IMPERIAL COLLEGE LONDON

BEng, MEng and ACGI Examinations 2015-16

Part 1

Biomedical Engineering
BE1-HMCP
MOLECULES, CELLS AND PROCESSES, Main Exam

13/05/2016, 14.00-15.30
Duration: 90 minutes

The paper has 10 COMPULSORY questions.
Answer 10 question(s).
Each question is worth 100 marks.

Marks for questions and parts of questions are shown next to the question. The marks for questions (and parts thereof) are indicative, and they may be slightly moderated at the discretion of the examiner.

Question 1. Click here to enter text.

a) Sketch the hydrogen bonding in water

40 marks

b) Why are the angles between the oxygen atom and all hydrogen atoms bonded to it in a chosen water molecule approximately tetrahedral?

40 marks

c) Explain why water decreases the electric field from a charged surface.

20 marks

Question 2. Click here to enter text

a) Explain with the aid of a diagram how phospholipids form a lipid bilayer membrane.

40 marks

b) Estimate how long it would take a phospholipid molecule to diffuse the length of a typical mammalian cell. Take lateral diffusion coefficient of phospholipid in a bilayer membrane to be 2 μm2 s-1

60 marks

Question 3. Click here to enter text.

a) Explain what is meant by secondary and tertiary protein structure.

40 marks

b) Explain with the aid of a diagram how a beta-sheet is stabilised.

30 marks

c) How does this structure allow the creation of the tertiary structural features of a slip-plane?

30 marks

Question 4. Click here to enter text.

a) Why do cells use ATP as a local energy source rather than oxidising glucose directly?

40 marks

b) Outline the role of protons (H+) in the production of ATP in the mitochondria.

60 marks

Question 5. This question is focused upon DNA structure and packaging.

a) Descibe the structure of DNA. What is meant by the terms: nucleotide, base, and backbone

50 marks

b) Describe the difference between a nucleosome and a histone.

50 marks

Question 6. Cells replicate and consequently DNA needs to replicate

a) What is an origin of replication.

40 marks

b) Describe Okazaki fragment and explain how they arise?

60 marks

Question 7. Cells adapt continuously to their environment by adapting their gene and protein signatures.

a) DNA needs to be transcribed to generate mRNA. Describe the three stages of DNA transcription.

40 marks

b) Directly formed mRNA is immature. Outline the maturation of mRNA.

60 marks

Question 8. Cells produce proteins from RNA in a process called translation.

a) Describe how translation is initiated in eukaryotic cells, e.g. up to the process of peptide formation**.**

40 marks

b) What is the role of transfer RNA or tRNA in this process. How many are there in a cell and what consequence does this have?

60 marks

Question 9. All cells have a membrane separating the environment from the intracellular compartment.

a) The cellular membrane or lipid bilayer can be described as a 2D-fluid with a viscosity. Which factors influence the viscosity of lipid bilayer

40 marks

b) Outline the general structure of phospholipids. Why are they amphiphilic?

60 marks

Question 10. Cells interact with their environment through highly controlled transmembrane proteins. Their function is the topic of the current question.

a) Explain the process of channel-mediated facilitated diffusion and give two examples of this process. **50 marks**

b) Explain what is meant by exocytosis and endocytosis and give one example of each. .

50 marks

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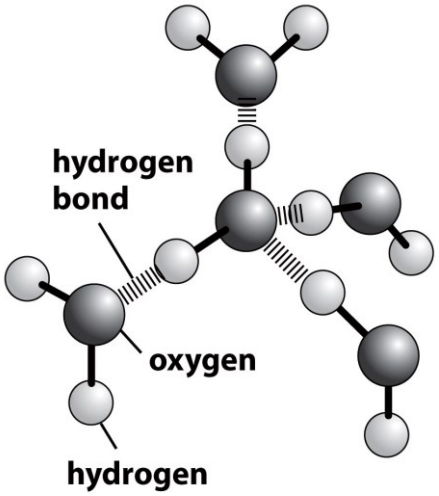
MODEL ANSWERS and MARKING SCHEME
First Examiner: [redacted] > Second Examiner: [redacted] [redacted]
Paper: **<COURSE CODE, eg 'BE1-HEE1'> - <COURSE TITLE>, Main Exam** Question: **1** Page **1** of **3**

Question 1 This is question 1.

a) Sketch the hydrogen bonding in water

40 marks

Picture showing the tetrahedral arrangement of 4 water molecules around a central molecule hydrogen bonding



Marks 20 for diagram indicating tetrahedral arrangement, 20 for correct number of H-bonds

40

b) Why are the bonds between oxygen and hydrogen approximately tetrahedral?

