - h. P = 0.989 bar; T = 8.709 K
    - i. P = 0.003 bar; T = 0.011 K
    - j. None of above

$$P_R = \frac{P}{P_c} = 0.0761 \qquad \overset{1}{P} = P_R \cdot \overset{1}{P_c} = 0.989 \text{ bar}$$

$$T_R = \frac{T}{T_c} = 2.6233 \qquad \overset{1}{T} = T_R \cdot \overset{1}{T_c} = 87.09 \text{ K}$$

5. The equilibrium constant K_c for a reaction $2\,A \Leftrightarrow 2\,Y + Z$ is 0.05 mol/l at T=900 K. Calculate K_P at that temperature. Give the result in bar.
   - a. 0.1432
   - b. 0.2932
   - c. 0. 3742
   - d. 1.432
   - [✓ e.] 3.742
   - f. 14.32
   - g. 37.42
   - h. 143.2
   - i. 374.2
   - j. none of above

$$\sum_i r_c = 2 + 1 - 2 = 1$$

$$K_p = K_c (RT)^{\sum_i r_c} = K_c RT$$

$$= 0.05 \cdot 8.3145 \cdot 900 \; \cancel{\text{m}} \; \frac{\text{mol}}{\text{l}} \cdot \text{J} / \cancel{\text{mol}}$$

$$= 374.15 \; \cancel{\text{Pa}} \; \frac{\cancel{\text{mol}}}{10^{-3} \text{m}^3} \cdot \frac{\cancel{\text{kg}}\,\text{m}^2}{\cancel{\text{s}^2}} \cdot \frac{\cancel{\text{kg}}\,\text{m}^2}{\text{s}^2} \; \text{N} \cdot \text{m}$$

$$= 374.15 \cdot 10^3 \; \text{Pa}$$

$$= 3.74.15 \cdot 10^5 \; \text{Pa}$$

$$= 3.7415 \; \text{bar}$$

6. Calculate the composition of the vapor in equilibrium at T=340 K with a liquid solution of 0.35 mol fraction of A with 0.65 mol fraction of B. A and B are miscible and form an ideal solution. The vapor pressure of pure A at this temperature is 7.0 kPa, and that of pure B 3.0 kPa. What is the fraction of A in the vapor?
    a. 0.1463
    b. 0.2313
    c. 0.4000
    [✓ d. 0.5568]
    e. 0.7500
    f. 0.7926
    g. 0.8371
    h. 0.9000
    i. 0.9326
    j. none of above

$$Y_A = \frac{P_A}{P_A+P_B} = \frac{x_A P_A^*}{x_A P_A^* + x_B P_B^*}$$

$$= \frac{0.35\cdot 7.0\ \text{kPa}}{0.35\cdot 7.0 + 0.65\cdot 3.0}$$

$$= \frac{2.45}{2.45 + 1.95}$$

$$= \frac{2.45}{4.4}$$

$$= 0.5568$$

7. In an experiment, the vapor pressure of a liquid is measured as 15 kPa at 300K, and as 200 kPa at 400 K. Calculate from these data the enthalpy of vaporization $\Delta_{vap}H$ of the liquid.
   a. −25.84 kJ/mol
   b. -12.92 kJ/mol
   c. -2.584 kJ/mol
   d. -1.292 kJ/mol
   e. -0.1292 kJ/mol
   f. 0.1292 kJ/mol
   g. 2.584 kJ/mol
   h. 12.92 kJ/mol
   [✓ i.] 25.84 kJ/mol
   j. None of above

$$\ln \frac{P_2}{T_1} = \frac{\Delta_{vap}H}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) = \frac{\Delta_{vap}H}{R} \quad \frac{T_2 - T_1}{T_1 T_2}$$

$$\Rightarrow \Delta_{vap}H = R \cdot \ln \frac{P_2}{P_1} \quad \frac{T_1 T_2}{T_2 - T_1}$$

$$= 8.3145 \cdot \ln \frac{200}{15} \cdot \frac{300 \cdot 400}{400 - 300} \ \frac{J}{mol}$$

$$= 8.3145 \cdot \ln 13.33 \cdot 1200 \ \frac{J}{mol}$$

$$= 8.3145 \cdot 2.5903 \cdot 1200 \ \frac{J}{mol}$$

$$= 25844.5 \ \frac{J}{mol}$$

$$= 25{,}84 \ \frac{kJ}{mol}$$

8. The ratio of a component A to water collected in a steam distillation is 7, when the mixture was boiled at 354 K and 95 kPa. If the vapor pressure of water at this temperature is 43.2 kPa, calculate the molar mass of A (molar mass of water: 18.02 g/mol)

   a. 21.31 g/mol
   b. 42.64 g/mol
   c. 62.46 g/mol
   [✓ d.] 105.2 g/mol
   e. 184.6 g/mol
   f. 21.31 kg/mol
   g. 42.64 kg/mol
   h. 105.2 kg/mol
   i. 184.6 kg/mol
   j. none of above

