Name (Last, First): ____________________________ ID Number: _______________________

Sample Questions for the Chemistry of Life Topic Test

1. Enzymes play a crucial role in biology by serving as biological catalysts, increasing the rates of biochemical reactions by decreasing their activation energies. A commonly-used model for these enzyme-catalyzed reactions is the Michaelis-Menten model:

$$E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES \xrightarrow{k_2} P$$

Where E is the enzyme, S is the substrate, ES is the enzyme-substrate complex, and P is the product.

a. Write 3 rate equations, one for the formation of ES from E and S, one for the reverse of that reaction, and one for the formation of P from ES, using the 3 different rate constant given above for this reaction model.

b. Using these three rate equations, one can derive the Michaelis-Menten equation describing reaction rate, V as a function of substrate concentration, [S]:

$$V([S]) = \frac{V_{max} * [S]}{K_m + [S]}$$

Where V_{max} and K_m are constants. Draw a graph of V as a function of [S]. As [S] approaches infinity, does the rate also approach infinity? Provide a brief relation in terms of kinetics for this relationship.

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c. An important enzyme-catalyzed reaction is the conversion of glucose into glucose-6-phosphate. Suppose Abhi wants to synthesize glucose-6-phosphate from glucose *in vitro*. However, when he mixes the reagents in a test tube, he notices that no glucose-6-phosphate forms. He decides to add some hexokinase enzyme to speed the reaction up. Supposing that at these conditions, the reaction is endergonic ($\Delta G > 0$), will Abhi's plan work? Briefly explain your answer, and suggest an alternative strategy that involves the enzyme phosphoglucose isomerase, which converts glucose-6-phosphate into fructose-6-phosphate, a different molecule.

d. In living cells, the synthesis of glucose-6-phosphate is just one step in a long pathway of chemical reactions whose end product is adenosine triphosphate (ATP), which is used ubiquitously as a source of energy to fuel the processes of life. As a fuel source, ATP is constantly being consumed. Explain how this allows endergonic reactions like the synthesis of glucose-6-phosphate to occur.

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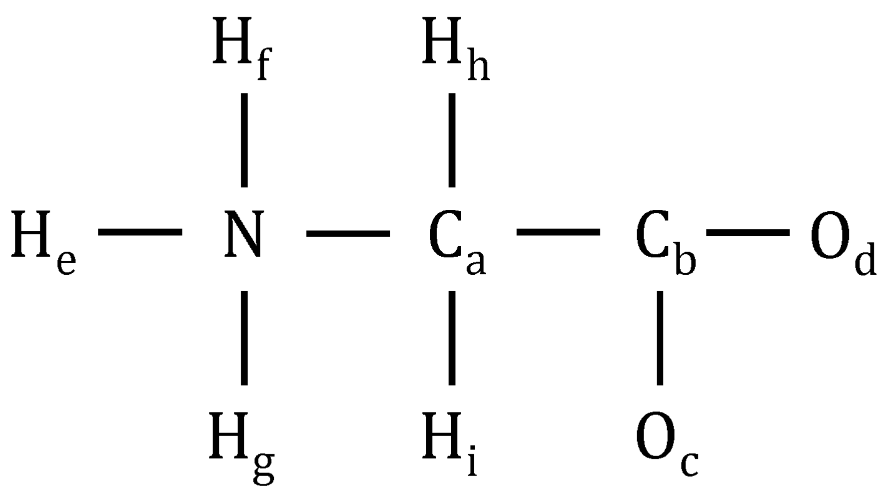
2. In biology there are 4 essential macromolecules that allow for the existence of organisms and each are essential in their own way. One class of these macromolecules is proteins. Proteins are more involved in the human body than many think. They act as enzymes, antibodies, hemoglobin, cell membrane receptors and many more vital structures. These large and complex proteins are composed of many amino acids. Unique combinations of amino acids give proteins unique properties and functions.

a. One specific amino acid is glycine, which is the smallest possible amino acid. Use the subscript letters on atoms help differentiate between identical atoms being questioned.

i. The skeleton structure of glycine is given below. Complete a single preferred Lewis structure of glycine by adding bonds and electrons wherever necessary. In addition, label all **non-zero** formal charges directly on each atom. The molecule should be **<u>neutral</u>** overall.



ii. What are the bond orders of **C_b-O_c** and **C_b-O_d**? Show necessary calculations.

