

# 7.014 Quiz I Handout

## Quiz I announcements:

**\*\*This will be a closed book exam\*\***

- Below is last year's Quiz I (solutions at the end). It should give you an idea of the format and types of questions we tend to ask on the exams. There is some difference in covered material and emphasis on various parts of the material between last year's and this year's versions of the course. We do not guarantee that this year's quiz will cover the exact same subtopics.

## Question 1 (26 points)

The protein complex, LETMEGOTHRUIN (LMGT for short), acts as a channel or pore through which charged proteins and ions can cross the phospholipid bilayer of the membrane. LMGT is composed of four polypeptides as shown in Figure A. Figure B shows a cross section of two of the polypeptides.

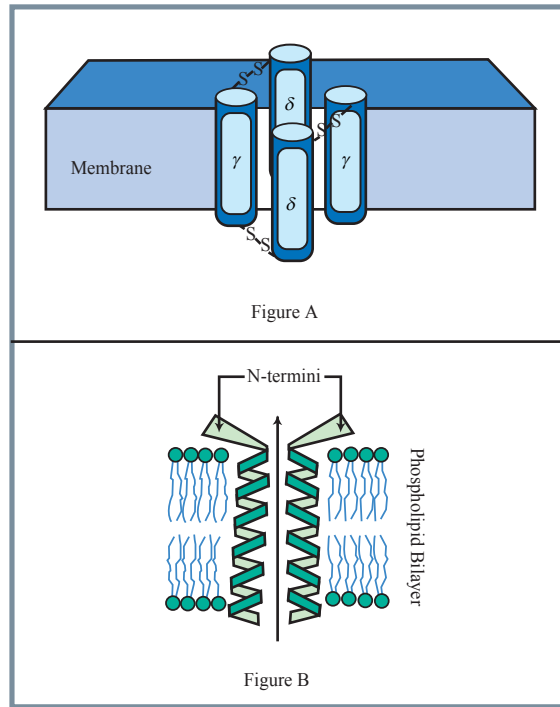


Figure by MIT OCW.

- What are the characteristics of phospholipids that are crucial to their ability to form lipid bilayers?
- In Figure B, the amino termini (N-termini) are closely associated with the phosphate groups at the surface of the phospholipid bilayer. Name three amino acids that would likely be found at the N-termini of these polypeptides.
- LMGT is composed of four polypeptides (two  $\gamma$  polypeptides and two  $\delta$  polypeptides).
  - How many unique primary protein structures compose the LMGT protein complex?
  - What protein secondary structure is part of the LMGT protein complex?
  - What is the strongest type of bond that maintains the quaternary structure of LMGT?

## Question 1, continued

d) Describe how the polypeptides of the LMGT protein can be surrounded by non-polar hydrocarbons but allow charged proteins and ions to transit the membrane.

e) One of the small molecules permitted to pass through the LMGT channel is PUNY, a tripeptide. PUNY is composed of asparagine-proline-alanine with asparagine at the amino terminus.

- Draw the chemical structure of PUNY.
- Circle the peptide bonds.

## Question 2 (30 points)

MIT has produced a time machine that can send a team of undergraduates back in time. The mission commander is expecting you to provide insight into the biology occurring at various time points visited.

a) Your first stop is 4 billion years ago where you collect the “primordial soup” containing the precursors of life. You observe a polymer in this “soup” that can copy itself. The mission commander wants to know...

- i) What is this molecule?
- ii) She asks you to sketch a single building block of this molecule below.

b) Your next stop is 3 billion years ago where you find organisms similar to cyanobacteria that produce glucose from  $\text{CO}_2$  using “photosynthesis release 1” (cyclic photophosphorylation). An eager colleague runs through the airlock to collect samples of this organism, but quickly turns blue and dies.

i) Your commander does not understand why this man suffocated when photosynthetic organisms are present. Explain why photosynthesis is occurring but no  $\text{O}_2$  is being produced.

ii) Cyclic photophosphorylation converts  $\text{CO}_2$  into glucose. Briefly describe how these organisms use ATP synthase to generate the ATP needed for this conversion.

iii) Once the glucose is made, these anaerobic organisms break it down to obtain energy.

