

## Solution Key- 7.013 EXAM 1 (2 / 25 / 13)

### Question 1 (25 points)

a) There are four major classes of biological macromolecules: carbohydrates, proteins, lipids and nucleic acids (deoxyribonucleic acid or DNA and ribonucleic acid or RNA).

i. Monomers for which class(s) of macromolecules **always** have phosphorous? Circle **all** that apply.

Carbohydrates

Proteins

Lipids

**DNA**

**RNA**

ii. Which class(s) of macromolecules may serve as **biological catalysts**? Circle **all** that apply.

Carbohydrates

**Proteins**

Lipids

DNA

**RNA**

b) The following is the sequence of two DNA helices. Which DNA helix (*helix 1 or helix 2*) needs a higher temperature to denature? **Explain** why you selected this option.

**Helix 1:**

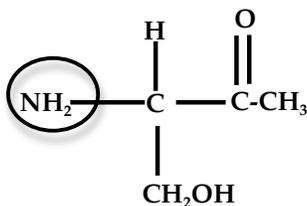
5' ATGCGGGAGA3'  
3' TACGCCCTCT5'

**Helix 2:**

5' ATGTTTTTAGA3'  
3' TACAAAATCT5'

*Helix 1 needs a higher temperature to denature. It has a higher % of GC base pair and hence more number of hydrogen bonds which need a higher temperature to disrupt allowing the DNA helix to unwind or denature.*

c) The following is a schematic of a non-essential amino acid.

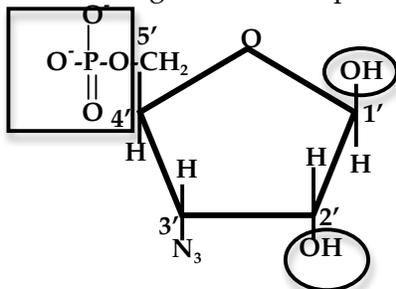


i. **Circle** the group that participates in forming a peptide bond if this amino acid was **added to a growing peptide chain**.

ii. If this is the **terminal amino acid of a growing peptide chain**, will it form a peptide bond with an incoming amino acid (Yes/ No)? Briefly **explain** your choice.

*No, since it lacks the  $\alpha$ -COOH group that gives the -OH, which becomes a part of the water molecule that is released as a byproduct during the formation of a peptide bond by condensation/ dehydration reaction.*

d) The following schematic represents ribose phosphate, a pentose sugar molecule.



i. On the schematic **circle** a group that would participate in a condensation reaction that joins two such molecules.

ii. This molecule forms a covalent bond with a base via condensation reaction. **List** the carbon atom of this molecule (1'C/ 2'C/ 3'C/ 4'C/ 5'C), which bonds with the base. 1'C

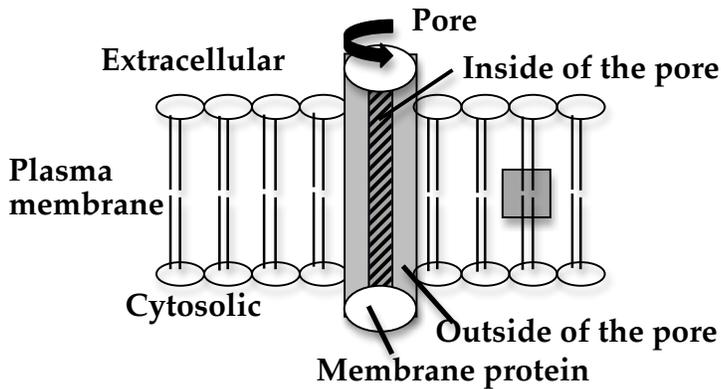
iii. On the schematic, **box** the group of atoms that participates in forming a phosphodiester bond if this molecule was **added to** a growing RNA polymer.

iv. If this molecule is a part of the terminal nucleotide of a growing RNA polymer could it form a phosphodiester bond with an **incoming nucleotide** (Yes/No)? **Explain** why you selected this option.

*No, since this molecule lacks the hydroxyl group (-OH group) at its 3'C position that participates in forming the phosphodiester bond with the incoming base.*

**Question 1 continued**

e) The following schematic represents a plasma membrane protein that creates a pore in the membrane and co-transporters **glucose** and **sodium ions (Na<sup>+</sup>)** across the membrane.

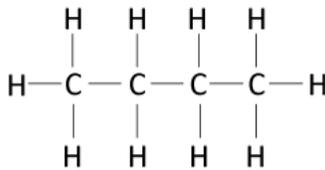


i. Circle ALL that apply. Most amino acids lining the inside of the pore will have side-chains that are ...