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iii. How do the bond strengths and bond lengths of the $\mathbf{C_b}$-$\mathbf{O_c}$ and $\mathbf{C_b}$-$\mathbf{O_d}$ bonds compare to the strength and length of the double bond present in diatomic oxygen? Explain in 2-4 sentences on the lines provided below.

iv. What is the bond angle between $\mathbf{H_e}$ and $\mathbf{H_f}$ and what is the hybridization of the nitrogen in glycine?

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b. A protein/enzyme located in the human body is catalase, which is known to act as a catalyst in order to break down hydrogen peroxide. In large quantities, hydrogen peroxide is lethal to humans, but with the addition of the catalase protein, it can decompose into harmless water and oxygen.

$$2H_2O_2 \quad \rightarrow \quad H_2O + O_2$$

i. Given the decomposition reaction for hydrogen peroxide above, explain whether the hydrogen peroxide is the reducing or oxidizing agent, using half-reactions as evidence.

ii. If this reaction results in the release of Gibbs free energy, why is the addition of catalase necessary in order to prevent the accumulation of hydrogen peroxide in the human body?

c. A cell membrane is present in, and essential for animal cells. This structure has both hydrophobic and hydrophilic properties. One fundamental aspect of animal cells is the movement of molecules and ions across both sides of the membrane. However, not all molecules/ions are able to move across this membrane and require the use of proteins to either facilitate or "pump" them into and/or out of a cell. A specific transport mechanism in certain animal cells is the sodium-potassium pump used to transport three sodium ions out of the cell as well as two potassium ions into the cell across the membrane.

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i. Since this pump requires the input of energy to allow the successful transport of the sodium and potassium, what does this imply about the relative concentrations of sodium and potassium inside and outside the cell? Remember that movement of a solute down its concentration gradient releases energy.

ii. Why does an electrochemical gradient forms as a result of the sodium-potassium pump? Remember that the ions cannot cross the membrane on their own, because of the hydrophobic parts of the membrane.

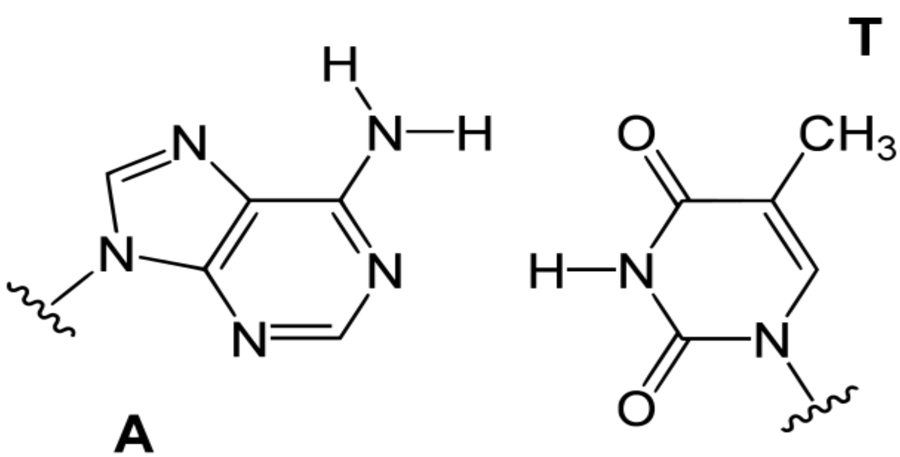
iii. In red blood cells, water is in equilibrium with the environment. Water is easily able to enter and exit these cells through aquaporin proteins solely by diffusion. If these red blood cells were introduced to a hypotonic solution (a solution with a lower concentration of ions than inside of the cell), describe the net movement of water into or out of the cell.

