IMPERIAL COLLEGE LONDON

Examinations 2017-18

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

10/05/2018, 14.00-15.00
Duration: 90 minutes

The paper has 22 COMPULSORY questions.
Answer all 22 questions.

Each multiple choice question (MCQ) is worth 2 marks.
There are 15 MCQs.

Each short answer question is worth 10 marks.
There are 7 short answer questions.

Please answer all MCQs on the paper and return with your answer book.

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. Which measurement is a good estimate for the length of an E.coli?

a) 2 fL
b) 2 μm
c) 6 fL
d) 6 nm

Question total: 2 marks

Question 2. Which bond type would be considered the strongest?

a) Covalent double bond between C and O (C=O)
b) Hydrogen bond between water molecules
c) Van der Waal's interaction between water and methane
d) Ionic forces between Na and Cl in water at > 10 nm

Question total: 2 marks

Question 3. What molecular bonding property of a phospholipid leads to formation of a self-sealing, bilayer cell membrane?

a) Covalently bonded micelle structures in high entropy water
b) Hydrogen bonding between the phosphatidylcholine head groups
c) Non-covalent, hydrophobic interactions between the lipid tail molecules
d) Ionic forces between the polar head and the non-polar tail groups

Question total: 2 marks

Question 4. Which of the following is **not** considered a secondary structure of a protein?

a) Anti-parallel β-pleated sheet
b) α-helix
c) β-Globin
d) Parallel β-pleated sheet

Question total: 2 marks

Question 5. Which of the following processes consume energy in a cell?

a) Maintaining thermal equilibrium
b) Linear motion
c) Making ATP molecules
d) All of the above

Question total: 2 marks

Question 6. ATP synthase is used during energy production in the cell mitochondria. Which of the following statements about ATP synthase is **not** correct?

a) ATP synthase is a multimeric enzyme
b) ATP synthase is a critical part of the electron transport chain
c) ATP synthase spans the inner mitochondrial membrane
d) Rotation of the β -subunit results in a conformational change which catalyses ATP from ADP

Question total: 2 marks

Question 7. Which of the following products of the Kreb's cycle **do not** contribute to energy production?

a) 1 molecule of $FADH_2$.
b) 1 molecule of GTP
c) 2 molecules of CO_2
d) 3 molecules of NADH

Question total: 2 marks

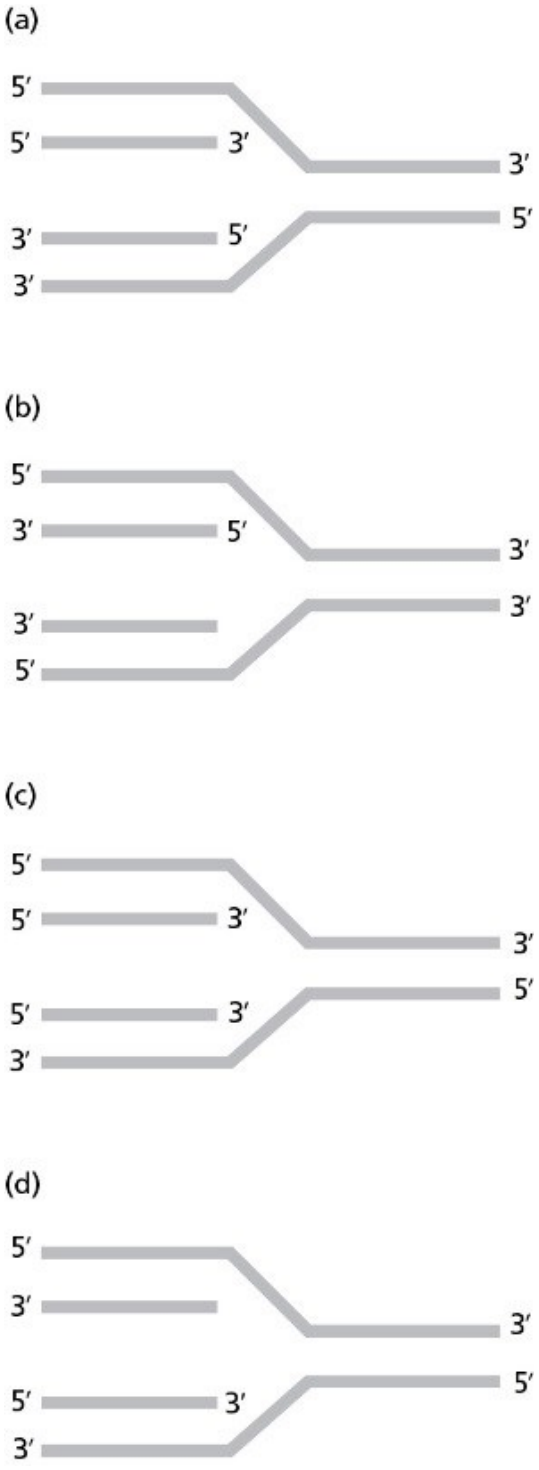
Question 8. Which of the following statements is correct with regard to a DNA double helix? _____

