Name: ______________________

SID: ______________________

GSI Name: __________________

- There are 24 Multiple choice questions worth 3.75 points each.
- There are 5 short answer questions.
- For the multiple choice section, fill in the Scantron form AND circle your answer on the exam.
- Put your final answers in the boxes provided. Answers outside the boxes may not be considered in grading.
- The homework and chemquizzes that each question is based upon is listed after the question e.g. [HW 1.13, CQ 7.3]

<table>
<thead>
<tr>
<th>Question</th>
<th>Page</th>
<th>Points</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 25 - 27</td>
<td>8</td>
<td>13</td>
<td></td>
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<tr>
<td>Question 28</td>
<td>9</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Question 29</td>
<td>10</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>
NOTE: 1) All thermodynamic variables refer to the system unless otherwise stated.  
2) The symbol “↔” will be used to denote potential equilibrium reactions.

For questions 1 – 6 consider the following three step process shown on the PV diagram for one mole of an ideal gas initially at 1 atm pressure and 273K.

Step I: The gas expands isothermally from 22.4 L to 44.8 L (point 1 to 2 on the PV diagram).
Step II: The gas is cooled and compressed back to its original volume (point 2 to 3 on the PV diagram).
Step III: The gas is warmed back to its original pressure and volume (point 3 to point 1 on the PV diagram).

1.) Which is true of the gas for step I? [CQ 23.1]
   A) \( \Delta T > 0 \)  \( \fbox{B) \Delta T = 0} \)  C) \( \Delta T < 0 \)  D) \( q = 0 \)  E) none of these

2.) What is the temperature (K) of the gas at point 3?
   A) 273  B) 425  C) 373  \( \fbox{D) 137} \)  E) 57

3.) Which is true of the gas for step I? [CQ 23.1]
   A) Work is done on the gas with no heat transfer.
   B) The gas does work with no heat transfer.
   C) \( \fbox{The gas does work and absorbs heat.} \)
   D) Work is done on the gas and it releases heat.
   E) Cannot be determined.
4.) Which is true of the gas for step II? [HW 6.5]
   A) Work is done on the gas with no heat transfer.
   B) The gas does work with no heat transfer.
   C) The gas does work and absorbs heat.
   D) Work is done on the gas and it releases heat.
   E) Cannot be determined.

5.) Which is true of the gas for step III? [HW 6.11]
   A) Heat absorbed and no work is done.
   B) Heat released and no work is done.
   C) Heat absorbed and work is done on the gas.
   D) Heat absorbed and the gas does work.
   E) Cannot be determined.

6.) Which is the correct arrangement of the three points (1, 2, 3) in the PV diagram from highest to lowest internal energy E? [CQ 23.1 HW 6.5]
   A) 3 > 2 > 1
   B) 3 = 2 > 1
   C) 1 > 3 > 2
   D) 1 = 2 > 3
   E) 1 > 2 = 3
For questions 7 – 16 consider the following table of data for reactions among two unknown diatomic molecules X₂ and Y₂.

<table>
<thead>
<tr>
<th>Rxn Number</th>
<th>Reaction</th>
<th>K (equilibrium)</th>
<th>Temp (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2 XY (g) ↔ X₂ (g) + Y₂ (g)</td>
<td>377</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>1000</td>
</tr>
<tr>
<td>II</td>
<td>X₂ (g) ↔ 2 X (g)</td>
<td>1.0 x 10⁻⁵</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.7 x 10⁻³</td>
<td>1200</td>
</tr>
<tr>
<td>III</td>
<td>Y₂ (g) ↔ 2 Y (g)</td>
<td>3.4 x 10⁻³</td>
<td>1000</td>
</tr>
</tbody>
</table>

7.) Which reaction(s) in the table are spontaneous at 1000K, starting from the standard state? [CQ 31.1 HW 9.15, 9.101]

A) I  
B) II  
C) III  
D) All three  
E) None

8.) Which is true of ΔH° for reaction II?

A) ΔH° > 0  
B) ΔH° = 0  
C) ΔH° < 0  
D) Cannot be determined from the information given.

9.) Which is true of ΔS° for reaction II? [HW 7.29]

A) ΔS° > 0  
B) ΔS° = 0  
C) ΔS° < 0  
D) Cannot be determined from the information given.

10.) What is the value of ΔG° (kJ) for reaction III at 1000K? [HW 9.15]

A) 33  
B) -45  
C) 22  
D) -86  
E) -11

11.) Which is true of reaction I?