40 marks

The answer should involve the fact that the hydridisation of the oxygen atom is sp3.(20 marks) This gives 4 equal sp3 hybrid orbitals pointing towards the corners of a tetrahedron. Two of these form sigma bonds to hydrogen, 2 are lone pairs forming H-binds (20 marks).

Marks:

40

c) Explain why water decreases the electric field from a charged surface.

20 marks

Each water molecule is an electrical dipole (10 marks) this aligns in opposition to the field from a changed surface decreasing it by a factor of about 80 (10 marks)

Marks:

10

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MODEL ANSWERS and MARKING SCHEME

First Examiner: [redacted] Second Examiner: [redacted]

[redacted]**>**

Paper: **<COURSE CODE, eg 'BE1-HEE1'> - <COURSE TITLE>, Main Exam** Question: **1**

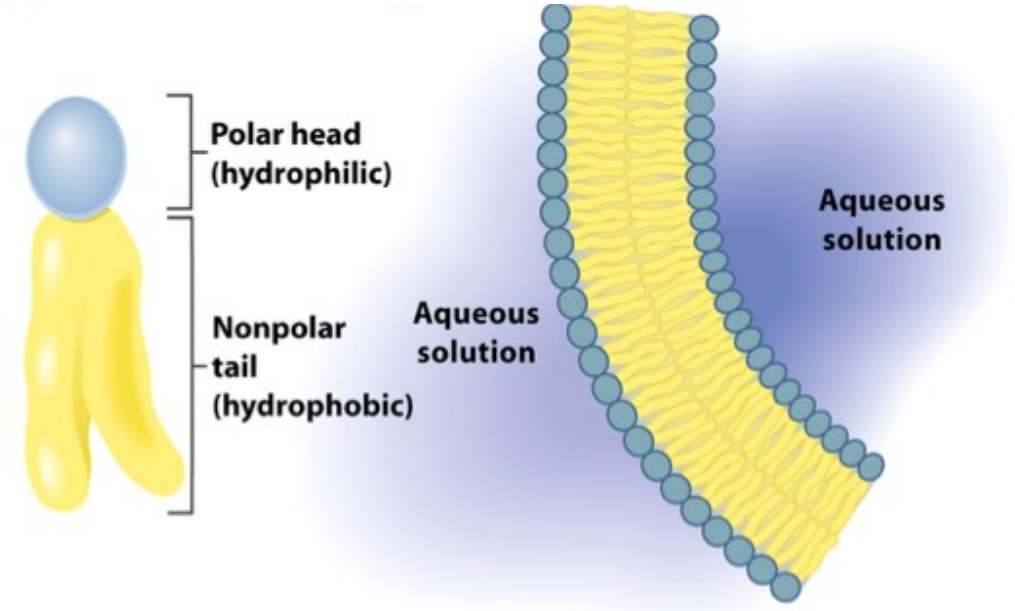
Page **2** of **3**

Question 2 Introduction to question 2.

a)Explain with the aid of a diagram how phospholipids form a lipid bilayer membrane

40 marks

Structure of phospholipid (20 marks). Tail too wide to form micelles, hence forms bilayer sheets, Stanilised by



Marks:

Structure of phospholipid (20 marks). Tail too wide to form micelles, hence forms bilayer sheets, Stanilised by

40

b) Estimate how long it would take a phospholipid molecule to diffuse the length of a typical mammalian cell. Take lateral diffusion coefficient of phospholipid in a bilayer membrane to be 2 $\mu m^2\ s^{-1}$

