Directions: (1) Put your name, signature and section number 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) 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. 
(5) There are a total of 29 questions (17 actual questions). 

PART 1

1&2. Which is the correct $K_c$ expression for the equilibrium: $2C(s) + O_2(g) \rightleftharpoons 2CO(g)$?

(a) $K_c = \frac{[CO]^2}{2[C][O_2]}$  
(b) $K_c = \frac{[C]^2[O_2]}{[CO]^2}$  
(c) $K_c = \frac{[CO]^2}{[C][O_2]}$  
(d) $K_c = \frac{[CO]^2}{[O_2]}$  
(e) $K_c = \frac{[O_2]}{[CO]^2}$

3&4. Consider the following rate law expression for the reaction: $X + 2Y \rightarrow 2Z$

\[ \text{Rate} = k[X]^2[Y] \]

The reaction is

(a) first order with respect to X, first order with respect to Y and second order overall.  
(b) second order with respect to X, first order with respect to Y and third order overall.  
(c) second order with respect to X, second order with respect to Y and second order overall.  
(d) first order with respect to X, second order with respect to Y and third order overall.  
(e) It is impossible to determine the order of the reaction from the information given.

5&6. Which of the following is a strong acid?

(a) HClO$_2$  
(b) HBrO$_4$  
(c) HClO$_3$  
(d) HF  
(e) HNO$_2$
7&8. The equilibrium constant for the gas phase reaction \[ \text{A} \rightleftharpoons \text{B} \] is \( 4.0 \times 10^{-13} \). Which of the following is TRUE?

(a) If only A is added to a container, most of it will convert to B.
(b) Adding a catalyst will increase the value of the equilibrium constant.
(c) Adding more A will increase the value of the equilibrium constant.
(d) Changing the temperature will change the value of the energy of activation for the forward reaction.
(e) The equilibrium concentration of A is greater than that of B.

9&10. Consider the gaseous system: \( \text{2CO} + \text{O}_2 \rightleftharpoons \text{2CO}_2 \) with \( K_c = 3.0 \times 10^3 \)

What is the value of \( K_c \) for \( \text{4CO}_2 \rightleftharpoons 4\text{CO} + 2\text{O}_2 \) at the same temperature?

(a) \( 3.0 \times 10^3 \)  
(b) 11  
(c) 0.54  
(d) \( 3.3 \times 10^{-4} \)  
(e) \( 1.1 \times 10^{-7} \)

11&12. Consider the gaseous system: \( \text{2CO} + \text{O}_2 \rightleftharpoons \text{2CO}_2 \) with \( \Delta H^0 = -599 \text{ kJ/mol rxn} \)

Which of the following will cause an increase in the number of moles of CO?

(a) Decreasing the volume of the system at constant temperature.
(b) Adding more oxygen gas to the system.
(c) Removing carbon dioxide from the system as it is formed.
(d) Increasing the temperature of the system.
(e) Adding a catalyst.
13&14. Rate data were collected for the following reaction at a particular temperature. What is the value of the specific rate constant?

\[ \text{NO}_2(g) + \text{CO(g)} \rightarrow \text{NO(g)} + \text{CO}_2(g) \]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>([\text{NO}<em>2]</em>{\text{initial}})</th>
<th>([\text{CO}]_{\text{initial}})</th>
<th>Initial Rate of Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.10 M</td>
<td>0.10 M</td>
<td>0.0050 M/s</td>
</tr>
<tr>
<td>2</td>
<td>0.40 M</td>
<td>0.10 M</td>
<td>0.080 M/s</td>
</tr>
<tr>
<td>3</td>
<td>0.10 M</td>
<td>0.20 M</td>
<td>0.0050 M/s</td>
</tr>
</tbody>
</table>

(a) 0.50 M\(^{-1}\)·s\(^{-1}\)  (b) 0.0050 M\(^{-1}\)·s\(^{-1}\)  (c) 0.055 s\(^{-1}\)

(d) 50. M\(^{2}\)·s\(^{-1}\)  (e) 5.0 M\(^{-1}\)·s\(^{-1}\)

15&16. In a 1.0 liter container there are, at equilibrium, 0.20 moles of I\(_2\), 0.30 moles of H\(_2\) and 0.20 moles of HI in the system.

\[ \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2 \text{HI(g)} \]

What is the value of \(K_c\) for this reaction?