A) ΔH° > 0  
B) ΔH° = 0  
C) ΔH° < 0  
D) Cannot be determined from the information given.
12.) Which is the best plot of $\Delta G^\circ$ vs. $T$ for reactions II and III (reaction II is the solid line, reaction III is the dotted line)? [CQ 31.2, 9.101]

A) \hspace{1cm} B) \hspace{1cm} C) \hspace{1cm} D) \hspace{1cm} E) 

13.) What is the value of K (the equilibrium constant) at 1000K for the reaction: $XY (g) \leftrightarrow X (g) + Y (g)$? [HW 9.25]

A) $4.1 \times 10^{-5}$
B) $5.5 \times 10^{-9}$
C) $7.0 \times 10^{-3}$
D) $1.2 \times 10^{-10}$
E) $2.3 \times 10^{-6}$

14.) Which is true for reaction II at 1000K when 1 atm $X_2$ and 1 atm $X$ are present? [HW 9.17, CQ 31.1]

A) $K = 1$
B) $\Delta G^\circ = 0$
C) $Q = 1$
D) $Q = K$
E) $Q < K$

15.) For which partial pressure of X atoms is $\Delta G = 0$ at 1000K for reaction II when 1.00 atm of $X_2$ is present [HW 9.17]?

A) 1.00 atm
B) 2.00 atm
C) $1.1 \times 10^3$ atm
D) $3.2 \times 10^3$ atm
E) $3.4 \times 10^3$ atm

16.) Which is true for the relative bond enthalpies X-X and Y-Y? [HW 9.39]

A) $X-X > Y-Y$
B) $X-X = Y-Y$
C) $X-X < Y-Y$
D) Cannot be determined from the information given.
Consider two compounds in their gas phase: ethanol (CH₃CH₂OH) and dimethyl ether (CH₃OCH₃) and their combustion in oxygen to form carbon dioxide and liquid water for questions 17 - 27. Unless instructed otherwise, you should use standard enthalpies and Hess’s Law to calculate enthalpies of reaction.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Abbreviation</th>
<th>ΔHᵣ (formation) (kJ/mol)</th>
<th>ΔHᵣ (combustion) (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethanol (g) (CH₃CH₂OH)</td>
<td>EtOH</td>
<td></td>
<td>-1271</td>
</tr>
<tr>
<td>dimethyl ether (g) (CH₃OCH₃)</td>
<td>DiMe</td>
<td></td>
<td>-1328</td>
</tr>
<tr>
<td>carbon dioxide (g) (CO₂)</td>
<td></td>
<td>-394</td>
<td></td>
</tr>
<tr>
<td>water (l) (H₂O)</td>
<td></td>
<td>-286</td>
<td></td>
</tr>
</tbody>
</table>

17.) What is the coefficient of O₂ in the balanced chemical reaction for the combustion of one (1) mole of dimethyl ether?

A) 1   B) 2   C) 3   D) 4   E) 5

18.) How much heat (kJ) is released when 50 g of ethanol is reacted with excess oxygen [HW 6.47]?

A) 1271  
B) 1382  
C) 1492  
D) 1555  
E) 1645

19.) Which of the following is responsible for the sign of ΔHᵣ (the enthalpy of combustion) for ethanol?

A) Breaking C-H and C-C bonds.  
B) Breaking O-H bonds.  
C) Forming C-H bonds and C-C bonds.  
D) Forming O-C and O-H bonds.  
E) Condensation of the water formed.

20.) Which statement(s) (I – IV) below are true regarding ΔHᵣ for the gas phase isomerization shown [HW 6.56, 6.61]?

CH₃CH₂OH → CH₃OCH₃

I  ΔHᵣ = ΔHᵣ(CO₂) - ΔHᵣ(EtOH)  
II  ΔHᵣ = ΔHᵣ(DiMe) - ΔHᵣ(EtOH)  
III  ΔHᵣ = ΔHᵣ(CO₂) - ΔHᵣ(H₂O)  
IV  ΔHᵣ = ΔHᵣ(EtOH) - ΔHᵣ(DiMe)

A) I only   B) I and II   C) II only   D) II and IV   E) III only
21.) What is $\Delta H^\circ$ (kJ) for the gas phase isomerization reaction shown? [HW 6.61, CQ24.2]

$$\text{CH}_3\text{CH}_2\text{OH} \ (g) \rightarrow \text{CH}_3\text{OCH}_3 \ (g)$$

A) -48  B) -13  C) +22  D) +57  E) +102

22.) Which is the arrangement of ethanol (EtOH), dimethyl ether (DiMe) and the combustion products (P) in terms of relative $\Delta H^\circ$ [CQ 24.2]?

$$\Delta H^\circ$$

A) EtOH  B) P  C) DiMe  D) DiMe  E) P

DiMe  EtOH  EtOH  P  DiMe

23.) Which combustion would release more energy? [CQ 25.4]

A) 1.0 mole ethanol in excess O$_2$?
B) 1.0 mole of dimethyl ether in excess O$_2$?
C) 1.5 mole ethanol in excess O$_2$.
D) 0.5 mole dimethyl ether in excess O$_2$.
E) A and B release the same amount of energy.