- What process do these organisms use to obtain energy from glucose?
- What products are generated in this process?
- What does the organism do with these products?

## Question 2, continued

c) Your next stop is 1 billion years ago where you find organisms similar to today's plants that produce glucose from  $\text{CO}_2$  and release  $\text{O}_2$ . These organisms also obtain energy from the glucose they synthesize.

i) When glucose is used to produce energy, what is conserved in the process these aerobic organisms use as compared to that used by the organisms from part (b)

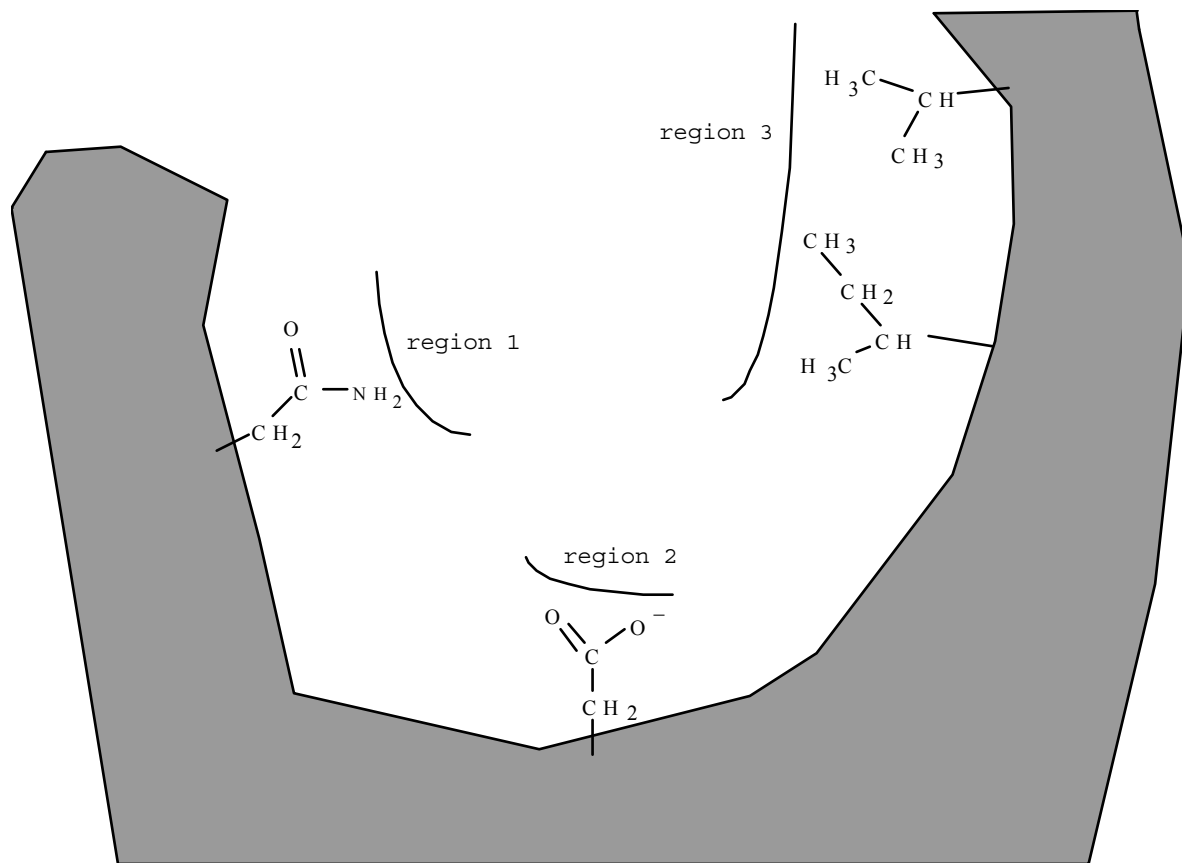
ii) These aerobic organisms generate 18 times more energy from glucose as compared to the organisms from part (b). Briefly describe how this additional energy is generated.