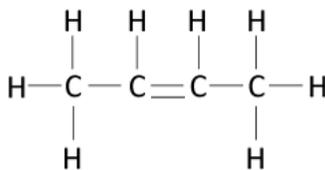
- |                    |             |                  |
|--------------------|-------------|------------------|
| <u>Hydrophilic</u> | Hydrophobic | <u>Polar</u>     |
| <u>Charged</u>     | Nonpolar    | <u>Uncharged</u> |

ii. List the elements (choose from C, H, N, O, S and P) that are predominant in the boxed region of the plasma membrane. Describe the most important property associated with this region. C and H are predominant. This region shows the hydrophobic tails of the phospholipids molecules that make the lipid bilayer. Hence this region is hydrophobic in nature.

iii. Plasma membranes having a higher concentration of unsaturated fats show higher fluidity compared to those with a higher concentration of saturated fats. Explain why is this so.



Saturated Fats



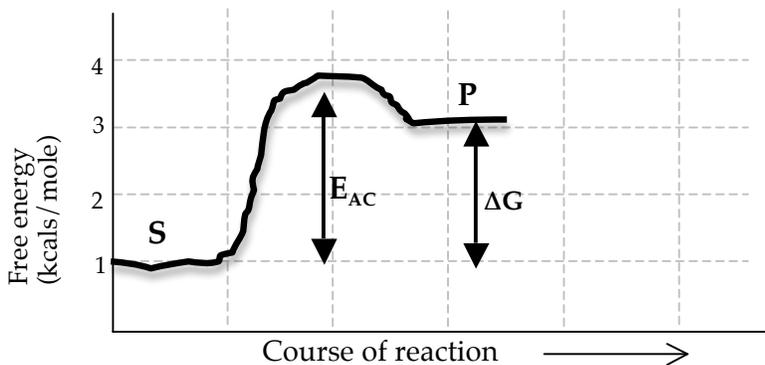
Unsaturated Fats

The double bonds between the carbon atoms in the unsaturated fats result in their loose packing. This results in the increased membrane fluidity.

**Question 2 (16 points)**

a) The following is a biological reaction catalyzed by enzyme E1.

i. On the axes below, draw and label the products and reactants, free energy change ( $\Delta G$ ), and energy of activation ( $E_{AC}$ ) for this reaction.



ii. Does E1 catalyze a reaction that requires or releases energy? Explain why you selected this option. This reaction requires energy since  $\Delta G > 0$ .

## Question 2 continued

b) The functional E1 is comprised of **two identical** polypeptide chains.

- i. What is the highest (most complex) level of protein structure (*choose from primary, secondary, tertiary or quaternary*) for...

Individual polypeptide chains of E1? *tertiary*

Functional E1? *Quaternary*

- ii. Would the functional E1 be encoded by only one gene (*Yes/ No*)? **Explain** why you selected this option.

*Yes, since it is comprised of TWO IDENTICAL polypeptide chains, which are encoded by the same gene but are then joining together to form a functional enzyme.*

c) Full activity of E1 is observed at **37°C and a pH of 7.4**. You isolate the **active form of E1**, subject it to a **pH of 2.0** and show that it cannot bind to the substrate. You revert to pH 7.4 and see that the enzyme does not resume its function. **Explain** why is this so.

*Altering the pH from 7.4 to 2.0 disrupts the active 3D- conformation of the enzyme by disrupting the higher orders of the enzyme structure without disrupting its primary structure. When the pH is reverted to 7.4 the primary structure tries to fold on itself to acquire the active 3D-conformation but fails to do so. Hence the enzyme cannot renature and thus remains inactive.*

d) You isolate a mutant version of **E1**, which has some function, but shows a **reduced catalytic activity compared to the original E1**. You perform the reaction using either the original E1 (reaction 1) or the mutant version of E1 (reaction 2) and measure the following reaction parameters for each reaction. **Circle** the reaction parameter(s) that would differ between the two reactions. **Explain** why you selected this option(s).

