Directions: (1) Put your name on PART 1 and your name and signature on PART 2 of the exam where indicated.
(2) Sign the Aggie Code on PART 2 of this exam.
(3) 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.
(4) Do NOT write on the envelope.
(5) When finished, put everything in the envelope and wait to be excused. At the table, take everything out of the envelope. You can pick up the multiple choice part with the answers outside my office after 3pm.
(6) There are a total of 30 questions (18 actual questions).

PART 1

1&2. Which is the correct $K_c$ expression for the equilibrium:
$$\text{Ni(s)} + 4\text{CO(g)} \rightleftharpoons \text{Ni(CO)}_4(g)$$
(a) $K_c = \frac{[\text{Ni(CO)}_4]}{[\text{Ni}][\text{CO}]}$
(b) $K_c = \frac{[\text{Ni}][\text{CO}]}{[\text{Ni(CO)}_4]}$
(c) $K_c = \frac{[\text{Ni}]}{[\text{CO}]}$
(d) $K_c = \frac{[\text{Ni(CO)}_4]}{4[\text{CO}]}$
(e) $K_c = \frac{[\text{Ni(CO)}_4]}{[\text{Ni}][\text{CO}]}$

3&4. The equilibrium constant for the gas phase reaction:
$$\text{C} \rightleftharpoons \text{D}$$
is $2.0 \times 10^9$. Which statement is TRUE?
(a) If only D is added to a container, most of it will convert to C.
(b) Adding a catalyst will change the value of the equilibrium constant.
(c) Adding more C 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 D is greater than that of C.

5&6. At 1000°C, the $K_c$ value for the following gas phase equilibrium was determined to be 9.00.
$$\text{N}_2 + \text{O}_2 \rightleftharpoons 2\text{NO}$$
What is the value of $K_c$ for
$$\text{NO} \rightleftharpoons \frac{1}{2} \text{N}_2 + \frac{1}{2} \text{O}_2$$
at the same temperature?
(a) 3.00  (b) 9.00  (c) 4.50  (d) 0.11  (e) 0.33
7&8. Consider the following rate law expression for the reaction: \[ 2A + B \rightarrow 2C \]

\[ \text{Rate} = k[A][B]^2 \]

The reaction is

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

9&10. The units of the specific rate constant for a reaction that is first order overall is __________.

(a) s\(^{-1}\)  
(b) M\(^{-2}\)s\(^{-1}\)  
(c) M\(^{-1}\)s\(^{-1}\)  
(d) M\(^{-3}\)s\(^{-1}\)  
(e) Ms\(^{-1}\)

11&12. Consider the gaseous system: \[ \text{N}_2 + \text{O}_2 \rightleftharpoons \text{2NO} \] with \(\Delta H^\circ = +180.5 \text{ kJ/mol rxn}\)

Which of the following will cause an increase in the equilibrium concentration of O\(_2\)?

(a) Removing N\(_2\) from the system.
(b) Increasing the volume of the system.
(c) Removing NO 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 value of the specific rate constant?

\[ 2\text{NO}(g) + 2\text{H}_2(g) \rightarrow \text{N}_2(g) + 2\text{H}_2\text{O}(g) \]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>[NO] initial</th>
<th>[H_2] initial</th>
<th>Initial Rate of Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.40 M</td>
<td>0.10 M</td>
<td>0.120 M/s</td>
</tr>
<tr>
<td>2</td>
<td>0.20 M</td>
<td>0.10 M</td>
<td>0.030 M/s</td>
</tr>
<tr>
<td>3</td>
<td>0.20 M</td>
<td>0.20 M</td>
<td>0.060 M/s</td>
</tr>
</tbody>
</table>

(a) 3.2 M\(^{-1}\)s\(^{-1}\)  (b) 7.5 M\(^{-2}\)s\(^{-1}\)  (c) 0.80 M\(^{-2}\)s\(^{-1}\)
(d) 30. M\(^{-2}\)s\(^{-1}\)  (e) 0.035 s\(^{-1}\)

15&16. The principal reason for the increase in reaction rate with increasing temperature is:

(a) molecules increase in size at high temperatures.
(b) the pressure exerted by reactant molecules increases with increasing temperature.
(c) the fraction of high energy molecules increases with increasing temperature.
(d) the activation energy increases with increasing temperature.
(e) the activation energy decreases with increasing temperature.
Consider the following equilibrium in which the $K_c = 36$: \[2 \text{HBr}(g) \rightleftharpoons \text{H}_2(g) + \text{Br}_2(g)\]
Initially in the container there is 0.20 M of HBr. At equilibrium, what is the concentration of H$_2$?

