Directions: (1) Put your name, S.I.D. number and signature on the free response part of the exam where indicated.
(2) Each multiple choice question is actually 2 questions on your scanning sheet. If you are sure of an answer, put the same answer down for both questions for 5 pts. If you cannot decide between two answers, put one answer down for one question and the other answer down for the other question. If you get one correct you'll get half credit for 2.5 pts. If there is an ambiguous multiple choice question, use the last page to explain your answer.
(3) Do NOT write on the envelope.
(4) Bubble in OPTION A on the scanning sheet IF you want your grade posted.
(5) When finished, put the free response answers in the envelope with the scanning sheet. You can keep the multiple choice part - the answers will be given to you as you leave.
(6) There are a total of 28 questions (16 actual questions).

PART 1

1&2. Which one of the following thermodynamic quantities is NOT a state function?

(a) $\Delta E$ (b) $\Delta G$ (c) $T$ (d) $(q + w)$ (e) $w$

3&4. The value of which of the following is equal to zero?

(a) $\Delta H_{298}^{\circ}$ $Cl_2(\ell)$ (b) $\Delta H_{298}^{\circ}$ $C$ (s, diamond) (c) $\Delta G_{298}^{\circ}$ Na(s)
(d) $\Delta G_{298}^{\circ}$ $H_2O(\ell)$ (e) $S_{298}^{\circ}$ $N_2(g)$

5&6. When a reaction absorbs heat from its surroundings, it is said to be

(a) spontaneous (b) nonspontaneous (c) exothermic
(d) endothermic (e) decreasing in entropy
7&8. A system has 20 J of heat removed from it and at the same time does 50 J of work. What is the change in the internal energy of the system?

(a) -70 J (b) +70 J (c) -30 J (d) +30 J (e) +45 J

9&10. Consider the following spontaneous reaction at constant pressure. Which response is FALSE?

\[ 2\text{HCl}(aq) + \text{CaCO}_3(s) \rightarrow \text{CO}_2(g) + \text{CaCl}_2(aq) + \text{H}_2\text{O}(l) \]

(a) The heat involved is measured in a coffee cup calorimeter.
(b) The entropy of the system is increasing.
(c) The work done by the system is a positive value.
(d) The heat measured is equal to \( \Delta H \).
(e) The value of the change in Gibbs free energy is negative.

11&12. What is the enthalpy change of the reaction below at 298 K and 1 atm pressure?

<table>
<thead>
<tr>
<th>( \Delta H_{298}^o \text{(kJ/mol)} )</th>
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<tbody>
<tr>
<td>Fe_3O_4(s) + CO(g) \rightarrow 3FeO(s) + CO_2(g)</td>
</tr>
</tbody>
</table>

(a) -263 kJ (b) -50 kJ (c) +54 kJ (d) +109 kJ (e) +19.5 kJ
13&14. Consider the following reaction: \(2\text{NO}(g) \rightarrow \text{O}_2(g) + \text{N}_2(g)\). Which of the following is always TRUE?

(a) \(\Delta E = \Delta H\)  
(b) \(\Delta H = \Delta G\)  
(c) \(\Delta G = 0\)  
(d) \(w > 0\)  
(e) \(\Delta H = 0\)

15&16. Which of the following processes correspond to a positive value of \(\Delta S\)?

(1) the freezing of water  
(2) the condensation of steam  
(3) the sublimation of dry ice, \(\text{CO}_2(s)\)  
(4) the lowering of the temperature of solid copper from 298 K to 0 K.

(a) 1, 4 only  
(b) 2, 4 only  
(c) 1, 2, 4 only  
(d) 3 only  
(e) another combination

17&18. Which of the following name/formula combinations are CORRECT?

(1) propane \(\text{C}_3\text{H}_6\)  
(2) calcium chlorite \(\text{Ca(ClO}_2)_2\)  
(3) dimethylamine \((\text{CH}_3)_2\text{NH}\)  
(4) iron(III) sulphate \(\text{FeSO}_4\)  
(5) ammonium carbonate \(\text{NH}_4(\text{CO}_3)_2\)

(a) 3, 5 only  
(b) 2, 3 only  
(c) 1, 3, 4 only  
(d) 2 only  
(e) another combination

19&20. For a reaction where \(\Delta H\) is -345 kJ/mol rxn and \(\Delta S = -48\) J/K, __________.