3. DNA (deoxyribonucleic acid), the molecule that stores all the genetic information of life, is a polymer made up of monomers called “bases.” These DNA bases are bonded covalently into long strands, where the covalent bonds run down the length of the strand. The full DNA molecule consists of two intertwined strands, which are connected to each other with strong intermolecular interactions.

a. One specific amino acid is glycine, which is the smallest possible amino acid. Use the subscript letters on atoms help differentiate between identical atoms being questioned.

i. What is the strong intermolecular force that holds these molecules together?

ii. On the diagram below, circle all pairs of groups that have the potential to form those intermolecular interactions from part a(i) between molecules.



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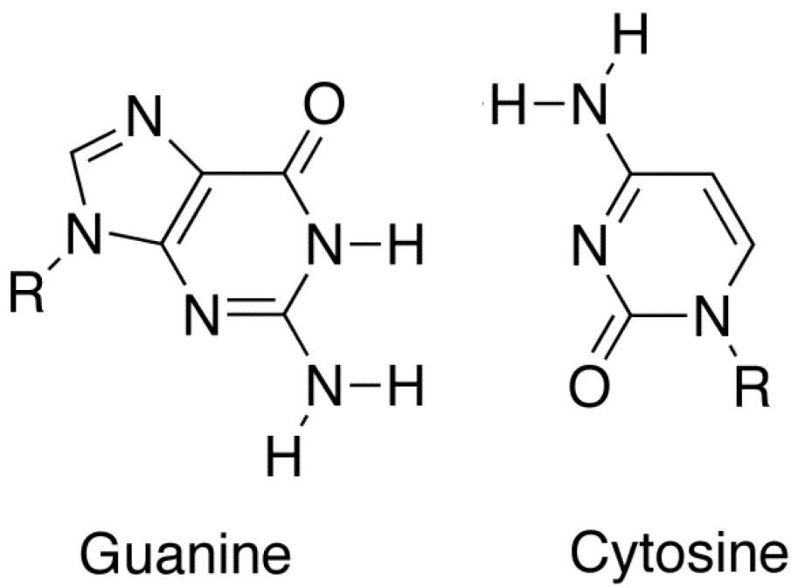
b. Shown below are the cytosine (C) and guanine (G) base pairs. Again, circle pairs of groups that are able to form the strong intermolecular interactions between the bases.



c. Assume that each of the intermolecular attractions identified in parts (a) and (b) are equally strong. The enthalpy of each interaction is 10 kJ/mol. A small amount of DNA is synthesized, with the composition being shown below. Each strand consists of covalently bonded DNA bases and base pairing occurs between A and T bases, and G and C bases on different strands.

Strand 1: A-T-G-C-G-A-T-A-G-C-T-A-T-G-C-T-A-A-T-T-G
Strand 2: T-A-C-G-C-T-A-T-C-G-A-T-A-C-G-A-T-T-A-A-C

How much energy, in joules, would be needed to separate these two strands?

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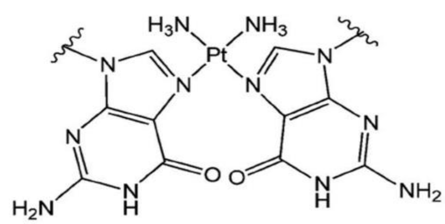
d. In order to replicate, cells must copy all of their DNA. The first step of this process is separating the two strands of each DNA molecule. This is done by a type of protein called a helicase.

i. Some helicase enzymes use the energy of a reaction called "ATP hydrolysis" to separate the strands. If the equilibrium constant for the hydrolysis of ATP at 37 °C is 19.4, calculate the change in free energy in kJ/mol of this hydrolysis.

ii. If cells cannot separate the strands of DNA, the result can be cell death. A drug called cisplatin is able to form covalent bonds between DNA bases on different strands, as shown below. The covalent bonds between the platinum of the drug and the nitrogen of the DNA base have estimated bond dissociation energies of 85 kJ/mol. Using the results of part d (i) and remembering that a normal intermolecular interaction between DNA strands is on the order of 10 kJ/mol, explain why cisplatin is able to kill cells.



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