24.) If you consume ethanol at 25°C it reacts with oxygen in your body to form carbon dioxide and water (both of which you exhale). The products you exhale then cool to carbon dioxide gas and liquid water at 25°C. How does this process compare with the combustion of ethanol in the laboratory where the products and reactants are also compared at 25°C?

A) The laboratory combustion has a larger $\Delta H$.
B) The reaction in your body has a larger $\Delta H$.
C) The free energy released by the reaction in your body is larger.
D) $\Delta G$ and $\Delta H$ are the same for the laboratory combustion and in your body.
E) No comparison of energy functions for different the two processes can be made.
The table from page 6 is repeated here for your exam-taking convenience.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Abbreviation</th>
<th>ΔH°_f (formation) (kJ/mol)</th>
<th>ΔH°_c (combustion) (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethanol (g)</td>
<td>EtOH</td>
<td></td>
<td>-1271</td>
</tr>
<tr>
<td>(CH₃CH₂OH)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dimethyl ether (g)</td>
<td>DiMe</td>
<td></td>
<td>-1328</td>
</tr>
<tr>
<td>(CH₃OCH₃)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>carbon dioxide (g)</td>
<td></td>
<td>-394</td>
<td></td>
</tr>
<tr>
<td>(CO₂)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>water (l) (H₂O)</td>
<td></td>
<td>-286</td>
<td></td>
</tr>
</tbody>
</table>

25.) (4 pt) What is ΔH°_f (the enthalpy of formation) for ethanol (kJ/mol) [HW 6.56, 6.61]?

\[
\Delta H°_c = \Sigma \Delta H°_f (products) - \Sigma \Delta H°_f (reactants)
\]

\[
\Delta H°_c = 2(\text{CO}_2) + 3(\text{H}_2\text{O}) - (\text{EtOH})
\]

\[
-1271 = 2 (-394) + 3 (-286) - \text{EtOH}
\]

\[
375 = - \text{EtOH}
\]

\[
\Delta H°_f = -375 \text{ kJ/mol}
\]

26.) (5 pt) Calculate ΔH°_c (the enthalpy of combustion) for ethanol from average bond energies (average bond enthalpies are on the reverse of the periodic table handout) [HW 6.71]?

\[
\text{CH}_3\text{CH}_2\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}
\]

\[
\begin{align*}
\text{C} - \text{H} - \text{O} - \text{H} & \rightarrow 2 \text{O} = \text{C} = \text{O} + 3 \text{H}_2\text{O} \\
\end{align*}
\]

\[
\Delta H°_c = 5(\text{C} - \text{H}) + (\text{C} - \text{C}) + (\text{C} - \text{O}) + (\text{O} - \text{H}) + 3(\text{O} - \text{O})
\]

\[
\begin{align*}
-\left[4(\text{C} = \text{O}) + 6(\text{O} - \text{H})\right] \\
= 5(414) + 347 + 351 + 464 + 3(498) \\
-\left[4(741) + 6(464)\right] \\
= 472.6 - 574.8
\end{align*}
\]

\[
\Delta H°_c = -1022 \text{ kJ/mol EtOH}
\]

27.) (4 pt) Does the value of ΔH°_c for ethanol calculated from average bond enthalpies agree with the value in the table (explain in 20 words or less)?

**Explanation:**

No, bond enthalpies are averages over many molecules so they seldom agree exactly with Hess's Law or experiment.