Confine your answer to the above white space.



### Question 3 (25 points)

A drug company has isolated the protein shown in schematic below.



a) What amino acid is present in region 2?

b) The substrate for this protein has not been identified. Given the diagram above...

i) What is the strongest interaction possible between the amino acid in region 1 and the substrate?

ii) What is the strongest interaction possible between the amino acid in region 2 and the substrate?

iii) What is the strongest interaction possible between the amino acids in region 3 and the substrate?

### Question 3, continued

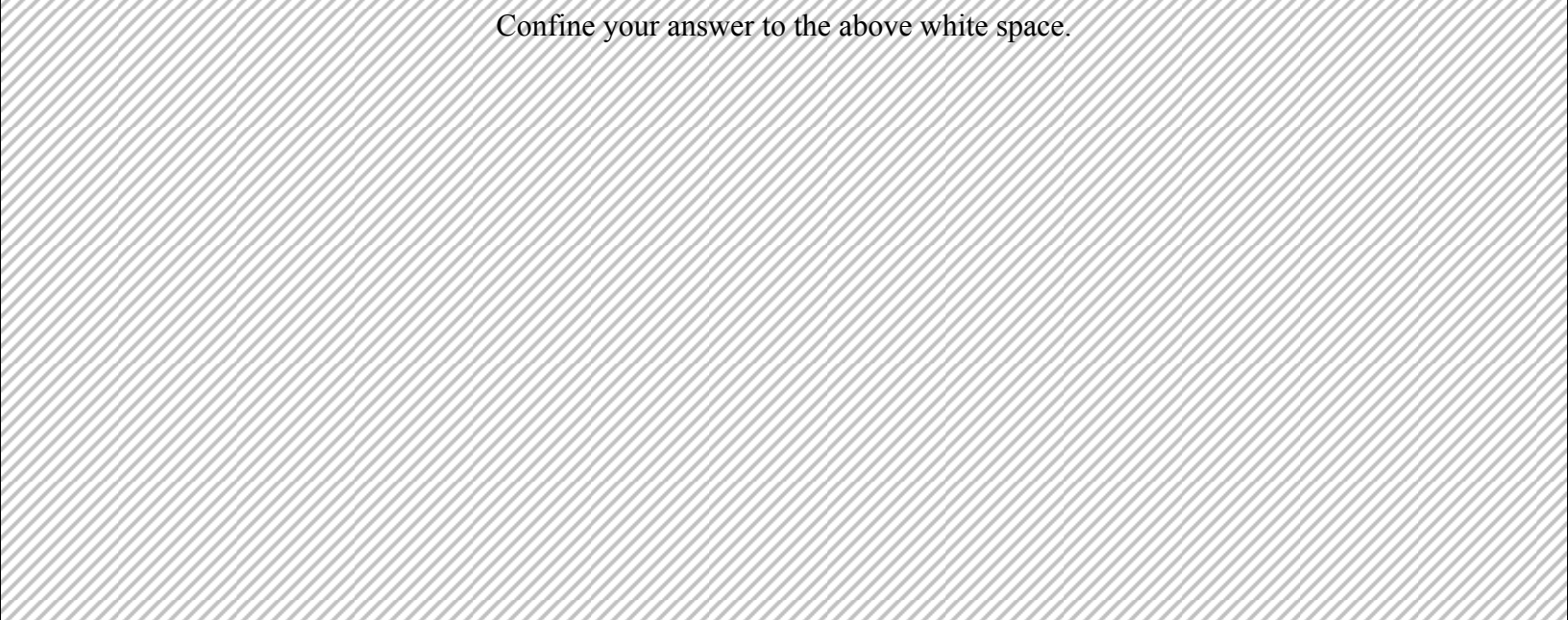
c) The drug company has asked you to design a protein that binds tightly in this pocket.

i) Would Alanine or Serine interact more strongly with region 1? Why?

ii) Would Lysine or Glutamic Acid interact more strongly with region 2? Why?