$E_{AC}$

$\Delta G$

Reaction rate

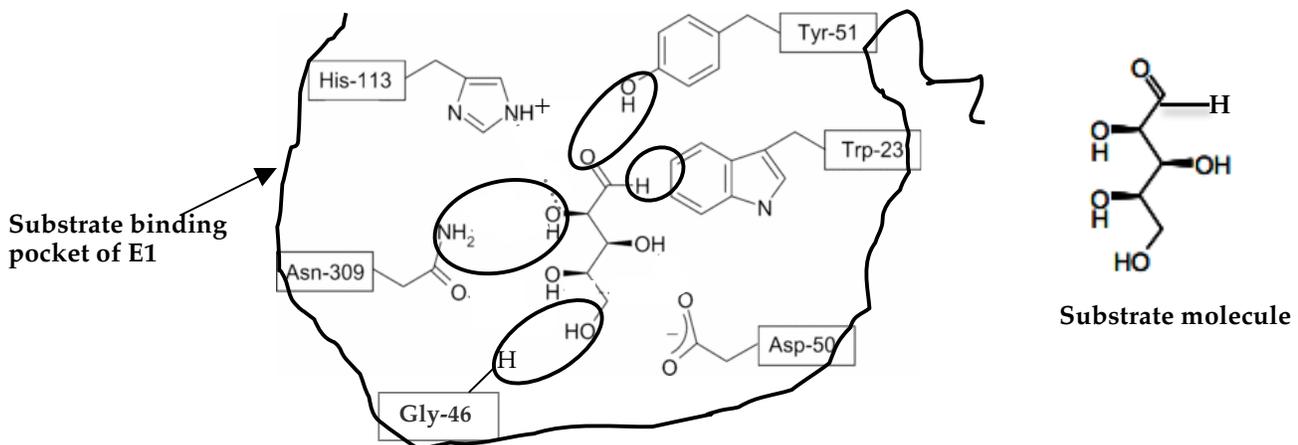
Reaction equilibrium

*Since the mutant version of E1 has a reduced catalytic activity compared to the wild type version, it will not be able to reduce the activation energy barrier as significantly as the original enzyme. Hence it will have a higher  $E_{AC}$  and a reduced reaction rate.*

## Question 3 (16 points)

The following schematic represents a substrate molecule bound to the substrate-binding site of E1.

**Note:** For simplicity, only the interacting groups in the amino acids side-chains and the groups in the substrate are shown. Each circled interaction is critical for the binding of substrate to E1.



### Question 3 continued

a) In the table below, use 'X' to indicate the **strongest interaction** that exists between the substrate and the side-chain of the following amino acids located in the substrate-binding pocket of E1.

Amino acid	Hydrogen	Ionic	Covalent	Hydrophobic / van der Waals forces
Tyr- 51	X			
Trp-23				X
Gly-46				X
Asn-309	X			

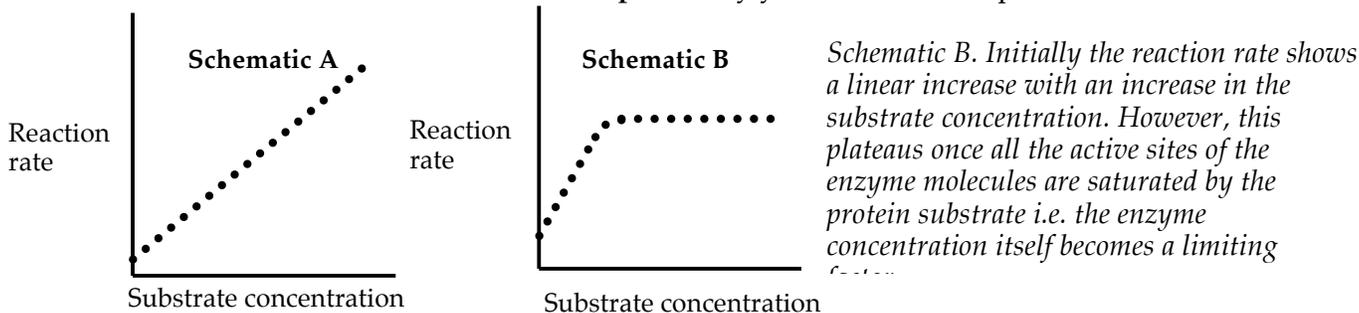
b) You create two new mutant versions (mutant 1 and mutant 2) of E1 each of which has only one amino acid substitution at its substrate- binding site.

- Mutant 1 has **Leu-46 (side-chain:  $-\text{CH}-\text{CH}_2-(\text{CH}_3)_2$ )** instead of **Gly-46 (side-chain:  $-\text{H}$ )**.
- Mutant 2 has **Val-309 (side-chain:  $-\text{CH}(\text{CH}_3)_2$ )** instead of **Asn-309 (side-chain:  $-\text{CH}_2-\text{CONH}_2$ )**.

Explain **in terms of the characteristics of the amino acid** why each of these mutant versions **cannot bind** to the substrate.

- **Mutant 1:** *Although both Leu and Gly are hydrophobic, nonpolar amino acids, the side-chain of leu is much bigger than that of Gly. Hence it might prevent the formation of the substrate binding site of E1 thus preventing its binding to the substrate.*
- **Mutant 2:** *Val has a hydrophobic side-chain compared to Asn. Thus it will not be able to Hydrogen bond with the substrate molecule.*

c) You perform the E1 catalyzed reaction in a test tube at 37°C and a pH of 7.4. You gradually increase the substrate concentration without changing the other reaction parameters and measure the rate of reaction. **Circle** the schematic from below that represents the most likely effect of the increased substrate concentration on the reaction rate. **Explain** why you selected this option.



d) You identify a **drug that non- covalently binds to the active site of E1** and completely inhibits the reaction. You find that if you double the substrate concentration without altering the E1 and the drug concentration, the reaction is restored. However, if you double the concentration of both substrate and the drug without altering the E1 concentration the reaction is not restored. You therefore conclude that the drug could be a... (Circle **all** that apply). Briefly **explain** why you selected this option(s).