a) the two DNA strands are identical and run parallel.
b) purines pair with purines
c) thymine pairs with cytosine
d) the two DNA strands run antiparallel

Question total: 2 marks

Question 9. Which diagram in the figure below accurately represents the directionality of DNA strands at one side of a replication fork?

a)
b)
c)
d) X



Question total: 2 marks

Question 10. The process of DNA replication requires that each of the parental DNA strands be used as a _____ to produce a duplicate of the opposing strand.

a) catalyst
b) competitor
c) template
d) copy

Question total: 2 marks

Question 11. Which of the following statements about the genetic code is correct?

a) All codons specify more than one amino acid.
b) The genetic code is redundant.
c) All amino acids are specified by more than one codon.
d) All codons specify an amino acid.

Question total: 2 marks

Question 12. Which of the following molecules is thought to have arisen first during evolution?

a) Protein
b) DNA
c) RNA
d) All came to be at the same time

Question total: 2 marks

Question 13. Which of the following statements is true?

a) The mitotic spindle is largely made of intermediate filaments.
b) The contractile ring is made largely of microtubules and actin filaments.
c) The contractile ring divides the nucleus in two.
d) The mitotic spindle helps segregate the chromosomes to the two daughter cells.

Question total: 2 marks

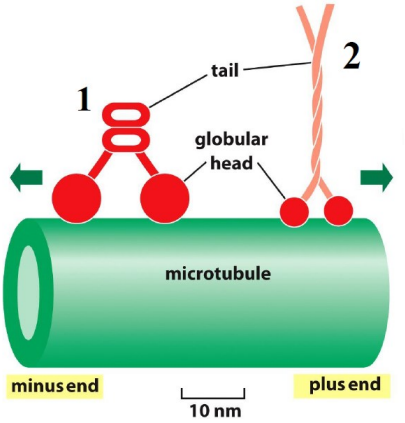
Question 14. Which of the following descriptions is consistent with the behavior of a cell that lacks a protein required for a checkpoint mechanism that operates in G_2?

a) The cell would be unable to enter M phase.
b) The cell would be unable to enter G_2.
c) The cell would enter M phase under conditions when normal cells would not.
d) The cell would pass through M phase more slowly than normal cells.

Question total: 2 marks

Question 15. For the diagram shown in the figure below, which of the following statements is correct?

a) 1 is a myosin molecule sliding on a microtubule, 2 is an actin filament.
b) 1 and 2 represent two molecules in the same family of motor proteins.
c) 1 represents dynein and 2 represents kinesin: Two motor proteins.
d) 1 represents kinesin and 2 represents dinein: Two motor proteins.



Question total: 2 marks

End of multiple choice questions.

Please write all remaining short answer questions in your answer booklets.

Question 16.

a) If the average brain weighs 1 kg and contains 10^{12} cells, calculate the size of a brain cell by assuming each cell is filled with water (1 cm^3 of water weighs 1 g). By modelling these cells as cubes, estimate the length of a brain cell.

4 marks

1000 g / 10^{12} = 10^{-9} g per cell

Because 1 g of water occupies 1 cm^3 (or $10^{12}\mu m^3$) the volume of 1 cell is 1000 μm^3

Therefore taking the cube root, the length of a cell is 10 µm

Marks

1 mark for g/cell, 1 mark for cell volume, 1 mark for length, 1 mark for correct units

b) A phospholipid takes 20 s to laterally traverse the length of the cell (calculated above) within the bilayer membrane. Calculate the diffusion constant of the phospholipid within the membrane.