$m = n \cdot M$

$$\frac{m_A}{m_{H_2O}} = \frac{n_A M_A}{n_{H_2O} \cdot M_{H_2O}} = \frac{p_A^*}{p_{H_2O}^*} \frac{M_A}{M_{H_2O}}$$

$$\Rightarrow M_A = \frac{p_{H_2O}^*}{p_A^*} \cdot \frac{m_A}{m_{H_2O}} \cdot M_{H_2O} \qquad \left| \begin{array}{l} p = p_A^* + p_{H_2O}^* \\ \Rightarrow p_A^* = p - p_{H_2O}^* \end{array} \right.$$

$$= \frac{p_{H_2O}^*}{p - p_{H_2O}^*} \frac{m_A}{m_{H_2O}} \cdot M_{H_2O}$$

$$= \frac{43.2 \text{ kPa}}{95 - 43.2} \cdot 7 \cdot 18.02 \frac{g}{mol}$$

$$= \frac{43.2}{51.8} \cdot 7 \cdot 18.02 \ g/mol$$

$$= 0.834 \cdot 7 \cdot 18.02 \ g/mol$$

$$= 105.2 \ g/mol$$

9. The equilibrium constant for a reaction A + B ⇔ Y + Z is 0.2. What amount of A must be mixed with 5 mol of B to yield, at equilibrium, 2 mol of Y?

a. 87 mol
b. 26 mol
c. 13 mol
[✓ d.] 8.7 mol
e. 2.6 mol
f. 1.3 mol
g. 0.87 mol
h. 0.26 mol
i. 0.13 mol
j. none of above

Initially : x mol of A, 5 mol of B, 0 mol of Y and Z

In equillibrium : 2 mol of Y, 2 mol of Z, 3 mol of B, x − 2 mol of A

$$K_c = \frac{2 \cdot 2}{(x-2) \cdot 3} = 0.2$$

$$\Rightarrow 4 = 0.2 \cdot 3 \cdot (x-2) = 0.6x - 1.2$$

$$\Rightarrow 0.6x = 5.2$$

$$\Rightarrow x = 8.67$$

10. A substance decomposes at 900 K with a rate constant of 1.5 x 10^{-5} s^{-1}. What fraction of the original amount will remain un-decomposed if the substance is heated for 3 h at 900 K?

   a. 0.01
   b. 0.27
   c. 0.48
   d. 0.62
   e. 0.76
   [✓ f.] 0.85
   g. 0.90
   h. 0.95
   i. 0.99
   j. none of above

$$[A] = [A]_0 \cdot e^{-kt}$$

$$\frac{[A]}{[A]_0} = e^{-kt}$$

$$= \exp(-1{,}5 \cdot 3 \cdot 60 \cdot 60 \cdot 10^{-5})$$

$$= \exp(-1{,}5 \cdot 0{,}108)$$

$$= \exp(-0{,}162)$$

$= \underline{0.\text{[illegible]}}\ 350$

11. How does the time required for a first-order reaction to go to 85% completion relate to the half-life of the reaction, i.e. what is the ratio $t_{85\%}/t_{1/2}$?

a. 1.44
b. 1.78
c. 2.00
d. 2.30
[✓ e.] 2.74
f. 3.32
g. 4.49
h. 5.78
i. 7.31
j. none of above

$$0,5[A]_0 = [A]_0 \cdot \exp(-K t_{50\%}) \Rightarrow 0.5 = \exp(-K t_{50\%}) \Rightarrow t_{50\%} = \frac{\ln 2}{K}$$

$$0.15[A]_0 = [A]_0 \cdot \exp(-K t_{85\%}) \Rightarrow 0.15 = \exp(-K t_{85\%}) \Rightarrow t_{85\%} = -\frac{\ln 0.15}{K}$$

$$\Rightarrow \frac{t_{85\%}}{t_{50\%}} = -\frac{\ln 0.15}{\ln 2} = \frac{1.89712}{0.69315} = 2,737$$