60 marks

This equation uses the Einstein relation

$$L = \sqrt{2Dt}$$

$$gives \quad t = \frac{L^2}{2D}$$

Where L is distance, D is diffusion coefficient and t is time (sec) (40 marks)
Estimate distance is say 20 µm (mammalian cell) (10 marks) applying with correct units gives 50 seconds (20 marks)
Marks:

60

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MODEL ANSWERS and MARKING SCHEME
First Examiner: [redacted] > Second Examiner: **P**[redacted]
Paper: **<COURSE CODE, eg 'BE1-HEE1'> - <COURSE TITLE>, Main Exam** Question: **1** Page **3**of **3**

3 a) Distinguish between secondary and tertiary protein structure

40 marks

Secondary structure is the use of structure motifs such as alpha helices and beta sheets.(20 Marks)

Tertiary structure: is the arrangement of secondary structural motifs in 3D space to give protein domains. (20 Marks)

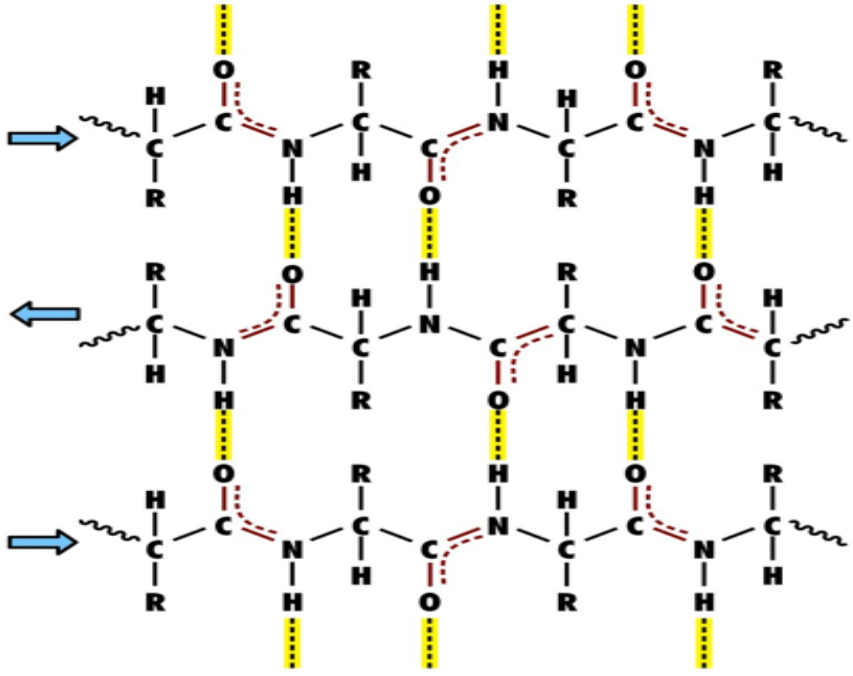
Marks:

40

b) Explain with the aid of a diagram how a beta-sheet is stabilised

30 marks

Here an antiparallel beta sheet is shown. Stabilised by hydrogen bonds between adjacent chains (30 Marks) In fact slightly corrugated



Marks:

30

c) How does this structure allow the creation of the tertiary structural features of a slip-plane?

30 marks

Alternate side chains are on alternate sides of the beta sheet plain (10 marks). Since the order of the amino-acids in the protein sequence is controlled by the DNA sequence all the AAs on one side of the beta sheet can be made hydrophobic. (10 marks). A slip plane has the hydrophobic faces of two beta sheets in opposition to give a low friction plane. (10 marks)

Marks:

30

4a) a) Why do cells use ATP as a local energy source rather than oxidising glucose directly?