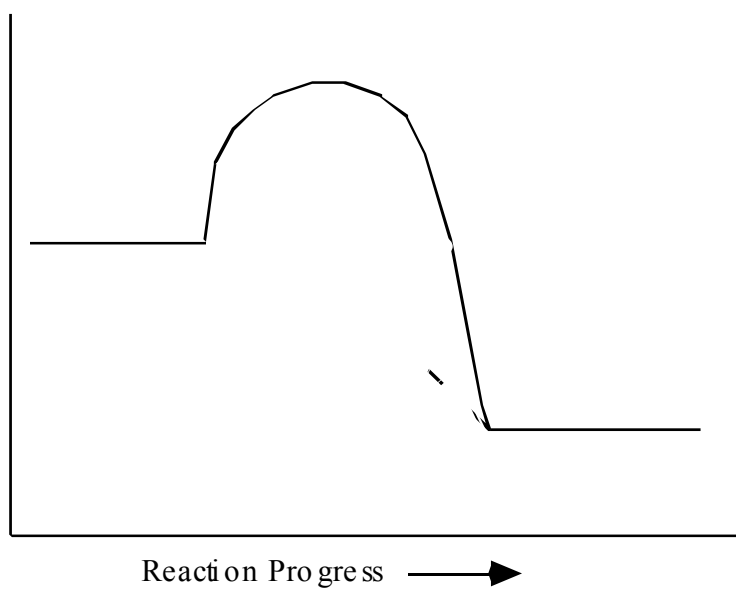
d) You design many proteins that bind tightly in this pocket. One of them has isoleucine associated with region 3. You substitute phenylalanine for isoleucine and find this prevents binding of this protein. Phenylalanine and isoleucine form the same kinds of interactions with the binding pocket, so why can't the phenylalanine version of the protein bind?

Confine your answer to the above white space.



#### Question 4 (19 points)

Under standard conditions, the reaction  $A + B \rightarrow C + D$  has a positive  $\Delta G_o$ .  
The reaction  $C + D \rightarrow A + B$  has a negative  $\Delta G_o$ .



a) On the energy diagram above, label the following:

- activation energy
- $\Delta G_o$
- C + D
- A + B

c) Modify the above diagram to show how it would change if an enzyme that catalyzed the reaction is added.

d) What effect, if any, would this have on the reaction?



# SOLUTIONS

## Question 1 (26 points)

The protein complex, LETMEGOTHRUIN (LMGT for short), acts as a channel or pore through which charged proteins and ions can cross the phospholipid bilayer of the membrane. LMGT is composed of four polypeptides as shown in Figure A. Figure B shows a cross section of two of the polypeptides.

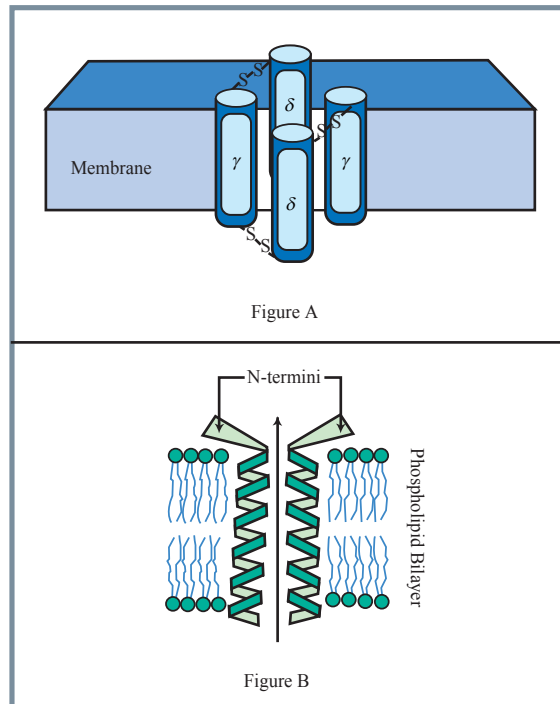


Figure by MIT OCW.

a) What are the characteristics of phospholipids that are crucial to their ability to form lipid bilayers?