**No + 1 reason + 3**
28.) A 1.00 kg block of iron is dropped into a small copper kettle (mass 300.0 g) containing, and in thermal equilibrium with, 100.0 g of water at 25°C. The maximum final temperature reached in the kettle, water, iron system is 55°C. The heat capacity of iron metal is 0.45 J/gK; copper metal is 0.51 J/gK. The heat capacity of water is 4.184 J/gK [HW 6.15]

A) (4 pt) How much heat is transferred from the iron?

\[ \Delta T = 55 - 25 = 30 \text{ K} \]
\[ q_{H_2O} = m_{C} \Delta T = (100.0 \text{ g})(4.184 \frac{J}{g \cdot K})(30 \text{ K}) = 12552 \text{ J} \]
\[ q_{Cu} = m_{C} \Delta T = (300.0 \text{ g})(0.51 \frac{J}{g \cdot K})(30 \text{ K}) = 4590 \text{ J} \]

\[ q = 17142 \text{ J} \]
\[ = 17000 \text{ J} \]

B) (4 pt) What percentage of the heat is transferred to the copper kettle?

\[ \frac{q_{Cu}}{q_{Total}} = \frac{4590}{17142} \times 100 = 27\% \]

\[ %q = 27\% \]

C) (4 pt) What was the initial temperature of the iron?

\[ q_{Fe} = m_{C} \Delta T \]
\[ 17142 \text{ J} = (1000 \text{ g})(0.45 \frac{J}{g \cdot K})(\Delta T) \]
\[ 38 \text{ K} = \Delta T \]
\[ 38 + 55 = 93 \text{ °C} \]

\[ T_i = 93 \text{ °C} \]
29.) For the following questions, consider the following exothermic reaction taking place in a large sealed container at 298K where the equilibrium constant \( K = 25 \).

\[ 2 \text{CH}_4 (g) + 8 \text{S}_8 (s) \leftrightarrow 2 \text{CS}_2 (l) + 4 \text{H}_2\text{S} (g) \]

A) (4 pt) What is the expression for \( Q \) for the reaction? [HW 9.5]

\[
Q = \frac{\frac{P_{\text{H}_2\text{S}}^4}{P_{\text{CH}_4}^2}}{1} = \frac{[\text{H}_2\text{S}]^4}{[\text{CH}_4]^2}
\]

B) (15 pt) Complete the following table that describes the effect of various changes on an equilibrium mixture of the reaction initially at 298K. \( K_i \) is the equilibrium constant before the change occurs. [HW 9.72, 9.73, 9.75, 9.109, CQ 30.1, 30.2, 30.3]

<table>
<thead>
<tr>
<th>Change</th>
<th>Q vs. ( K_i )</th>
<th>Shift toward (Circle one)</th>
<th>Change in ( K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase pressure of ( \text{H}_2\text{S} )</td>
<td>( Q &gt; K_i )</td>
<td>Products</td>
<td>Increase</td>
</tr>
<tr>
<td>( Q = K_i )</td>
<td>Reactants</td>
<td>Decrease</td>
<td></td>
</tr>
<tr>
<td>( Q &lt; K_i )</td>
<td>No Change</td>
<td>No Change</td>
<td></td>
</tr>
<tr>
<td>Reduce volume</td>
<td>( Q &gt; K_i )</td>
<td>Products</td>
<td>Increase</td>
</tr>
<tr>
<td>( Q = K_i )</td>
<td>Reactants</td>
<td>Decrease</td>
<td></td>
</tr>
<tr>
<td>( Q &lt; K_i )</td>
<td>No Change</td>
<td>No Change</td>
<td></td>
</tr>
<tr>
<td>Increase total pressure by adding ( \text{Ar} (g) )</td>
<td>( Q &gt; K_i )</td>
<td>Products</td>
<td>Increase</td>
</tr>
<tr>
<td>( Q = K_i )</td>
<td>Reactants</td>
<td>Decrease</td>
<td></td>
</tr>
<tr>
<td>( Q &lt; K_i )</td>
<td>No Change</td>
<td>No Change</td>
<td></td>
</tr>
<tr>
<td>Add ( \text{S}_8 (s) )</td>
<td>( Q &gt; K_i )</td>
<td>Products</td>
<td>Increase</td>
</tr>
<tr>
<td>( Q = K_i )</td>
<td>Reactants</td>
<td>Decrease</td>
<td></td>
</tr>
<tr>
<td>( Q &lt; K_i )</td>
<td>No Change</td>
<td>No Change</td>
<td></td>
</tr>
<tr>
<td>Increase temperature</td>
<td>( Q &gt; K_i )</td>
<td>Products</td>
<td>Increase</td>
</tr>
<tr>
<td>( Q = K_i )</td>
<td>Reactants</td>
<td>Decrease</td>
<td></td>
</tr>
<tr>
<td>( Q &lt; K_i )</td>
<td>No Change</td>
<td>No Change</td>
<td></td>
</tr>
</tbody>
</table>