3 marks

This equation uses the Einstein relation: $L = \sqrt{2Dt}$

Using L from above as 10 µm and rearranging

D = $L^2/(2 \times t)$

D = $10^2/(2x20)$

D = 100/40 = 2.5 $\mu m^2/s$

Marks: 1 for equation, 1 for rearrangement and substitution, 1 for correct answer.

c) Describe the type of forces (or bonds) created by interactions between stearate (linear) hydrophobic tails within a lipid bilayer?

3 marks

Linear hydrophobic tails in the lipid bilayer commonly interact through Van der Waals forces. These are weak and transitory but in high numbers help maintain the robustness and fluidity of the cell membrane.

Marks: 1 mark for van der Waals, 1 mark for transitory, 1 mark for either weak, high numbers or description of electron cloud sharing.

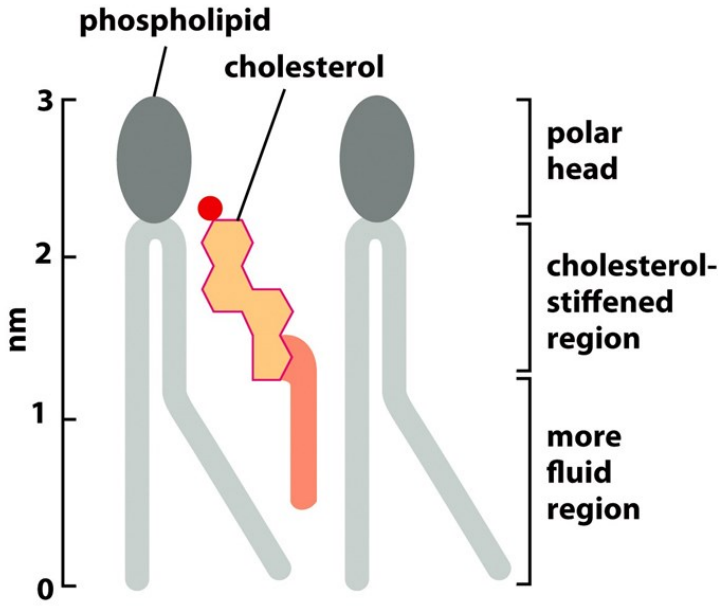
Question total: 10 marks

Question 17.

a) What is the role of cholesterol within the lipid bilayer membrane? Explain using a diagram and description of the molecular structure of cholesterol.

3 marks

Cholesterol contains a rigid planar steroid ring structure. It accounts for some 20% of the lipid content in mammalian cells. Cholesterol makes cell membranes more rigid and less permeable.

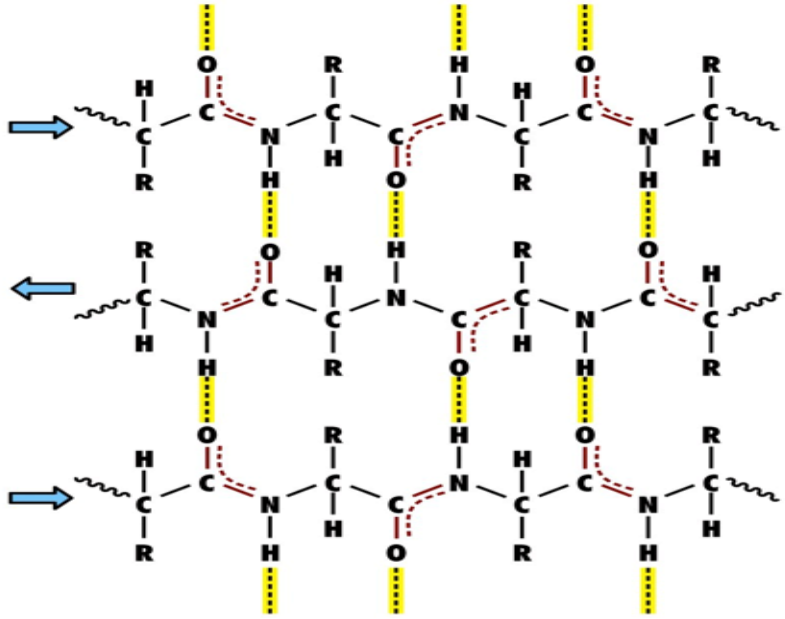


Marks: 1 mark for rigid ring structure. 1 mark for supporting cell membrane shape and permeability. 1 mark for correct diagram.

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

4 marks

Here an antiparallel beta sheet is shown. Stabilised by hydrogen bonds between adjacent chains.



