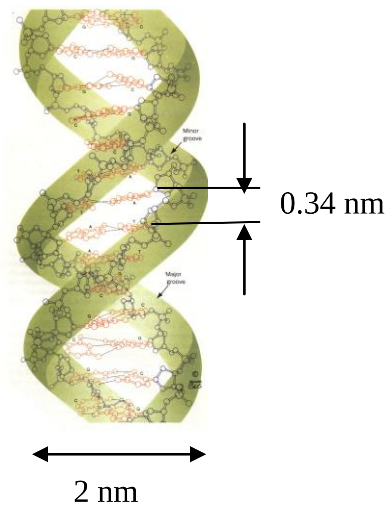
<u>Short Option: Introduction to Biophysics.</u> Trinity Term 2011

<u>Problem set 1 (Lecture 8)</u>

<u>DNA, RNA, the Central Dogma</u>

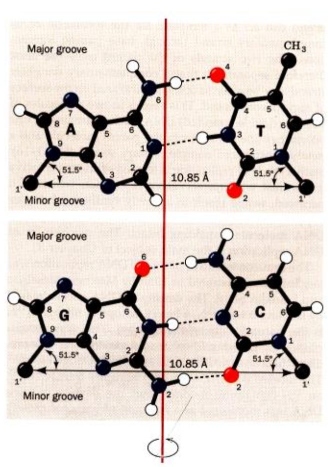
1. Describe the structure of DNA and RNA and their roles in living organisms.

2. The human genome contains approximately 3.4 x 10^9 base-pairs. With the aid of the dimensions shown below, estimate the capacity of DNA as a data-storage medium, and compare this capacity to that of other storage media.



How do the following effect the storage capacity of DNA in living organisms: The genetic code; multiple reading frames; the double helix (as opposed to single strand).

3. Explain the essential elements of Darwin's theory of Natural Selection.



Base-pairs containing one purine (A or G) and one pyrimidine (C or T) can be accommodated in the DNA double helix as shown.
Considering only the contribution of hydrogen bonding to base-pair stability, estimate the probabilities that mis-matched base pairs will be formed (a typical hydrogen bond energy is ~5 kT), and thus the number of base-pair errors that might be predicted in copying the entire human genome. Compare this to the observed value of approximately 10^5.
Evolutionary mutations appear at a rate of approximately one base pair per human generation. Explain the difference between this rate and the values above.

4. What is the probability that a codon in a random RNA sequence will be a stop codon? Derive an expression for the probability that a polypeptide translated from a random RNA sequence will not be terminated before the i^{th} amino acid. After how many amino acids is the above probability less than one half? What is the probability of such a polypeptide reaching a length of 300 amino-acids or more ? Compare this to the length of a typical protein.

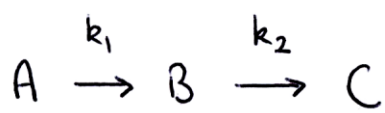
Protein Structure

5. Describe the "linear" and 3-D structure of proteins, and discuss the factors that determine the folding of the former into the latter.

Brownian motion, Diffusion, Kinetics

6. By modeling free diffusion as a random walk, show that the root-mean-squared distance moved in a time interval t is proportional to $t^{½}$.

7. Derive an expression for the probability that the conversion of ***A*** to ***C*** by the pathway shown below occurs at time ***t***, where k_1 and k_2 are unimolecular rate constants for the sequential, irreversible reactions ***A*****→ *B*** and ***B*****→*C*** respectively**.**



Lipids and Membranes

8. Estimate the capacitance per unit area of a typical biological lipid bilayer. You may assume a thickness of 5 nm and a relative dielectric constant of 2.5.

9. Describe and sketch a phospholipid molecule and several different stable structures that can form when phospholipids are mixed with water. Discuss the factors that determine which of these structures is most likely to form

10. By considering the electrostatic self-energy, estimate the energy required to transfer a positive ion of radius 0.3 nm from water to the centre of a lipid bilayer, both with and without consideration of the screening of the ion's electric field by water due to the finite thickness of the bilayer. Comment on the connection between this result and the permeability of the bilayer to simple ions.

11. What would be the Nernst potential across a typical lipid bilayer permeable to only one species of ion if that species were present at concentrations of 100 mM and 50 mM on either side of the membrane?
    How much charge has to cross the membrane per unit area to establish this potential (you may find your answer to question 8 useful)? How many ions is this for a typical small cell or vesicle? How does that compare to the total number of ions in the cell/vesicle ?
    Give examples of biological Nernst potentials dominated by sodium and potassium conductivity.

12. Describe at least two typical structural features and at least two functions of integral membrane proteins. Discuss how the former contribute to the proteins' stability in the membrane.