CHEM 3423 001 Spring 2024 **Name:** KEY
ID:

Midterm Exam # 1

Answer Sheet: (All problems are multiple choice. List the letter that corresponds to the correct answer. Maximum number of points you can get is 18 pts!)

Conceptual questions (each 0.75 pts:

1) d
2) d
3) d
4) d
5) A
6) B
7) C
8) B
9) C
10) C
11) B
12) B

Problems and Calculations (each 1.5 pts):

1) F
2) H
3) C
4) A
5) E
6) F

Conceptual Questions:

1. Which of the following properties is extensive?
   a. Density
   b. Temperature
   c. Pressure
   d. Particle number
   e. None of a) - d)

2. The internal energy U of an *ideal gas* is made up
   a. Only of potential energy due to interaction between the particles
   b. Both potential and kinetic energy
   c. Neither of potential nor of kinetic energy
   d. Only of kinetic energy of the gas molecule

3. Suppose we increase the temperature of a gas by a factor 2 ($T_2 = 2\,T_1$). What is the relationship between the average speed of molecules?
   a. $v_2 = 4\,v_1$
   b. $v_2 = v_1$
   c. $v_2 = 2\,v_1$
   d. $v_2 = \sqrt{2}\,v_1$
   e. $v_2 = \frac{1}{2}\,v_1$
   f. None of a) – e)

4. The Maxwell distribution law gives the probability distribution of the speed of gas molecules. When temperature increases,
   a. the distribution curve becomes sharper
   b. the area under the distribution becomes smaller
   c. the average speed of the molecules decreases
   d. the distribution curve becomes flatter
   e. none of a)-d)

5. Atmospheric pressure
   a. decreases exponentially with altitude
   b. increases exponentially with altitude
   c. does not depend on temperature
   d. None of a) – c)

6. In the van der Wall's equation, the correction for volume accounts for
   a. interactions between gas molecules
   b. finite size of gas molecules
   c. Neither a) nor b)

7. The first law of thermodynamic states that
   a. The energy of an isolated system increases as it approaches equilibrium
   b. The energy of an isolated system decreases as it approaches equilibrium
   c. The energy does not change with time in an isolated system
   d. None of a)-c)

8. For a system at constant pressure, heat added to, or subtracted from, a system is equal to
   a. the change ΔU in internal energy
   b. the change ΔH in enthalpy
   c. the change ΔS in entropy
   d. none of a) – c)

9. The second law of thermodynamic states that
   a. The energy is conserved in an isolated system
   b. The entropies of all perfectly crystalline substances is zero at $T = 0$ K.
   c. External work is needed to pump heat from a system at low temperature to one at a higher temperature.

10. The entropy change in a Carnot cycle is
   a. positive
   b. negative
   c. zero

11. The efficiency of a Carnot engine depends only on
   a. the type of gas
   b. the ratio of temperatures T_L/T_H, where T_H is the higher temperature
   c. neither a) nor b)

12. An isolated system is said to be in equilibrium if
   a. $\Delta S > 0$
   b. $\Delta S = 0$
   c. $\Delta S < 0$

Problems and Calculations: :

1. A gas that behaves ideally has a density ρ of 4.0 g $(dm)^{-3}$ at pressure P= 400 kPa and T=1200K. What is its molar mass M?
    a. 99.8 kg/mol
    b. 0.0125 kg/mol
    c. 24.94 kg/mol
    d. 0.0249 kg/mol
    e. 4989 g/mol
    (f) 99.8 g/mol
    g. 0.099 g/mol
    h. none of a) - g)

$$PV = nRT = \frac{m}{M} RT \Rightarrow M = \frac{m}{V}\frac{RT}{P} = \rho \frac{RT}{P}$$

$$\Rightarrow M = 4.0 \frac{Kg}{m^3} \cdot \frac{8.3145 \cdot 1200}{400 \cdot 10^3} \frac{J}{mol\,K} \frac{K}{Kg}$$

$$= \frac{39909.6}{400 \cdot 10^3} \frac{Kg}{mol}$$

$$= 99.774 \cdot 10^{-3} \frac{Kg}{mol}$$

$$= 99.8 \frac{g}{mol}$$

2. Two mol of an ideal gas is reversibly expanded at constant temperature until $V_2 = 6\ V_1$. If the gas performed W = -30 kJ of work, what is its temperature?
    a. 5.61 K
    b. 11.22 K
    c. 56.04 K
    d. 100.69 K
    e. 273.15 K
    f. 350.56 K
    g. 560.45 K
    h. 1006.9 K
    i. none of a) –h)