(a) 0.051 M  (b) 0.092 M  (c) 0.11 M  (d) 0.18 M  (e) 0.25 M

Calculate $\Delta G^\circ$ for the reaction at 46°C if the value of the thermodynamic equilibrium constant, $K_{\text{thermo}}$ is 0.67.

\[\text{N}_2\text{O}_4(g) \rightleftharpoons 2 \text{NO}_2(g)\]

$R = 8.314 \text{ J/mol} \cdot \text{K}$

(a) +1.06 kJ/mol rxn  (b) −1.06 kJ/mol rxn  (c) +158 kJ/mol rxn
(d) −158 kJ/mol rxn  (e) +10.5 kJ/mol rxn
21&22. What is the half-life of the following reaction if after 5.00 days only 1.50 g of a 60.0 g sample of CS₂ remains at a certain temperature? The decomposition reaction is first order.

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

(a) 0.528 d  (b) 0.844 d  (c) 1.06 d  (d) 0.939 d  (e) 1.24 d

23&24. Consider the gas phase equilibrium system: \( \text{A} + 2\text{B} \rightleftharpoons \text{C} \). Initially in the 10.00 L container we have 2.00 moles of A, B and C. When the system is at equilibrium, there are 4.00 moles of B in the container. Calculate \( K_c \).

(a) 11.30  (b) 0.48  (c) 2.08  (d) 1.60  (e) 0.80
25. I want my OWL to count _____% of an exam grade (Choose any number between 20% and 100%).

(1 pt) (extra credit)

26. Consider the following 2 step mechanism for a gas phase reaction. In the first step, a molecule of A collides with a molecule of B to form a molecule of X. In the second step, a molecule of X collides with a molecule of B to form a molecule of A and a molecule of Y.

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

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

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

(4 pts) (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.)
27. (a) Consider the reaction: \( X \rightarrow Y \). What is the activation energy for the forward reaction (in kJ) when the rate constant at 50°C is 0.00611 s\(^{-1}\) and the rate constant at 100°C is 0.483 s\(^{-1}\)?

\[
\log\left(\frac{k_2}{k_1}\right) = \frac{E_a}{2.303R} \left( \frac{T_2 - T_1}{T_1T_2} \right) \quad \text{or} \quad \ln\left(\frac{k_2}{k_1}\right) = \frac{E_a}{R} \left( \frac{T_2 - T_1}{T_1T_2} \right)
\]

\( R = 8.314 \text{ J/mol} \cdot \text{K} \)

(b) The \( \Delta H \) (\( = \Delta E \)) for this reaction is +30.0 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 200.0 kJ. Label the axes correctly.

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

28. Consider the following one-step reaction: \( \text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 \), in which NO and O\(_2\) are linear and O\(_3\) and NO\(_2\) (N is the central atom) are bent. What is necessary to have an effective collision? Illustrate your answer with a drawing.
29. (a) Consider this system at equilibrium: $X(g) \rightleftharpoons 3Y(g)$. Write the $K_c$ expression.

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

(c) Sketch a picture of the final equilibrium mixture when $K_c \ll 1$ when $X$ is represented by ◯ and $Y$ is represented by ●.

30. Consider the gas phase equilibrium system: $C \rightleftharpoons 2D$ in a 1.00 L container at 350°C. The equilibrium concentrations were determined to be:

$[C]_{eq} = 2.00 \text{ M}$  \quad $[D]_{eq} = 0.10 \text{ M}$

(a) Calculate $K_c$ for the equilibrium.

(b) How many moles of $C$ must be added to increase the concentration of $D$ to 0.30 M?