12. The rate constant for a reaction at 330 K is found to be five times the value at 280 K. Calculate the activation energy in kJ/mol.
    a. 0.1793
    b. 1.7934
    c. 2.4723
    d. 17.934
    [✓ e.] 24.723
    f. 179.34
    g. 247.23
    h. 17934
    i. 24723
    j. none of above

$$K(T) = A \cdot e^{-E_a/RT} \Rightarrow \ln K = \ln A - E_A/RT$$

$$\Rightarrow \ln K_1 - \ln K_2 = -\frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\Rightarrow E_a = R \ln \frac{K_2}{K_1} \Big/ \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$= 8.3145 \cdot \ln 5 \Big/ \left(\frac{1}{280} - \frac{1}{330}\right)$$

$$= 8.3145 \cdot 1.609 \Big/ \frac{330 - 280}{330 \cdot 280}$$

$$= 8.3145 \cdot 1.609 \cdot \frac{330 \cdot 280}{50}$$

$$= 8.3145 \cdot 1.609 \cdot 1848$$

$$= 24722.6 \ \mathrm{J/mol}$$

13. The water flea *Daphnia* performs a constant number of heart beats and then dies. The flea lives twice as long at 16⁰C as at 26⁰C. Calculate the activation energy for the reaction that controls the heart beat.

   a. 23.97 J/mol
   b. 49.85 J/mol
   c. 239.7 J/mol
   d. 498.5 J/mol
   e. 2.397 kJ/mol
   f. 23.97 kJ/mol
   [✓ g.] 49.85 kJ/mol
   h. 239.7 kJ/mol
   i. 498.5 kJ/mol
   j. none of above

$T_1 = 16^\circ C = 289.15\ K$; $T_2 = 26^\circ C = 299.15\ K$

$K = A e^{-E_a/RT} \Rightarrow \ln K = \ln A - E_o/RT$

$v[T_1] = \frac{1}{2} v[T_2] \Rightarrow K_1 = \frac{1}{2} K_2 \Rightarrow K_2 = 2 K_1$

$\Rightarrow \ln \frac{K_2}{K_1} = \ln 2 = -\frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) = -\frac{E_a}{R} \frac{T_1 - T_2}{T_1 T_2} = \frac{E_a}{R} \frac{T_2 - T_1}{T_1 T_2}$

$\Rightarrow E_a = \ln 2 \cdot R \cdot \frac{T_1 T_2}{T_2 - T_1}$

$= 0.69315 \cdot 8.3145 \cdot \frac{289.15 \cdot 299.15}{10}$

$= 0.69315 \cdot 8.3145 \cdot 8649.9\ J/mol$

$= 49851{,}2\ J/mol$

$= 49.85\ kJ/mol$

14. In an enzyme-catalyzed reaction, we obtain reaction rates at two substrate concentrations: [S] = 0.75 x 10^{-4} mol/l and v = 0.5 x 10^{-4} mol/(l s); [S] = 1.75 x 10^{-3} mol/l and v = 3.0 x 10^{-4} mol/(l s). Assume that the Michaelis-Menten equation applies. Calculate the Michaelis constant K_M in mol/l.

   a. 5,05 x 10^{-2}
   b. 10.77 x 10^{-2}
   c. 5.05 x 10^{-3}
   d. 10.77 x 10^{-3}
   [✓ e.] 5.05 x 10^{-4}
   f. 10.77 x 10^{-4}
   g. 5.05 x 10^{-5}
   h. 10,77 x 10^{-5}
   i. 15.35 x 10^{-5}
   j. none of above

$$v_1 = \frac{V[S]_1}{K_m + [S]_1} \quad ; \quad v_2 = \frac{V[S]_2}{K_m + [S]_2}$$

$$\Rightarrow v_1 \frac{K_m + [S]_1}{[S]_1} = v_2 \frac{K_m + [S]_2}{[S]_2}$$

$$\Rightarrow K_m \left(\frac{v_1}{[S]_1} - \frac{v_2}{[S]_2} \right) = v_2 - v_1$$

$$\Rightarrow K_m = \frac{v_2 - v_1}{\frac{v_1}{[S]_1} - \frac{v_2}{[S]_2}}$$

$$= \frac{3.0 \cdot 10^{-4} - 0.5 \cdot 10^{-4}}{\frac{0.5 \cdot 10^{-4}}{0.75 \cdot 10^{-4}} - \frac{3.0 \cdot 10^{-4}}{1.75 \cdot 10^{-3}}}$$

$$= \frac{2.5 \cdot 10^{-4}}{0.6667 - 1.7143 \cdot 10^{-1}}$$

$$= \frac{2.5}{1.6667 - 0.1714} \quad 10^{-4} \approx \frac{2.5}{0.495} \cdot 10^{-4}$$