40 marks

Glucose oxidation directly to carbon dioxide and water

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

Gives 2872 kJ / mol^{-1} or about 1180 kT.This is far too much energy to be taken up by any cell in one go, it would destroy any call or acceptor molecule. (20 marks) ATP gives 31 kJ / mol^{-1} or 12kT. This is very suitable to promote a reaction by for example phosphorelation of a reactant., yet can npot brak any C-C bond (450 kJ / mol^{-1}) 20 marks)

Marks:

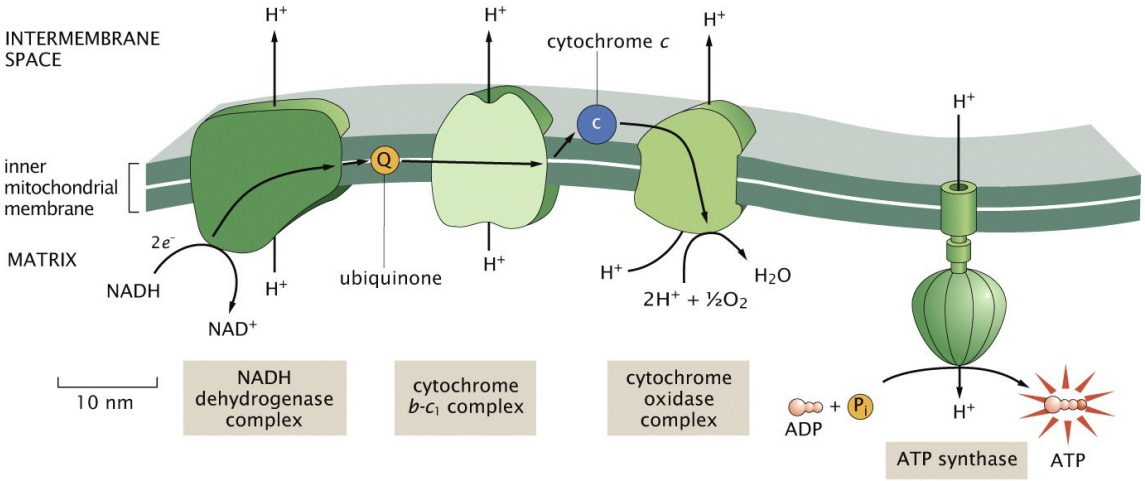
40

b) Outline the role of protons (H+) in the production of ATP in the mitochondria.

60 marks

The electron transport chain converts the energy stored in NADH into a proton gradient. This is used by ATP synthase to make ATP (20 Marks). At each stage passage of the electrons from NADH, ubiquinone or cytochrome-c result in translocation of protons against a concentration gradient.

Details



(40 marks)

Marks:

60

5a) What is a nucleotide, what is a base and what is the backbone of DNA?

50 marks

DNA consists of a long chain of elements, whereby each element consists of a base, a sugar, and a phosphorus group. A base is the information carrier consisting of pyrimidines (Thymine and Cytosine) and purines (Adenine and Guanine:20 points). The backbone consists of the sugar group and the phosphoric acid (10 points). A nucleotide is the backbone with the base (10 points)