*Phospholipids are amphipathic, the hydrocarbon tails are hydrophobic and cluster together to exclude water. The phosphate heads are hydrophilic and associate with the aqueous environment.*

b) In Figure B, the amino termini (N-termini) are closely associated with the phosphate groups at the surface of the phospholipid bilayer. Name three amino acids that would likely be found at the N-termini of these polypeptides.

*The positively charged amino acids: Arginine, Histidine, and Lysine*

c) LMGT is composed of four polypeptides (two  $\gamma$  polypeptides and two  $\delta$  polypeptides).

i) How many unique primary protein structures compose the LMGT protein complex?

*Two*

ii) What protein secondary structure is part of the LMGT protein complex?

*$\alpha$ -helix*

iii) What is the strongest type of bond that maintains the quaternary structure of LMGT?

*Covalent, disulfide bond*

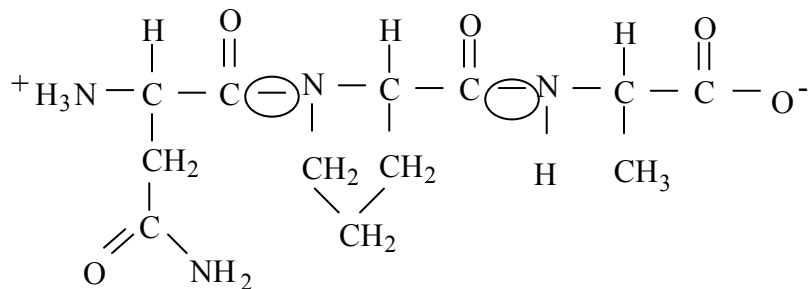
## Question 1, continued

d) Describe how the polypeptides of the LMGT protein can be surrounded by non-polar hydrocarbons but allow charged proteins and ions to transit the membrane.

*The LMGT protein must have non-polar amino acids on the surfaces associated with the lipid part of the membrane and charged or polar amino acids lining the pore of the channel.*

e) One of the small molecules permitted to pass through the LMGT channel is PUNY, a tripeptide. PUNY is composed of asparagine-proline-alanine with asparagine at the amino terminus.

- Draw the chemical structure of PUNY.
- Circle the peptide bonds.

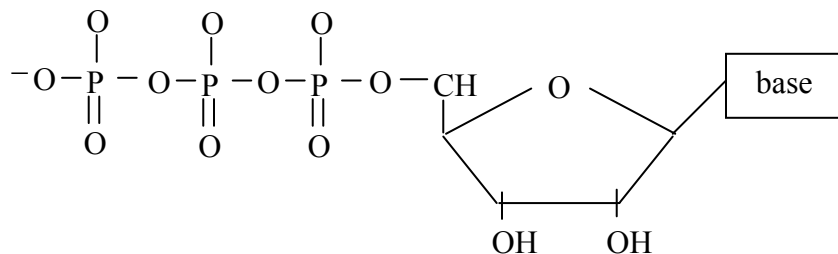


## Question 2 (30 points)

MIT has produced a time machine that can send a team of undergraduates back in time. The mission commander is expecting you to provide insight into the biology occurring at various time points visited.

a) Your first stop is 4 billion years ago where you collect the “primordial soup” containing the precursors of life. You observe a polymer in this “soup” that can copy itself. The mission commander wants to know...

- What is this molecule? *RNA*
- She asks you to sketch a single building block of this molecule below.



b) Your next stop is 3 billion years ago where you find organisms similar to cyanobacteria that produce glucose from CO<sub>2</sub> using “photosynthesis release 1” (cyclic photophosphorylation). An eager colleague runs through the airlock to collect samples of this organism, but quickly turns blue and dies.

i) Your commander does not understand why this man suffocated when photosynthetic organisms are present. Explain why photosynthesis is occurring but no O<sub>2</sub> is being produced.

*Cyclic photophosphorylation produces glucose from CO<sub>2</sub> but uses the redox reaction  $H_2S \rightarrow S$  as a source of electrons for the production of NADPH, Thus O<sub>2</sub> is not released as a waste product.*

ii) Cyclic photophosphorylation converts CO<sub>2</sub> into glucose. Briefly describe how these organisms use ATP synthase to generate the ATP needed for this conversion.

