CHEM 3423 001 Spring 2026 **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) E
3) C
4) A
5) B
6) A
7) B
8) B
9) C
10) A
11) C
12) B

Problems and Calculations (each 1.5 pts):

1) F
2) I
3) I
4) A
5) E
6) F

Conceptual Questions: **Name:**
ID:

1. Which of the following properties is intensive?
   - **a.** Mass
   - **b.** Volume
   - **c.** Particle number
   - ✓**d.** Density
   - **e.** None of a) - d)

2. Suppose we decrease the temperature of a gas by a factor 3 ($T_2 = T_1/3$). What is the relationship between the kinetic energies?
   - a. $E_2 = 9 E_1$
   - b. $E_2 = E_1$
   - c. $E_2 = 3 E_1$
   - d. $E_2 = E_1/\sqrt{3}$
   - ✓e. $E_2 = E_1/3$
   - f. None of a)-e)

3. If N_2 and H_2 behave as an ideal gas, and are at the same temperature, the average kinetic energy
   - a. of N_2 is smaller than that of H_2
   - b. of N_2 is larger than that of H_2
   - ✓ c. of the molecules in both gases is the same

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

5. Atmospheric pressure
   - a. decreases linearly with altitude
   - ✓b. decreases exponentially with altitude
   - c. increases exponentially with altitude
   - d. None of a) – c)

6. Let P_W be the pressure resulting from a 2 m column of water, and P_{Hg} be the pressure resulting from a 2 m column of mercury. Which statement is true?
   - ✓a. $P_w < P_{Hg}$
   - b. $P_w = P_{Hg}$
   - c. $P_w > P_{Hg}$

7. During reversible isothermal compression of an ideal gas,
    a. $\Delta U = 0$ and $\Delta H > 0$
    ✓ b. $\Delta U = 0$ and $\Delta H = 0$
    c. $\Delta U = 0$ and $\Delta H < 0$
    d. None of a) – c)

8. The first law of thermodynamic states that
    a. The energy of an isolated system increases as it approaches equilibrium
    ✓ b. The energy is conserved in an isolated system
    c. The energy of an isolated system decreases as it approaches equilibrium
    d. The entropy of all perfectly crystalline substances is zero at T = 0 K.
    e. External work is needed to pump heat from a system at low temperature to one at a higher temperature.
    f. None of a) - e)

9. The second law of thermodynamic states that
    a. The energy is conserved in an isolated system
    b. The entropy 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.
    d. None of a)-c)

10. Which of the following statements is true for a Carnot cycle?
    ✓ a. The efficiency of a Carnot Cycle depends on the ratio of temperatures T_L/T_H,, where T_H is the higher temperature
    b. Not all Carnot engines have the same efficiency.
    c. A Carnot engine cannot be used as a refrigerator
    d. None of a)-c)

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

12. For a reversible adiabatic expansion of a real gas, the entropy changes as
    a. $\Delta S > 0$
    ✓ b. $\Delta S = 0$
    c. $\Delta S < 0$

Problems and Calculations:

1. A gas that can be described as an ideal gas 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. An ideal gas occupies a volume V of 1.25 dm^3 at a pressure P of 5.0 x 10^5 Pa. What is the new volume of the gas maintained at the same temperature T if the pressure P is reduced to 1.0 x 10^5 Pa?
   a. 0.25 dm^3
   b. 0.32 dm^3
   c. 0.42 dm^3
   d. 0.63 dm^3
   e. 1.25 dm^3
   f. 2.50 dm^3
   g. 3.75 dm^3
   h. 5.00 dm^3
   i. 6.25 dm^3 ✓
   j. none of a) – i)

$PV = nRT \Rightarrow V = nRT/P$

$P_{new} = P_{old}/5 \Rightarrow V_{new} = 5 \times V_{old} = 6.25\ dm^3$

3. For O_2 gas at 600 K, calculate the ratio of the fraction of molecules that have the speed $u_2 = 3\,u_1$ to the fraction that have speed u_1. Assume that $u_1 = \bar{u}$ (the average speed of molecules at this temperature).
   a. 1.42×10^{-9}
   b. 4.26×10^{-9}
   c. 1.28×10^{-8}
   d. 1.06×10^{-5}
   e. 3.17×10^{-5}
   f. 9.50×10^{-5}
   g. 3.77×10^{-5}
   h. 1.13×10^{-4}
   ✓ i. 3.39×10^{-4}
   j. none of a) –i)

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

$$\frac{N(u_2)}{N(u_1)} = \frac{u_2^2}{u_1^2} \cdot \exp\left(-\frac{m}{2k_BT}(u_2^2 - u_1^2)\right)$$

$$= 9 \cdot \exp\left(-\frac{m}{2k_BT}(9-1)u_1^2\right)$$

$$= 9 \cdot \exp\left(-8u_1^2 \frac{m}{2k_BT}\right) \qquad u_1 = \bar{u} = \sqrt{\frac{8k_BT}{\pi m}}$$

$$= 9\exp\left(-\frac{32}{\pi}\right) \qquad \Rightarrow u_1^2 = \frac{8k_BT}{\pi m}$$

$$= 9 \cdot \exp(-10.186)$$

$$= 9 \cdot 3.77 \cdot 10^{-5}$$

$$= 3.39 \times 10^{-4}$$

4. Calculate the pressure of 2.5 dm^3 of a gas weighing 60.0 g at 700 K using the van der Waal's equation (use a = 0.85 Pa m^6 /mol^2; b= 0.00007 m^3/mol). The molar mass of the gas is M = 15.0 g/mol