(a) the reaction is spontaneous at all temperatures.  
(b) the reaction is nonspontaneous at all temperatures  
(c) the reaction is spontaneous only at temperatures above a certain value.  
(d) the reaction is spontaneous only at temperatures below a certain value.  
(e) It is impossible to tell if the reaction is or is not spontaneous.
21&22. Consider the reaction below at 25°C for which $\Delta G^\circ = -159$ kJ/mol rxn. Calculate $\Delta S^\circ$ at 25°C.

$$\text{HCN(g)} + \text{NH}_3(g) \rightarrow \text{CH}_4(g) + \text{N}_2(g) + 163.8 \text{ kJ}$$

(a) -16.1 J/K   (b) -67.8 J/K   (c) -1.54 J/K   (d) -44 J/K   (e) -109 J/K

23&24. Estimate the sublimation temperature of the metal, sodium (in °C) using thermodynamic data given below taken from Appendix K:

$$\text{Na(s) } \overset{\rightarrow}{\rightarrow} \text{Na(g)}$$

<table>
<thead>
<tr>
<th></th>
<th>$\Delta H^\circ_{298}$ (kJ/mol)</th>
<th>$S^\circ$ (J/mol·K)</th>
<th>$\Delta G^\circ_{298}$ (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na(g)</td>
<td>108.7</td>
<td>153.6</td>
<td>78.11</td>
</tr>
<tr>
<td>Na(s)</td>
<td>0</td>
<td>51.0</td>
<td>0</td>
</tr>
</tbody>
</table>

(a) 1044°C   (b) 893°C   (c) 786°C   (d) 911°C   (e) 649°C
25. Consider the following reaction: \( 2 \text{N}_2\text{O}_5(g) \rightarrow 4 \text{NO}_2(g) + \text{O}_2(g) \)

(3 pts) (a) Express the rate of reaction as a function of each of the compounds using \( \frac{\Delta \text{[compound]}}{\Delta t} \).

(3 pts) (b) If \( \text{N}_2\text{O}_5 \) is reacting at a rate of 1.00 M/min at a certain time, at what rate is \( \text{O}_2 \) being produced at that same time?
(8 pts) 26. (a) A 1.200 g sample of isoprene, C_5H_8(l), was completely burned in a bomb calorimeter containing 4800. g of water which increased in temperature from 24.000°C to 26.651°C. The calorimeter constant was 855 J/°C. The specific heat of the water is 4.184 J/g°C. What is ΔE for the reaction in kJ/mol C_5H_8?

(3 pts) (b) Write the balanced combustion reaction:

(5 pts) (c) Calculate the work when 1 mole of isoprene undergoes complete combustion. Use the final temperature.
27. Consider the following balanced reaction:

\[ 2\text{Al(s)} + \text{Fe}_2\text{O}_3(s) \rightarrow 2\text{Fe(s)} + \text{Al}_2\text{O}_3(s) \quad \Delta H^\circ = -852 \text{ kJ/mol rxn} \]

(5 pts) (a) If 300.0 kJ of heat are released, how many grams of Fe must have been formed?

(5 pts) (b) Now, consider this reaction combined with the reaction given above:

\[ 4\text{Al(s)} + 3\text{O}_2(g) \rightarrow 2\text{Al}_2\text{O}_3(s) \quad \Delta H^\circ = -3352 \text{ kJ/mol rxn} \]

Using Hess's Law, determine the enthalpy of formation of \( \text{Fe}_2\text{O}_3(s) \).
28. The following drawing represents a spontaneous gaseous reaction of A(g) atoms forming gaseous products:

(a) Write the balanced equation for the reaction.

(b) What are the signs of $\Delta H^\circ$, $\Delta S^\circ$, and $\Delta G^\circ$ for the reaction? Explain your reasoning briefly.