Marks: Either parallel or anti-parallel will be acceptable. 1 mark for writing and describing H-bond, 1 mark for showing correct H-bond, 2 marks for other diagram constituents (Cs, peptide bonds, R groups etc.)

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

3 marks

Alternate side chains are on alternate sides of the beta sheet plain (1 mark). 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. (1 mark). A slip plane has the hydrophobic faces of two beta sheets in opposition to give a low friction plane. (1 mark)

Marks: 1 mark for side chain alternation, 1 mark for hydrophobic orientation, 1 mark for opposition resulting in low-friction interaction.

Question total: 10 marks

Question 18.

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

4 marks

Glucose oxidation can be undertaken to form carbon dioxide and water directly

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

However, this 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 cell or acceptor molecule. (2 marks) ATP gives 31 kJ / mol^{-1} or 12kT. This is very suitable to promote a reaction by for example phosphorylation of a reactant, yet cannot break C-C bonds (450 kJ / mol^{-1}) (2 marks)

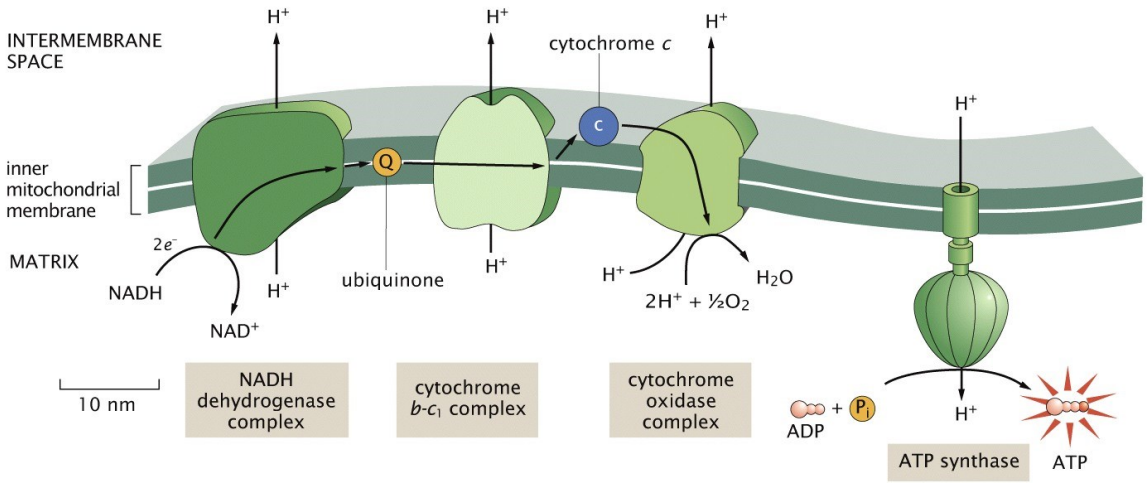
Marks: 2 marks for description of oxidation or equation, along with conclusion of this being too much energy for a cell. 2 marks for description of ATP energy production as a lower energy currency and match to required energy consumption without breaking common covalent bonds.

b) Using a diagram and description of the key steps, outline the role of protons (H+) in the production of ATP in the mitochondria.

6 marks

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

Details



Marks: 2 marks for energy conversion through NADH to proton gradient. 1 mark for pumping across the inner mitochondrial membrane and return through ATP synthase. 3 marks for diagram including – 1 for showing correct complexes, 1 for showing direction of proton pumping, 1 for showing translocation of electron carriers between complexes.

Question total: 10 marks

Question 19.

a) Describe the basic structure of the monomeric units (building blocks) in the DNA molecule. What is meant by the terms: base, sugar, nucleoside, nucleotide, and backbone?

6 marks

DNA consists of a long chain of elements (nucleotides), whereby each element consists of a base, a sugar, and a phosphate group. A base is the information carrier consisting of pyrimidines (Thymine and Cytosine) and purines (Adenine and Guanine). The sugar is a pentose (deoxyribose). The nucleoside is the base and the sugar. The backbone consists of the sugar group and the phosphate group. A nucleotide is the backbone with the base.

Marks: Definition of nucleotide (1 mark), base information carrier (1 mark), base classification (1 mark), sugar (1 mark), nucleoside (1 mark), backbone (1 mark).

b) Describe the double helix DNA structure.