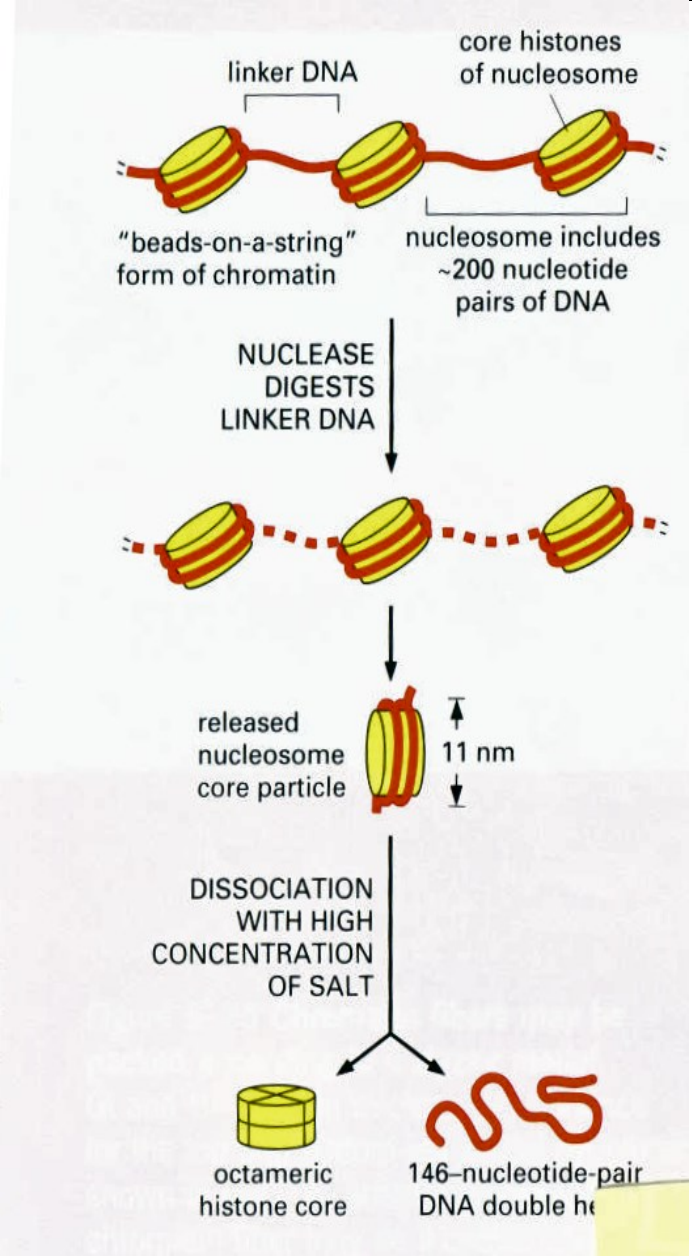
Marks: 50

50

b) Name the differences between a nucleosome and a histone.

50 marks

A histone is an octamer of 2 pairs of 4 different proteins (small, only about 100 amino-acids each) with about **146 nucleotide pairs** wound around it. Histones are interconnected through a DNA linker consisting of 80 nucleotides. A histone with the linker is called a nucleosome. Details: See below a way to study these histones and nucleosomes.



(50 marks)

Marks:

50

6a) What is the origin of replication. Howmany are there??

40 marks

An origin of replication is the start site of replication. It is a special sequence of nucleotides, often rich in A-T bonds as this is less energy demanding than C-G bonds **(only 2 H-bonds**

compared with 3 for C-G).

Marks:

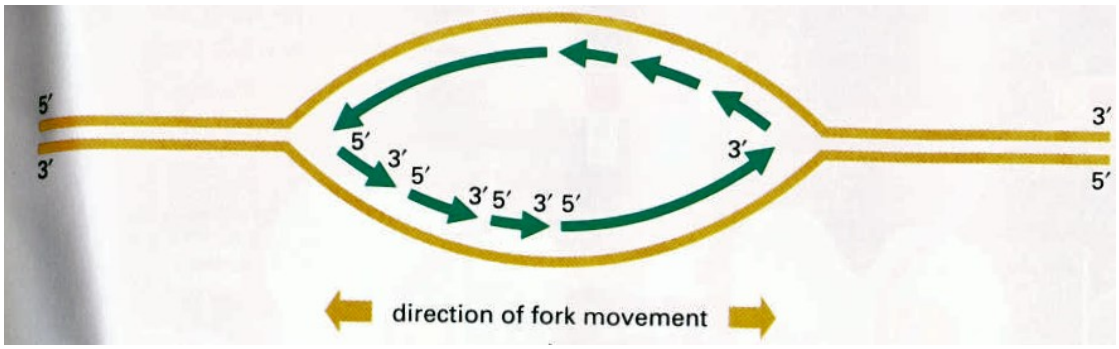
40

b) What is an Okazaki fragment? How do they arise?

60 marks

Okazaki fragments are the small fragments of the lagging strand in a region of replicating DNA (see figure). They arise because of the fact that DNA can only replicate in the 5'-3' direction.

Details



(40 marks)

Marks:

60

7a) DNA needs to be transcribed to generate mRNA. Describe the three stages of DNA transcription?