$$W = n R T \ln \frac{V_1}{V_2} \Rightarrow T = \frac{W}{n R \ln V_1/V_2}$$

$$= \frac{-30 \cdot 10^3}{-2 \cdot 8.3145 \cdot \ln 6} \text{ K}$$

$$= \frac{30 \cdot 10^3}{16.629 \cdot 1.7917} \text{ K}$$

$$= \frac{30}{29.795} \cdot 10^3 \text{ K}$$

$$= 1006.9 \text{ K}$$

3. At what temperature T and pressure P will H_2 be in a corresponding state with CH_4 at 600 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 = 355.7 bar ; T = 18.66 K
   b. P = 2.15 bar; T = 0.021 K
   c. P = 0.989 bar; T = 104.51 K
   d. P = 0.003 bar; T = 0.009 K
   e. P = 4.05 bar; T = 105.08 K
   f. P = 0.989 bar; T = 10.451 K
   g. P = 545.7 bar; T = 97.08 K
   h. P = 545.7 bar; T = 0.011 K
   i. P = 0.003 bar; T = 0.011 K
   j. None of a) – i)

$$P_R = \frac{P}{P_c^{(1)}} = \frac{3.5}{46.0} = 0.07609 \qquad P = P_R \cdot P_c^{(2)} = 0.9891 \text{ bar}$$

$$T_R = \frac{T}{T_c^{(1)}} = \frac{600}{190.6} = 3.14795 \qquad T = T_R \cdot T_c^{(2)} = 104.51 \text{ K}$$

4. A Carnot engine operates between a temperature T_C=50 K and a higher temperature T_H and produces W = -60 kJ of work per cycle. The entropy change during the isothermal expansion at T_H is 300 J/K. What is the value of T_H?
   a. 250 K
   b. 300 K
   c. 350 K
   d. 400 K
   e. 450 K
   f. 500 K
   g. none of a) – f)

$$\Delta S = \frac{Q_H}{T_H} \quad ; \quad \frac{Q_H}{T_H} + \frac{Q_C}{T_C} = 0 \Rightarrow Q_C = -\Delta S \cdot T_C$$

$$W = -(Q_H + Q_C) \Rightarrow Q_H = -W - Q_C = -W + \Delta S\, T_C$$

$$\Delta S = \frac{Q_H}{T_H} \Rightarrow T_H = \frac{Q_H}{\Delta S} = \frac{\Delta S\, T_C - W}{\Delta S} = T_C - \frac{W}{\Delta S}$$

$$= 50\,K - \frac{-60 \cdot 10^3\,J}{300\,J/K}$$

$$= 50\,K + 200\,K$$

$$= 250\,K$$

5. A certain gas has a molecular collision diameter d of 0.58 nm. Calculate the mean free path λ of that gas at T= 800 K and P = 700 kPa.
    a. 4.95×10^{-87}m
    b. 4.95×10^{-8} m
    c. 4.95×10^{-9} m
    d. 1.06×10^{-7} m
    e. 1.06×10^{-8} m
    f. 1.06×10^{-9} m
    g. 3.1×10^{-7} m
    h. 3.1×10^{-8} m
    i. 3.1×10^{-9} m
    j. none of a) – i)

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

$$\Rightarrow \lambda = \frac{RT}{\sqrt{2}\,\pi L P d_A^2}$$

$$= \frac{8.3145 \cdot 800}{1.414 \cdot 3.14 \cdot 6.022 \cdot 10^{23} \cdot 700 \cdot 10^{3} \cdot 0.58^{2} \cdot 10^{-18}}$$

$$= \frac{6651.6}{6300.28 \cdot 10^{8}} \text{ m}$$

$$= 1.06 \cdot 10^{-8} \text{ m}$$

6. Calculate the pressure of 1 dm^3 of a gas weighing 40.0 g at 600 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 = 10.0 g/mol
   a. 0.12944 Pa
   b. 1.2944 Pa
   c. 12.944 Pa
   d. 129.44 kPa
   e. 1294.4 kPa
   (f.) 12944 kPa
   g. none of a) – f)

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

$$\Rightarrow P = \frac{nRT}{V - nb} - \frac{an^2}{V^2} \qquad n = \frac{m}{M} = \frac{40}{10} = 4$$

$$= \frac{4 \cdot 8.3145 \cdot 600}{0.001 - 4 \cdot 0.00005} Pa - \frac{0.75 \cdot 4^2}{10^{-6}} Pa$$

$$= \frac{19954.8}{0.0008} Pa - \frac{12}{10^{-6}} Pa$$

$$= 2.4944 \cdot 10^7 Pa - 12 \cdot 10^6 Pa$$

$$= 12944 \ kPa$$