Bonus Question:

1. A Carnot engine operates between temperatures T_H=1500 ^{0}C and T_C=50 ^{0}C. How much heat needs to be put into the engine at T_H in order to obtain W=1900 J of work from the engine?
   a. 196.6 J
   b. 232.3 J
   c. 307.1 J
   d. 1966 J
   [✓ e.] 2323J
   f. 3071 J
   g. 19.66 kJ
   h. 23.23 kJ
   i. 30.71 kJ/mol
   j. none of above

$1500\,^\circ C = 1773.15\,K \; ; \; 50\,^\circ C = 323.15\,K$

$$\eta = 1 - \frac{T_C}{T_H}$$

$$= \frac{W}{Q_H}$$

$$\Rightarrow Q_H = \frac{W}{\eta} = \frac{W}{1 - \frac{T_C}{T_H}}$$

$$= \frac{1900}{1 - \frac{323.15}{1773.15}} \; J$$

$$= \frac{1900}{1 - 0.18225}$$

$$= \frac{1900}{0.8178} = 2323.31 \; J$$

Useful Equations and Constants:

$$\text{K.E.} = \frac{1}{2}mu^2 \qquad \text{P.E.} = mgh \qquad PV = nRT$$

$$\overline{u^2} = \frac{3k_BT}{m} \qquad \bar{u} = \sqrt{\frac{8k_BT}{\pi m}} \qquad u_{mp} = \sqrt{\frac{2k_BT}{m}}$$

$$\bar{\varepsilon} = \frac{3}{2}k_BT \qquad \left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT \qquad \lambda = \frac{V}{\sqrt{2}\pi d^2 N}$$

$$\frac{dN}{N} = 4\pi\left(\frac{m}{2\pi k_BT}\right)^{3/2} e^{-mu^2/2k_BT}u^2\,du$$

$$Z = \frac{PV}{nRT} = \frac{PV_m}{RT} \qquad \left(P_r + \frac{3}{V_r^2}\right)\left(V_r - \frac{1}{3}\right) = \frac{8}{3}T_r \qquad P_t = \frac{RT}{V}\sum_i n_i$$

$$\Delta U = q + w \qquad w = -\int_{V_i}^{V_f} P_{ext}\,dV$$

$$\Delta H_m(T_2) = \Delta H_m(T_1) + \int_{T_1}^{T_2} \Delta C_p\,dT$$

$$w = -P_{ext}\Delta V \qquad w = -nRT\ln\left(\frac{V_2}{V_1}\right) \qquad H = U + PV$$

$$\Delta H = \Delta U + \Delta(PV) \qquad \Delta H = \Delta U + \Delta nRT \qquad \Delta U = nC_{v,m}(T_2 - T_1)$$

$$\Delta H = nC_{p,m}(T_2 - T_1) \qquad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \qquad \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$\gamma = \frac{C_{p,m}}{C_{v,m}} \qquad C_{p,m} - C_{v,m} = R \qquad \Delta U = -n^2a\left(\frac{1}{V_2} - \frac{1}{V_1}\right)$$

$$w = -nRT\ln\left(\frac{V_2 - nb}{V_1 - nb}\right) - n^2a\left(\frac{1}{V_2} - \frac{1}{V_1}\right) \qquad \eta = \frac{T_h - T_c}{T_h}$$

$$\Delta S = nR\ln\frac{V_f}{V_i} \qquad \Delta S = nR\ln\frac{P_i}{P_f} \qquad \Delta S = nC_{p,m}\ln\frac{T_f}{T_i}$$

$$\Delta S = nC_{v,m}\ln\frac{T_f}{T_i} \qquad \Delta S = -R(x_1\ln x_1 + x_2\ln x_2) \qquad G = H - TS \qquad \Delta S = Q_{\text{Rev}}/T$$

$$\Delta G = \Delta H - T\Delta S \qquad \Delta S = n_1R\ln\left(\frac{V_1 + V_2}{V_1}\right) + n_2R\ln\left(\frac{V_1 + V_2}{V_2}\right)$$

$$A = U - TS \qquad \Delta A = \Delta U - T\Delta S \qquad \left(\frac{\partial U}{\partial V}\right)_T = -P + T\left(\frac{\partial P}{\partial T}\right)_V$$

$$\left(\frac{\partial H}{\partial P}\right)_T = V - T\left(\frac{\partial V}{\partial T}\right)_P \qquad RT\ln\frac{f}{P} = \int_0^P \left(V_m - \frac{RT}{P'}\right) dP'$$

