Name: ________________________________

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'          Helix 2:  5'ATGTTTTAGA3'
            3'TACGCCCTCT5'                      3'TACAAAATCT5'

   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.

   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.

   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.
Question 1 continued

e) The following schematic represents a plasma membrane protein that creates a pore in the membrane and co-transport glucose and sodium ions (Na⁺) across the membrane.

- Circle ALL that apply. Most amino acids lining the inside of the pore will have side-chains that are ...
  - Hydrophilic
  - Hydrophobic
  - Polar
  - Charged
  - Nonpolar
  - Uncharged

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.

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 this so.

- Saturated Fats
- Unsaturated Fats

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 (ΔG), and energy of activation (Eₐ) for this reaction.

\[ S \quad \xrightarrow{\text{E1}} \quad P, \text{ where the forward reaction has } \Delta G = +2, \text{ and } E_{ac} = +2.5 \]

ii. Does E1 catalyze a reaction that requires or releases energy? Explain why you selected this option.
Name: ____________________________

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

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.

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).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Reaction rate</th>
<th>Reaction equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>E&lt;sub&gt;AC&lt;/sub&gt;</td>
<td>ΔG</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

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.

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Hydrogen</th>
<th>Ionic</th>
<th>Covalent</th>
<th>Hydrophobic / van der Waals forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tyr-51</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trp-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gly-46</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asn-309</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Name: ________________________________

Question 3 continued
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: \(-\text{CH-CH}_2-(\text{CH}_3)_2\)) instead of **Gly-46** (side-chain: \(-\text{H}\)).
- Mutant 2 has **Val-309** (side-chain: \(-\text{CH(CH}_3)_2\)) 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:
- Mutant 2:

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.

<table>
<thead>
<tr>
<th>Reaction rate</th>
<th>Reaction rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate concentration</td>
<td>Substrate concentration</td>
</tr>
<tr>
<td>Schematic A</td>
<td>Schematic B</td>
</tr>
</tbody>
</table>

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

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.

<table>
<thead>
<tr>
<th>Sets</th>
<th>P1 fish</th>
<th>P2 fish</th>
<th>F1 red fish</th>
<th>F1 yellow fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Question 4 continued
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.

<table>
<thead>
<tr>
<th>Phenotype class</th>
<th>Associated Genotype</th>
<th>Approximate number of F2 fish for each class</th>
</tr>
</thead>
</table>

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.

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?

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 Downs 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^D x aaX^d^Y  
Paternal grandparents: AAX^d^d x aaX^D^Y

Genotype of Sara’s Mom:  
Genotype of Sara’s Dad:  


**Question 5 continued**

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.

<table>
<thead>
<tr>
<th>Gametes produced by Sara's...</th>
<th>Genotype of gametes ...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gamete 1</td>
</tr>
<tr>
<td>Dad</td>
<td></td>
</tr>
<tr>
<td>Mom</td>
<td></td>
</tr>
</tbody>
</table>

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

Name: ________________________