(a) 0.33  (b) 2.7  (c) 0.67  (d) 1.3  (e) none of these
17&18. Consider this same equilibrium as in Question 15&16 at a different temperature in which the $K_c = 25$.

$$\ce{H2(g) + I2(g) <=> 2 HI(g)}$$

Initially in the container there is 0.40 M of HI. At equilibrium, what is the concentration of H$_2$?

(a) 0.057 M  (b) 0.032 M  (c) 0.071 M  (d) 0.015 M  (e) 0.048 M

19&20. Calculation $\Delta G^{\circ}$ for the reaction at 25°C if the value of the thermodynamic equilibrium constant, $K_{\text{thermo}}$ is $2.47 \times 10^{-29}$?

$$3/2 \ce{O2(g) <=> O3(g)}$$

(a) $+163$ kJ/mol rxn  (b) $-163$ kJ/mol rxn  (c) $-13.7$ kJ/mol rxn

(d) $+13.7$ kJ/mol rxn  (e) $+1.61$ kJ/mol rxn
21&22. What is the half-life of the following reaction if after 6.00 days only 2.50 g of a 50.0 g sample of \( \text{CS}_2 \) remains at a certain temperature? The decomposition reaction is first order.

\[
\text{CS}_2 \rightarrow \text{CS} + \text{S}
\]

(a) 0.223 d  (b) 1.39 d  (c) 0.785 d  (d) 0.174 d  (e) 1.48 d

23&24. Calculate the pH of a 0.030 M solution of \( \text{Ca(OH)}_2 \). (All the sucker answers are present).

(a) 1.22  (b) 1.52  (c) 12.48  (d) 12.78  (e) 12.11
PART 2

(3 pts) 25. (a) Consider this system at equilibrium: \( \text{A}_2(g) + \text{B}_2(g) \rightleftharpoons 2\text{AB}(g) \). Write the \( K_c \) expression.

(1 pt) (b) Suppose that the value of \( K_c \gg 1 \), will there be a lot more products or reactants at equilibrium?

(3 pts) (c) Sketch a picture of the final equilibrium mixture when \( K_c \gg 1 \) when

\[
\text{A is represented by } \bigcirc \text{ and B is represented by } \bullet
\]
26. Consider the following 2 step mechanism for a gas phase reaction. In the first step, a molecule of X collides with a molecule of Y to form a molecule of A. In the second step, a molecule of A collides with a molecule of Y to form a molecule of X and a molecule of B.

(a) Write out the mechanism and the overall reaction.

(b) Identify the catalyst (if any): _______
Identify the intermediate (if any): _______

(c) Write the rate law expression for this mechanism if the first step is the slow step.

(d) Write the rate law expression for this mechanism if the first step is a fast equilibrium step and the second step is the slow step. (Remember: show all your work to get full credit.)
(5 pts) 27. (a) Consider the reaction: $A \rightarrow B$. What is the activation energy for the forward reaction (in kJ) when the rate constant at $20^\circ C$ is $0.0850 \text{ min}^{-1}$ and the rate constant at $50^\circ C$ is $1.34 \text{ min}^{-1}$?

$$\log\left(\frac{k_2}{k_1}\right) = \frac{E_a}{2.303R} \left(\frac{T_2 - T_1}{T_1T_2}\right) \quad \text{or} \quad \ln\left(\frac{k_2}{k_1}\right) = \frac{E_a}{R} \left(\frac{T_2 - T_1}{T_1T_2}\right) \quad R = 8.314 \text{ J/mol} \cdot \text{K}$$

(3 pts) (b) The $\Delta E$ for this reaction is -40.0 kJ. Draw the potential energy diagram for this reaction using the answer for part (a). If you were unable to do the calculation, assume that the activation energy for the forward reaction is 150. kJ. Label the axes correctly.

(2 pts) (c) Determine the activation energy for the reverse reaction.

OVER ⇒
(5 pts) **28.** Consider the gas phase equilibrium system: \( C \rightleftharpoons D + 2X \). Initially in the 10.0 L container we have 1.00 mole of \( C \), \( D \) and \( X \). When the system is at equilibrium, there are 2.00 moles of \( X \) in the container. Calculate \( K_c \).

(5 pts) **29.** Write a short paragraph about catalysts. Include in your discussion:

1. The definition of a catalyst and how to recognize a catalyst
2. The two kind of catalysts
3. Whether or not a catalyst participates in the reaction.