1. (5 pts) Which of the following energy diagrams best represents a reaction which will be the fastest and most spontaneous. Circle your choice and include your reasoning below (brief statement).

![Energy Diagrams]

d) is a spontaneous reaction (downhill from reactants to products) and has the smallest activation energy.

2. (5 pts) Consider the energy diagram to the right:
Circle the following diagram below that best represents the effect of adding a catalyst to the reaction. Include your reasoning below (brief statement).

![Energy Diagrams]

c) has the same reactant/product energies ($\Delta G$), while all the others have changed. $\Delta G$ is a thermodynamic parameter and catalysts never change the thermodynamics of a reaction. They just lower the activation energy for that reaction.

3. (5 pts) Consider the following reaction that is quite important for the manufacturing of many chemicals:

\[
\text{cyclohexane} \quad \rightarrow \quad \text{benzene} + 3\text{H}_2
\]

\[
\Delta G = +200 \text{ kJ/mol} \quad \text{Activation Energy} = +400 \text{ kJ/mol}
\]

Circle the energy curve shown below (R = reactants, P = products) that best represents the reaction described above? Include your reasoning below (brief statement).

![Energy Diagrams]

d) is the correct answer because it is non-spontaneous (product energy higher than reactant) and the $E_a$ is about twice as big as $\Delta G$. 
4. (5 pts) Consider the following reaction and kinetic data. Circle the correct kinetic rate expression for this reaction. Clearly show and briefly discuss your reasoning.

\[ A + B \rightarrow C \]

<table>
<thead>
<tr>
<th>Exp #</th>
<th>[A]</th>
<th>[B]</th>
<th>Initial Rate (Msec(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5 M</td>
<td>1.5 M</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>1.5 M</td>
<td>3.0 M</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>3.0 M</td>
<td>3.0 M</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>6.0 M</td>
<td>3.0 M</td>
<td>0.8</td>
</tr>
</tbody>
</table>

In Exp # 1 & 2 we double the concentration of B (while holding A at the same concentration), which increases the rate by a factor of 4. Thus we have square power relationship: rate \( \propto [B]^2 \).

In Exp 2 & 3 (or 3 & 4), doubling the concentration of A has NO EFFECT on the rate. Therefore, A is NOT part of the kinetic rate expression (it has a order of zero!).

a) rate = \( k[A][B] \)  

b) rate = \( k[A] \)  

c) rate = \( k[B] \)  

d) rate = \( k[B]^2 \)  

e) not enough data

5. (4 pts) Consider the following reaction and kinetic data. What is the rate constant for the reaction? Clearly show all your work and reasoning.

First you have to determine the rate law from the exp data!!

\[ \text{H}_2\text{NCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2 + 2\text{HCl} \rightarrow \text{[H}_3\text{NCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_3]^{2+} (\text{Cl}^-)_2 \]

Order on \([\text{(N)}_2]x\) is determined from experiments 2 & 1:

\[(0.2/0.1)^x = (0.4/0.2)\]

\[(2)^x = 2\quad x = 1\]

Order on \([\text{HCl}]y\) is determined from experiments 4 & 1:

\[(0.2/0.1)^y = (0.8/0.2)\]

\[(2)^y = 4\quad y = 2\]

Rate Law: \( \text{rate} = k([\text{(N)}_2][\text{HCl}]^2 \)

To calculate the rate constant, plug in one of the experimental sets of data (#1, for example) and solve for \( k \):

\( k = \text{rate} / ([\text{(N)}_2][\text{HCl}]^2 = 0.2 \text{ Msec}^{-1} / (0.1 \text{ M})(0.1 \text{ M})^2 \)

\( k = 0.2 \text{ M sec}^{-1} / (0.001 \text{ M}^3) = k = 200 \text{ M}^{-2}\text{sec}^{-1} \)

6. (6 pts) The reaction in question 3 is non-spontaneous at room temperature.

\[ \text{cyclohexane} + 3\text{H}_2 \rightarrow \text{benzene} \]

\( \Delta G = +200 \text{ kJ/mol} \)  

Activation Energy = +400 kJ/mol

Discuss the one thing that you can do that will increase the rate of reaction **and** make the reaction more spontaneous. Clearly discuss how this change will influence the rate of reaction and why it will affect the thermodynamics (spontaneity) of the reaction.

**Increase the temperature!** Raising the temperature increases the rate of all chemical reactions – this is a classic kinetic effect. It will also make this particular reaction more spontaneous, that is, make \( \Delta G \) less positive by magnifying the effect of the entropy term in the \( \Delta G = \Delta H - T\Delta S \) formula. At room temperature, this reaction has a positive \( \Delta G \), making it non-spontaneous. But the generation of 4 particles from one will definitely increase the entropy of the reaction, giving us a fairly large positive \( \Delta S \) entropy term. \( \Delta S_{\text{prod}} \) is multiplied by the temperature magnifying its effect as the temperature is increased. So eventually, as we raise the temperature the entropy term will dominate making \( \Delta G \) go negative, thus giving us a spontaneous reaction.