$$\Delta G = \Delta G^0 + RT\ln Q \qquad K_P = \left(\frac{\cdots P_Y^y P_Z^z}{P_A^a P_B^b \cdots}\right)_{eq}$$

$$K_C = \left(\frac{\cdots [\mathrm{Y}]^y [\mathrm{Z}]^z}{[\mathrm{A}]^a [\mathrm{B}]^b \cdots}\right)_{eq} \qquad \Delta G = \Delta G^0 + RT\ln\left(\frac{\cdots [\mathrm{Y}]^y [\mathrm{Z}]^z}{[\mathrm{A}]^a [\mathrm{B}]^b \cdots}\right)^u$$

$$K_a = \left(\frac{\cdots a_{\mathrm{Y}}^y a_{\mathrm{Z}}^z}{a_{\mathrm{A}}^a a_{\mathrm{B}}^b \cdots}\right)_{eq} \qquad K_P = K_C (RT)^{\sum\nu} \qquad K_P = K_x P^{\sum\nu}$$

$$\mu_{\mathrm{A}} = \left(\frac{\partial G}{\partial n_{\mathrm{A}}}\right)_{T,P,n_{\mathrm{B}},n_{\mathrm{Y}}\cdots} \qquad \frac{d\ln K_P^\circ}{d(1/T)} = -\frac{\Delta H^\circ}{R} \qquad \ln K_P^\circ = -\frac{\Delta H^\circ}{R}\left(\frac{1}{T}\right) + \frac{\Delta S^\circ}{R}$$

$$\frac{d\ln K_C^\circ}{dT} = \frac{\Delta U^\circ}{RT^2} \qquad \frac{d\ln K_C^\circ}{d(1/T)} = -\frac{\Delta U^\circ}{R} \qquad x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

$$f = c - p + 2 \qquad P_i = P_i^* x_i \qquad [\mathrm{A}] = [\mathrm{A}]_0 - kt$$

$$[\mathrm{A}] = [\mathrm{A}]_0 e^{-kt} \qquad \frac{1}{[\mathrm{A}]} - \frac{1}{[\mathrm{A}]_0} = kt \qquad \frac{1}{[\mathrm{A}]_0 - [\mathrm{B}]_0}\ln\frac{[\mathrm{B}]_0[\mathrm{A}]}{[\mathrm{A}]_0[\mathrm{B}]} = kt$$

$$\frac{1}{[\mathrm{A}]_0 - [\mathrm{B}]_0}\ln\frac{[\mathrm{B}]_0([\mathrm{A}]_0 - [\mathrm{P}])}{[\mathrm{A}]_0([\mathrm{B}]_0 - [\mathrm{P}])} = kt \qquad kt = \frac{1}{(n-1)}\left[\frac{1}{[\mathrm{A}]^{n-1}} - \frac{1}{[\mathrm{A}]_0^{n-1}}\right]$$

$$t_{1/2} = \frac{[\mathrm{A}]_0}{2k} \qquad t_{1/2} = \frac{\ln 2}{k} \qquad t_{1/2} = \frac{1}{[\mathrm{A}]_0 k}$$

$$t_{1/2} = \frac{2^{n-1} - 1}{k(n-1)[\mathrm{A}]_0^{n-1}} \qquad k = \frac{k_B T}{h} e^{-\Delta^\ddagger G^\circ/RT} \qquad k = \frac{k_B T}{h} e^{\Delta^\ddagger S^\circ/R} e^{-\Delta^\ddagger H^\circ/RT}$$

$$k = e\left(\frac{k_B T}{h}\right) e^{\Delta^\ddagger S^\circ/R} e^{-E_a/RT} \qquad E_a = \Delta H^\ddagger + nRT \qquad k = e^2\left(\frac{k_B T}{h}\right) e^{\Delta^\ddagger S^\circ/R} e^{-E_a/RT}$$

$$K_C = \frac{k_1}{k_{-1}} \qquad K_C = K_1 K_2 K_3 \cdots = \frac{k_1 k_2 k_3 \cdots}{k_{-1} k_{-2} k_{-3} \cdots} \qquad K_M = \frac{k_{-1} + k_2}{k_1}$$

$$v = \frac{V[S]}{k_M + [S]}$$

R = 8.3145 J K^{-1} mol^{-1} = 0.082057 atm dm^3 K^{-1} mol^{-1} = 1.98719 cal K^{-1} mol^{-1}

k_B = 1.381×10^{-23} J K^{-1}

h = 6.626×10^{-34} J s $\quad L$ = 6.022×10^{23} mol^{-1}