   ✓ a. 83.11 bar
   b. 8.311 bar
   c. 0.8311 bar
   d. 1.049 bar
   e. 10.49 bar
   f. 104.9 bar
   g. 126.6 bar
   h. 12.66 bar
   i. 1.266 bar
   j. none of a) – i)

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

$$\Rightarrow P = \frac{nRT}{V-nb} - \frac{an^2}{V^2} \qquad n = \frac{m}{M} = \frac{60}{15}\,\text{mol} = 4\,\text{mol}$$

$$= \frac{4 \cdot 8.3145 \cdot 700}{2.5\times10^{-3} - 4 \cdot 0.00007}\,\text{Pa} - \frac{0.85 \cdot 4^2}{2.5^2 \cdot 10^{-6}}\,\text{Pa}$$

$$= \frac{23280.6}{2.5\times10^{-3} - 2.8\cdot10^{-4}}\,\text{Pa} - \frac{13.6}{6.25\cdot10^{-6}}\,\text{Pa}$$

$$= \frac{23280.6}{2.22\times10^{-3}}\,\text{Pa} - \frac{2.176}{10^{-6}}\,\text{Pa}$$

$$= 10486.5 \cdot 10^3\,\text{Pa} - 2.176\cdot10^6\,\text{Pa}$$

$$= 10.487 \cdot 10^6\,\text{Pa} - 2.176\cdot10^6\,\text{Pa}$$

$$= 8.311\times10^6\,\text{Pa}$$

$$= 83.11\,\text{bar}$$

5. Two mol of an ideal gas is reversibly expanded at a constant temperature until $V_2 = 8\ V_1$. If the gas performed W = -24 kJ of work, what is its temperature T?
   a. 2670 K
   b. 1441 K
   c. 1388 K
   d. 720 K
   e. 694 K ✓
   f. 612 K
   g. 413 K
   h. 223 K
   i. 103 K
   j. none of a) – i)

$$W = nRT \ln \frac{V_1}{V_2} \Rightarrow T = \frac{W}{nR \ln V_2/V_1}$$

$$T = \frac{-24 \cdot 10^3}{-2 \cdot 8.3145 \ln 8} \cdot 10^3\ K$$

$$= \frac{12}{8.3145 \cdot 2.0794} \cdot 10^3\ K$$

$$= \frac{12}{17.2895} \cdot 10^3\ K$$

$$= 0.6941 \cdot 10^3\ K$$

$$= 694.1\ K$$

6. A Carnot engine operates between temperatures T_H=3000 K and T_C=75 K. How much heat (absolute value) needs to be put into the engine at T_H in order to obtain W=-6000 J of work from the engine?
   a. 1625.0 kJ
   b. 162.50 kJ
   c. 16.250 kJ
   d. 1.6250 kJ
   e. 5.8537 kJ
   ✓ f. 6.1538 kJ
   g. 61.538 kJ
   h. 615.38 kJ
   i. 6153.8 kJ
   j. none of a) – i)

$$\eta = 1 - \frac{T_C}{T_H} = 1 - \frac{75}{3000} = 1 - 0.025 = 0.975$$

$$= -\frac{W_{rev}}{Q_H} \Rightarrow Q_H = \frac{-W_{rev}}{\eta} = \frac{6000\,J}{0.975} = 6153.8\,J$$

$$= 6.1538\,kJ$$

Useful Equations and Constants:

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

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

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

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

$$\Delta U = q + w \qquad w = -\int_{V_i}^{V_f} P_{ext}\, dV \qquad \Delta H_m(T_2) = \Delta H_m(T_1) + \int_{T_1}^{T_2} \Delta C_p\, dT$$

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

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

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

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

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

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

$$\Delta S = nC_{V,m}\ln\frac{T_f}{T_i} \qquad \Delta S = -R(x_1\ln x_1 + x_2\ln x_2) \qquad G = H - TS$$

$\Delta G = \Delta H - T\Delta S$

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

$A = U - TS$

$\Delta A = \Delta U - T\Delta S$

$$\left(\frac{\partial U}{\partial V}\right)_T = -P + T\left(\frac{\partial P}{\partial T}\right)_V$$

$$\left(\frac{\partial H}{\partial P}\right)_T = V - T\left(\frac{\partial V}{\partial T}\right)_P$$

$$RT \ln\frac{f}{P} = \int_0^P \left(V_m - \frac{RT}{P'}\right) dP'$$

L = 6.022×10^{23} mol^{-1}
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}

1 atm = 101325 Pa, 1 bar = 100000 Pa
1 m^3 = 1000 liter = 1000 dm^3
1 W = 1 J s^{-1}
1 horsepower = 745.6 W

Thermodynamic data for compounds (all values are for 298.15 K and 1 bar)

	$\Delta_f H^o$ / kJ mol^{-1}	S^o / JK^{-1} mol^{-1}	$C_{P,m}$ / JK^{-1} mol^{-1}
$H_2(g)$	0	130.68	28.82
$N_2(g)$	0	191.61	29.13
$O_2(g)$	0	205.14	29.34
$CO(g)$	–110.53	197.67	29.14
$CO_2(g)$	–393.51	213.74	37.11
$H_2O(l)$	–285.83	69.91	75.29
$H_2O(g)$	–241.82	188.83	33.58
C(*graphite*)	0	5.74	8.527
$C_2H_5OH(s)$	–277.69	160.7	111.5
$C_6H_5OH(s)$	–165.47	144.0	221.2

Scratch paper