Microbiology Review – Chemical Basis of Life

Work Completed fo Oral Exam: Using *Schaum's Outline of Microbiology* by Alcamo [1], presents basic concepts in microbiology (with an emphasis on topics related to proteins) through directed questions. Specifically reviews the central dogma of molecular biology, DNA/RNA, and the structure of proteins and the building blocks.

1 Questions and Answers

1. **What are the two important nucleic acids in biological organisms?**

   The molecules deoxy-ribonucleic acid (DNA) and ribonucleic acid (RNA) form two foundational pillars of the central dogma of DNA. RNA, which comes in a variety forms, is transcribed from DNA and is used for translation (the creation of polypeptide chains).

2. **What is the significance of the sequence of nitrogenous bases in the DNA molecule?**

   There are four nitrogenous bases associated with DNA: thymine, adenine, guanine, and cytosine. Thymine and adenosine bind together in the molecule while guanine and cytosine bind together.

   The sequence of nitrogenous bases defines the genome of an organism. It serves as the first part of the central dogma of molecular biology (i.e., transcription) and thus comprises the template for which mRNA is created and the starting point of protein translation.

3. **What is the difference between oxidation and reduction reactions?**

   Oxidation reactions involve a molecule losing an electron (Historically it was initially characterized as the gain of an oxygen). Reduction reactions involve a molecule gaining an electron. From the symmetry of their definitions, it's clear that the two reactions occur together. See Fig. 1.

   Redox reactions are also important in the biologically fundamental processes of cellular respiration and photosynthesis.

$$\text{Cellular Respiration:} \quad C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\;CO_2 + 6\,H_2O \tag{1}$$

$$\text{Photosynthesis:} \quad 6\;CO_2 + 6\,H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6\,O_2 \tag{2}$$

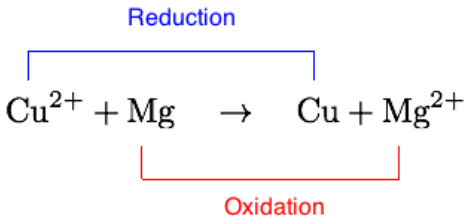

Figure 1: Example of a Redox Reaction

4. **What is the significance of covalent bonding in carbon?** A covalent bond is a bond where the electrons are shared between neutral atoms in such a way to complete the valence orbitals of the atoms. For example, neutral hydrogen and neutral carbon have one and four empty electron slots, respectively,

in their outer orbital. Thus the molecules H_2 and CH_4 are formed through the sharing of electrons between the neutral atoms.

Because carbon requires four electrons to complete its outer shell (and the shell is thus half-filled), it can covalently bond with many other atoms in an order 4 rotationally symmetric way. Carbon thus exists as a convenient structural element in the formation of long complex molecules, and is found in every type of biological macromolecule.

5. **What distinguishes acids and bases?**

   Acids release hydrogen ions when placed in water, while bases accept hydrogen ions in water. Acids and bases combine to form salt and water.

   The strength of an acid HA is measured by $\mathrm{pKa} = -\log_{10} \mathrm{K}_a$, where

$$\mathrm{K}_a = \frac{[\mathrm{H}^+][\mathrm{A}^-]}{[\mathrm{HA}]}, \tag{3}$$

   with brackets denoting concentration. K_a is the equilibrium dissociation constant and defines how easily an acid loses a proton. The stronger the acid, the more $[\mathrm{H}^+]$ produces for each [HA], and thus the higher (lower) the value of K_a (pKa).

   The pH of an acid, defined (according to some normalized concentration) as

$$\mathrm{pH} = -\log_{10} [\mathrm{H}^+] \tag{4}$$

   however, is a measure of the concentration of an acid rather than its strength. For example, diluting an acid solution would lower the pH, but would not lower the pKa.

6. **Why is DNA replication described as semi-conservative?**

   Semi-conservative replication refers to the way DNA is replicated by splitting the double helix strand and making a copy of each strand. This process is termed semi-conservative in relation to the theorized conservative form of replication where the entire double helix is replicated without separating the two strands.

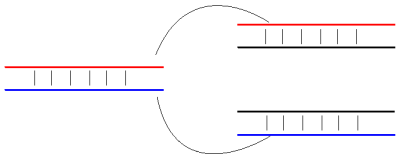

Figure 2: Semi-conservative replication: Depiction of semi-conservative replication, where the original DNA double helix (represented in blue and red) is split and each strand is copied.

7. **How is dehydration synthesis relevant to polypeptides?**

   Peptide bonds are links between amino acids. When two amino acids join together they form a peptide bond and release water. Because water is released (i.e., removed) in the reaction and two originally distinct molecules are joined together we call the reaction a "dehydration synthesis".

   Three fatty acids and a glycerol also combine through dehydration synthesis to create a triglyceride molecule.