40 marks

1. **Initiation phase: binding of transcription factor with accessory proteins, which includes the pre-initaion complex and RNA-pol-II**
2. **Elongation phase. Movement of RNA-pol II over the DNA strand. which is either continuous, discontinue with pauses and backsliding.**
3. **Termination phase: occurs as an atvie process with formation of a hairpin.**

Marks:

40

b) Directly formed mRNA is immature. Outline the maturation process of mRNA.

60 marks

Maturation of mRNA encompasses the following steps

1. **Capping of the 5' region by the addition of a methylated guanine**
2. **Poly adenylation (poly AAA-tail) addition to the 3' region of the mRNA**
3. **Splicing of introns by the splicosome**

8a) Describe how translation is initiated in eukaryotic cells, eg upto the process of peptide formation

40 marks

1 The translation always starts with a special initiator tRNA which carries methionine. This, with initiator factors, bind to the P Site on the small subunit - it is the only tRNA capable of doing this. *(note the initiator tRNA is different from the one normally carrying methionine)*

2. The subunit then binds to the 5' end of the mRNA (the 5' capping promotes this)
3. The subunit moves along the mRNA in the 3' direction until it finds the start codon AUG
4. The initiation factors fall away and the large subunit binds on
5. Because the first tRNA is in the P Site, when the A site is filled with the next tRNA, peptide bond formation and protein growth can begin.

Note Thus methionine is always the starting amino acid of a growing polypeptide chain. However it is usually removed in subsequent processing.

Marks:

40

b) What is the role of transfer RNA or tRNA in this process. How many are there in a cell and what consequence does this have?

.

60 marks

Transfer RNA or tRNA has a structure that allows it to recognise the codon on the mRNA through binding with an anti-codon. Each tRNA is charged with a amino-acyltransferase. After hybridisation of the correct anti-codon with the codon of the mRNA, the amino acid is released and bound to the peptide chain.

There are 20 Amino acids and >20 (dependent on cell) tRNA's implying that also here the code is degenerative.

Marks:

60

9a) The cellular membrane or lipid bi-layer can be described as a 2D-fluid with a viscosity. Which factors influence the viscosity of the bi-layer.

40 marks

The viscosity or fluidity of the lipid bi-layer is influenced by the density of phospholipids and the absence/presence of cholesterol. The density of phospholipids is reduced in the presence of non-saturated phospholipids reducing the viscosity. In general the viscosity is influenced by temperature

Marks:

40

b) Outline the structure of phospholipids. .

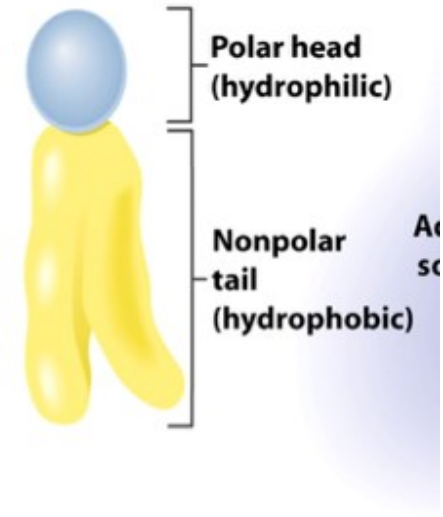
60 marks

Phospholipids carry a hydrophilic or polar head and hydrophobic or non-polar tail. That means they can dissolve in watery solutions by forming either micelles or liposome's

Details

(40 marks)

Marks:



60

10a) What is channel-mediated facilitated diffusion. Name two examples.

40 marks

Channel- mediated facilitated diffusion is the process of simple diffusion (eg. Movement of solutes in the direction of a concentration gradient) but now the permeability is regulated. Two examples are: potassium and sodium channels

Marks:

50

b) What is exocytosis and endocytosis. Name two examples. .

60 marks

Endocytosis is the process of invagination, vesicle formation and internalisation of products into the cell, exocytosis isd the opposite of endocytosis.

Used for transferrin (carries Fe), LDL, some vitamins some hormones.

Marks:

50