**Competitive inhibitor**

**Non- competitive inhibitor**

**Allosteric inhibitor**

*It is a competitive inhibitor since the inhibitory effect of the drug on E1 can be reversed by the increase in the substrate concentration meaning that they are both competing to bind to the same binding site on the enzyme.*

**Question 4 (29 points)**

You are studying three traits in a fish variety; **body color (A or a), fin length (B or b) and size (D or d)**. Note: Use the uppercase letters for the alleles associated with the dominant phenotypes and the lowercase letters for the alleles associated with the recessive phenotypes. Assume that each of these traits is regulated by one gene.

a) You mate a red fish (P1) with a yellow fish (P2) and obtain 100 fish in F1, of which 50 are red and 50 are yellow. Write two sets of the possible **genotypes** of the parental and the resulting F1 fish by filling in the table below.

Sets	P1 fish	P2 fish	F1 red fish	F1 yellow fish
1	<i>Aa</i>	<i>aa</i>	<i>Aa</i>	<i>aa</i>
2	<i>aa</i>	<i>Aa</i>	<i>aa</i>	<i>Aa</i>

b) You mate a true breeding **big fish** having **long fins (P3)** with a true breeding **small fish** having **short fins (P4)**. All of the resulting F1 fish are **big and have short fins**.

i. Write the **genotype** of the parental fish (P3 and P4) using the outlined nomenclature.

Genotype of P3:

*DDbb*

Genotype of P4:

*ddBB*

ii. You **test cross an F1 fish** and obtain 100 progeny in F2 generation. Assuming that the genes regulating the size and fin length **assort independently**, fill in the table for each class of fish that you would obtain in F2 generation.

Phenotype class	Associated Genotype	Approximate number of F2 fish for each class
<i>Big and Long fins</i>	<i>Dbdb</i>	25
<i>Small and Short fins</i>	<i>dBdb</i>	25
<i>Big and Short fins</i>	<i>DBdb</i>	<u>25</u>
<i>Small and Long fins</i>	<i>dbdb</i>	<u>25</u>

iii. Circle the **recombinant or non-parental** phenotypic and genotypic classes in the table above.

iv. However, after analyzing **ALL** the F2 fish you conclude that the genes regulating size and fin length **are 10cM apart**. Therefore, which column (*choose from the phenotypic classes, associated genotype, approximate number of F2 fish for each class*) would you change in the table above and what would be the change?

*The last column will now change: Big and long fins fish (45): Small and Short fins fish (45), Big and short fins fish (5) and small and long fins fish (5).*

v. Circle the **correct option(s)** from the choices below. The recombinant classes are produced by crossing over that involves...

- Two **sister chromatids** in **Meiosis I**
- Two **sister chromatids** in **Meiosis II**
- Two **parental homologs** in **Meiosis I** \_\_\_\_\_
- Two **parental homologs** in **Meiosis II**

**Question 5 (14 points)**

Sara suffers from Down's syndrome i.e. each cell in her body has three copies of the **chromosome 21** instead of two copies. You want to investigate meiosis and non-disjunction that may have led to the trisomy of chromosome 21. You follow the segregation of two genes; Gene A located on chromosome 21 and Gene D located on X chromosome.

a) Sara's **grandparents** had the following genotypes. What is the genotype of Sara's parents?

**Maternal grandparents:**  $AAX^D X^D \times aaX^d Y$

**Paternal grandparents:**  $AAX^d X^d \times aaX^D Y$

**Genotype of Sara's Mom:**

$AaX^D X^d$

**Genotype of Sara's Dad:**  $AaX^d Y$

b) Assume that a cell from Sara's dad undergoes meiosis without any error. However, a cell from Sara's mom undergoes **non-disjunction** involving the chromosome 21 during **Meiosis I**. **Meiosis II proceeds in this cell without any error**. All other chromosomes separate normally. Depending on the alignment of chromosomes, give **all the possible genotypes of the gametes** produced by Sara's parents.

Gametes produced by Sara's...	Genotype of gametes ...			
	Gamete 1	Gamete 2	Gamete 3	Gamete 4
<b>Dad</b>	$\underline{AX^d}$	$AY$	$\underline{aX^d}$	$aY$
<b>Mom</b>	$\underline{AaX^D}$	$X^d$	$\underline{AaX^d}$	$X^D$

c) In the table, **circle one gamete from dad and one from mom**, which can fuse together to produce Sara.

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7.013 Introductory Biology  
Spring 2013

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