   Because water is produced in the forward direction of the reaction, water can be used in the reverse direction to split a dipeptide bond. Such a reaction is called a hydrolysis reaction. (Such a reaction forms the basis of the estimation of the entropy of bacterial cell division in [2])

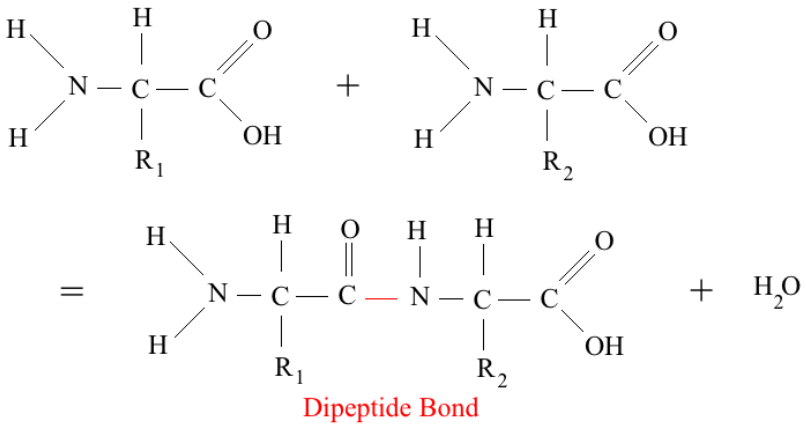

Figure 3: Formation of Dipeptide Bond: In an example of a dehydration synthesis reaction, two amino acids combine to form a dipeptide bond and a water molecule.

8. **Where do proteins function in a cell and why are they important?**

   Proteins function in all parts of a cell and they act as enzymes (biological catalysts) of reactions within the cell. Proteins are also the major structural building blocks of cells.

   - Proteins in the cell membrane form channels and pumps to control the passage of molecules through the cell.
   - Topoisomerase untangles DNA; Kinesin moves organelles.

9. **What distinguishes RNA from DNA?**

   - **Sugar Base:** RNA and DNA are distinguished by the carbohydrate base which forms the backbone of each nucleotide chain.
   - **Double vs. Single:** DNA also exists primarily (that is, when it is not undergoing replication or transcription) as a double helix, while mRNA is single stranded.
   - **Nucleic Acids:** The nucleic acids which comprise DNA are adenine and thymine (which bind together) and guanine and cytosine (which bind together). In RNA the nucleic acids are adenine and *uracil* (which bind together) and guanine and cytosine (which bind together).

10. **What are the basic features of nucleotides?**

    Nucleotides are the building blocks of DNA and RNA (in much the same way that amino acids are the building blocks of polypeptides and proteins). Nucleotides consist of a sugar, a phosphate, and a nitrogenous base (adenine, cytosine, guanine, thymine).

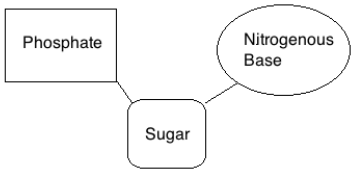

Figure 4: Nucleotide Basic Structure

Nucleotides are linked via phosphodiester bonds between the hydroxyl groups in the phosphoric acid (phosphate group) and the (deoxy)ribose sugar.

11. **What is the central dogma of molecular biology?** The central dogma outlines the way the genetic material of a cell produces the proteins which serve as the structural and functional building blocks of a cell. The central dogma states that DNA is used to transcribe mRNA which is then used to translate amino acid chains which make up a protein. We depict this in Fig. 5.

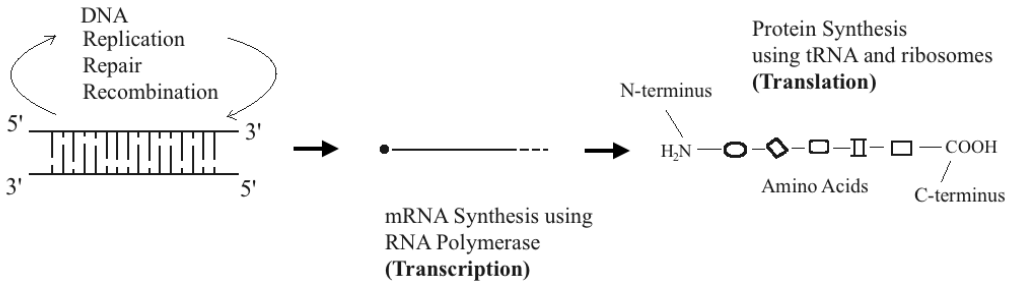

Figure 5: Central Dogma of Molecular Biology

References

[1] I. E. Alcamo and J. Warner, *Schaum's outline of microbiology*. McGraw Hill Professional, 2009.

[2] J. L. England, "Statistical physics of self-replication," *The Journal of chemical physics*, vol. 139, no. 12, p. 121923, 2013.