*Light energy excites electrons in chlorophyll. These electrons are donated to a series of membrane proteins, each more electronegative than the last. As the electrons are passed from protein to protein, H<sup>+</sup> ions are pumped across the membrane to create an H<sup>+</sup> gradient. H<sup>+</sup> ions move through the ATP synthase protein, down the charge and concentration gradient this movement is coupled to the synthesis of ATP from ADP.*

iii) Once the glucose is made, these anaerobic organisms break it down to obtain energy.

- What process do these organisms use to obtain energy from glucose? *Glycolysis*
- What products are generated in this process? *ATP, NADH and pyruvate*
- What does the organism do with these products?

*ATP is used as energy to drive cellular processes, Pyruvate accepts electrons from NADH to form lactic acid (or ethanol and CO<sub>2</sub>) thereby regenerating the NAD<sup>+</sup> required for glycolysis to continue.*

c) Your next stop is 1 billion years ago where you find organisms similar to today's plants that produce glucose from CO<sub>2</sub> and release O<sub>2</sub>. These organisms also obtain energy from the glucose they synthesize.

i) When glucose is used to produce energy, what is conserved in the process these aerobic organisms use as compared to that used by the organisms from part (b)

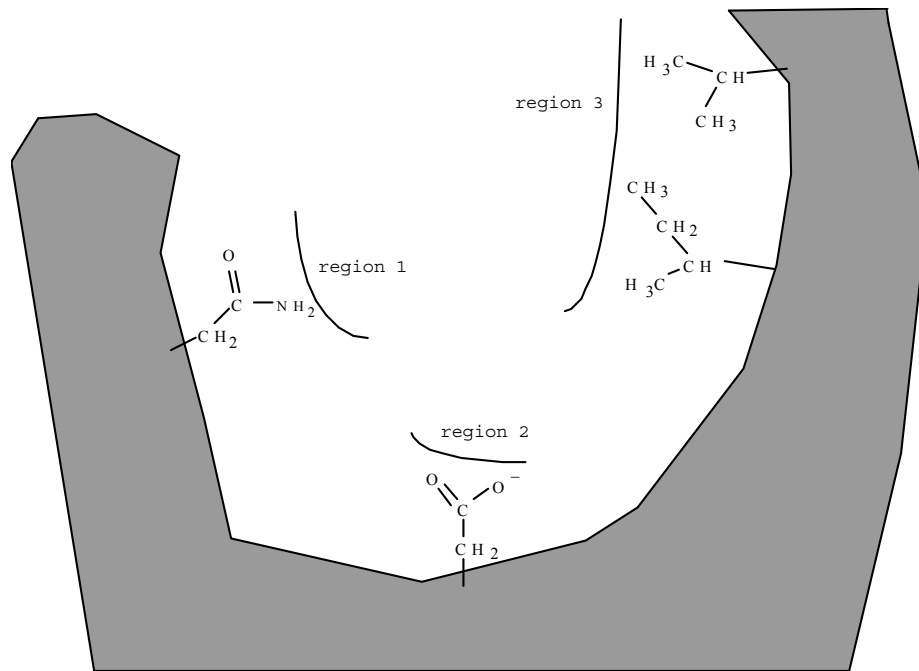
*All the steps of glycolysis*

ii) These aerobic organisms generate 18 times more energy from glucose as compared to the organisms from part (b). Briefly describe how this additional energy is generated.

*Some of this additional energy comes directly from further oxidation of pyruvate into CO<sub>2</sub>. The electrons from NADH are used to generate further energy. These electrons are donated to a series of membrane proteins, each more electronegative than the last. As the electrons are passed from protein to protein, H<sup>+</sup> ions are pumped across the membrane to create an H<sup>+</sup> gradient. H<sup>+</sup> ions move through the ATP synthase protein, down the charge and concentration gradient and drive the synthesis of ATP from ADP.*

### Question 3 (25 points)

A drug company has isolated the protein shown in schematic below.



a) What amino acid is present in region 2? *Aspartic acid*

b) The substrate for this protein has not been identified. Given the diagram above...

i) What is the strongest interaction possible between the amino acid in region 1 and the substrate?