C) (6 pt) What is the equilibrium pressure of \( \text{H}_2\text{S} \) at 298K if at equilibrium the pressure of \( \text{CH}_4 \) is 5.43 atm and 10 g of \( \text{S}_8 \) and 15 ml of \( \text{CS}_2 \) are present? [HW 9.29]

\[
\frac{P_{\text{H}_2\text{S}}^4}{P_{\text{CH}_4}^2} = 25 \implies P_{\text{H}_2\text{S}} = 25(5.43 \text{ atm})^2 = 5.21 \text{ atm}
\]

\[
P = 5.21 \text{ atm}
\]
Quantum:
E = hν
\lambda V = c
\lambda_{\text{det}} = h / p = h / mv
E_{\text{kin}} (e^-) = hv - \Phi = hv - hv_0
\frac{E_n}{Z^2} \frac{R_n}{n^2} = \Delta x \Delta p \sim h
p = mv
Particle in a box (1-D Quantum):
E_n = \frac{h^2 n^2}{8 mL^2}; n = 1, 2, 3...
Vibrational:
E_v = \left( v + \frac{1}{2} \right) \hbar A / 2\pi; A = (k/m)^{1/2}
Rotational:
E_n = n(n + 1) \hbar B; B = h/8\pi^2 l; l = 2m^2
m = m_A m_B / (m_A + m_B)

Ideal Gas:
PV = nRT
E_{\text{kin}} = \frac{3}{2} RT
\sqrt{\frac{3RT}{M}}

Constants:
N_0 = 6.02214 \times 10^{23} \text{ mol}^{-1}
R_o = 2.179874 \times 10^{-18} \text{ J}
R_o = 8.38984 \times 10^{15} \text{ Hz}
k = 1.38066 \times 10^{-23} \text{ J K}^{-1}
h = 6.62608 \times 10^{-34} \text{ J s}
m_e = 9.101939 \times 10^{-31} \text{ kg}
c = 2.99792 \times 10^8 \text{ m s}^{-1}
T (K) = T (C) + 273.15
F = 96,485 \text{ C / mol}
1 \text{ V} = 1 \text{ J / C}

Gas Constant:
R = 8.31451 \text{ J K}^{-1} \text{ mol}^{-1}
R = 8.20578 \times 10^{-2} \text{ L atm K}^{-1} \text{ mol}^{-1}
1 \text{ nm} = 10^{-9} \text{ m}
1 \text{ kJ} = 1000 \text{ J}
1 \text{ atm} = 760 \text{ mm Hg} = 760 \text{ torr} \approx 1 \text{ bar}
1 \text{ L atm} \approx 100 \text{ J}

Thermodynamics:
\Delta G^\circ = \Delta H^\circ - T \Delta S^\circ
\Delta H^\circ = \sum \Delta H^\circ_r (\text{products}) - \sum \Delta H^\circ_i (\text{reactants})
\Delta S^\circ = \sum S^\circ (\text{products}) - \sum S^\circ (\text{reactants})
\Delta G^\circ = \sum \Delta G^\circ_r (\text{products}) - \sum \Delta G^\circ_i (\text{reactants})
S = k_B \ln W
\Delta S = q_{\text{rev}} / T
\Delta E = q + w
w = - P_{\text{ext}} \Delta V
\text{for } aA + bB \rightarrow cC + dD
Q = \frac{[C]^c [D]^d}{[A]^a [B]^b}
\text{At equilibrium, } Q = K
\Delta G^\circ = \Delta G^\circ + RT \ln Q
G = G^\circ + RT \ln(a); a = \text{ activity} = \gamma P / P^o \text{ or } \gamma[A]/[A]^\circ
\Delta G^\circ = -RT \ln K
\Delta G^\circ = -nF \Delta C^\circ
\Delta C = \Delta C^\circ - (RT/nF) \ln Q
\ln K = \frac{\Delta H^\circ}{R} \frac{1}{T} + \frac{\Delta S^\circ}{R}
\Delta T = \frac{i k_B T}{m}
\Pi = iMRT
P_{\text{total}} = P_A + P_B = X_A P_A^o + X_B P_B^o

Acid Base:
pH = - \log[H_3O^+]
pX = - \log X
pH = pK_a + \log \frac{[A^-]}{[HA]}

Kinetics:
[A]_t = [A]_0 e^{-kt}
ln[A]_t = ln[A]_0 - kt
t_{1/2} = \ln 2 / k
1/[A]_t = 1/[A]_0 + kt
k = A e^{(-E_a/RT)}
ln(k_1/k_2) = E_a / R (1/T_2 - 1/T_1)
t_{1/2} = 1/[A]_0 k
k_{1/2} = [A]_0 / k