*Hydrogen bonds.*

ii) What is the strongest interaction possible between the amino acid in region 2 and the substrate?

*Ionic bonds*

iii) What is the strongest interaction possible between the amino acids in region 3 and the substrate?

*van der Waals forces*

c) The drug company has asked you to design a protein that binds tightly in this pocket.

i) Would Alanine or Serine interact more strongly with region 1? Why?

*Serine, it is polar and can form hydrogen bonds with region 1. Alanine would only interact with van der Waals forces*

ii) Would Lysine or Glutamic Acid interact more strongly with region 2? Why?

Lysine, it is (+) charged and can form ionic bonds with region 2. Glutamic acid is also (-) charged and would repel.

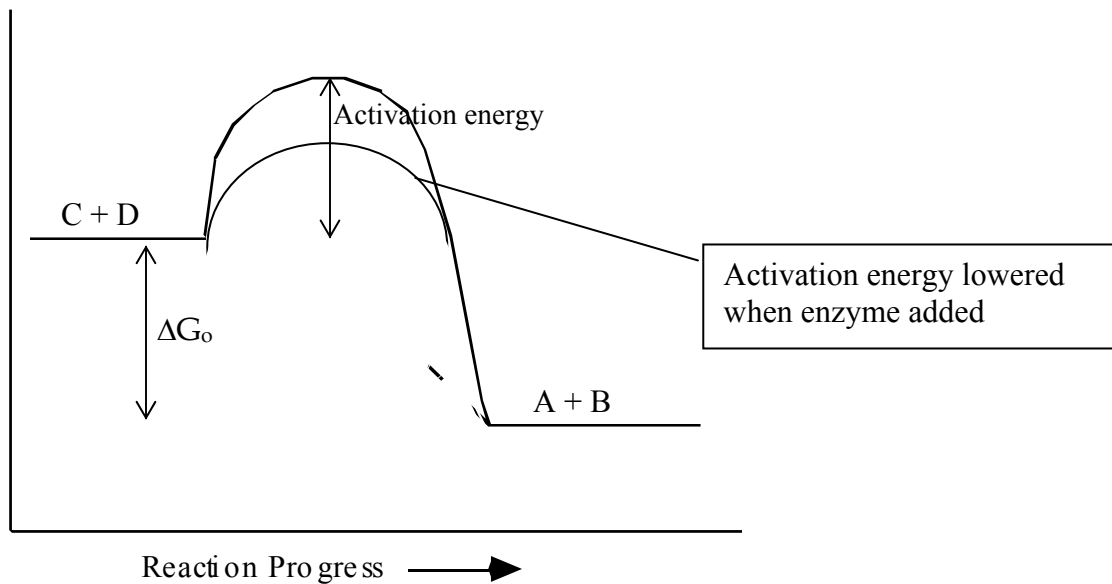
d) You design many proteins that bind tightly in this pocket. One of them has isoleucine associated with region 3. You substitute phenylalanine for isoleucine and find this prevents binding of this protein. Phenylalanine and isoleucine form the same kinds of interactions with the binding pocket, so why can't the phenylalanine version of the protein bind?

*Phenylalanine has a large side chain that prevents the substrate from fitting into the pocket. Steric hinderence.*

#### Question 4 (19 points)

Under standard conditions, the reaction  $A + B \rightarrow C + D$  has a positive  $\Delta G_o$ .

The reaction  $C + D \rightarrow A + B$  has a negative  $\Delta G_o$ .



a) On the above energy diagram above, label the following:

- activation energy
- $\Delta G_o$
- C + D
- A + B

c) Modify the above diagram to show how it would change if an enzyme that catalyzed the reaction is added.

d) What effect, if any, would this have on the reaction?

*An enzyme does not change the  $\Delta G_o$  of the reaction, but by lowering the activation energy, it speeds up the reaction  $C + D \rightarrow A + B$ .*