4 marks

The DNA molecule has two nucleotide strands. Strands are antiparallel – oriented with opposite polarities (one strand 5'-end to 3'-end and the other 3'-end to 5'-end). The two strands are held together by hydrogen bonds between the bases of the nucleotide chains. The coiling of the two DNA strands around each other creates a right-handed double helical structure with two grooves. The wider groove is called the major groove and the smaller the minor groove.

Marks: Definition of two DNA strands (1 mark), antiparallel (1 mark), right-handed double helix (1 mark), grooves (1 mark).

Question total: 10 marks

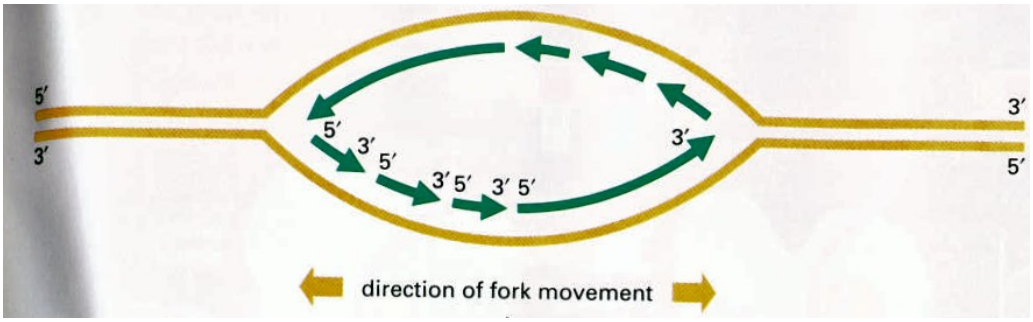
Question 20.

a) What are Okazaki fragments? Draw diagram when needed.

5 marks

The Okazaki fragments arise during DNA replication, where they are present at the lagging strand. They are made discontinuously and later joined together by the enzyme ligase to form a continuous DNA strand. They are approximately 1000bp long in prokaryotes and 100bp in eukaryotes.

Marks: Definition of two DNA strands (1 mark), process occurring in DNA replication (1 mark), in lagging strand (1 mark), made discontinuously (1 mark), joined together by ligase (1 mark). Alternatively 1 mark for the sizes of fragments.



b) Explain how they arise.

5 marks

They arise at the lagging strand of DNA during replication by the fact that elongation of new DNA occurs in the 5'-3' direction only. The 5'- to -3' direction of the DNA polymerization reaction brings a problem at the replication fork. Because of the chemical polarity of the DNA molecule and because both strands run antiparallel the replication fork is asymmetrical. This means that the DNA polymerase can move in the direction of the replication fork only in one strand (the leading strand). To solve this problem, the lagging strand is synthesized in fragments in the direction 5'-3' with the DNA moving backwards to the movement of the replication fork.

Marks: Definition of problem at the replication fork (2 mark), elongation of DNA occurs in the 5'-3' direction only (1 mark), identification of chemical polarity of leading and lagging strand (1 mark), DNA polymerase can move in the direction of the replication fork only in the leading strand (1 mark).

Question total: 10 marks

Question 21.

a) What makes RNA different from DNA?

6 marks

RNA has a different sugar (ribose versus deoxy-ribose in DNA) in the backbone, it has Uracil instead of Thymine as base, it is single-stranded, encodes a single gene (average size much smaller then DNA), has a short half-life, and mature RNA has a different composition (exons only, poly-AAA tail, and 5' cap). RNA has structural, catalytic and information carrier roles, whereas DNA carries genetic information.

Marks: 1 mark for different sugars, 1 mark for Uracil, 1 mark for single strand, 1 mark for mature RNA (exons only, poly-AAA tail, and 5' cap), 2 marks for structural, catalytic and information carrier roles. Alternatively 1 mark for short half-life.

b) Describe the process of RNA maturation.

4 marks

RNA is a single strand copy of DNA, which is matured by the splicing the introns from the RNA, by adding a poly-AAA tail on the 3' site and by capping the 5'part of RNA by methylated guanine. In addition, 3' and 5' UTRs are present that regulate translation efficiency.

Marks: 1 mark for RNA splicing, 1 mark for poly-AAA tail on the 3' site, 1 mark for capping the 5'part of RNA by methylated guanine, 1 mark for 3' and 5' UTRs are present that regulate translation efficiency.

Question total: 10 marks

Question 22.

a) Describe the structure and function of the nucleus, the ribosome, and the endoplasmic reticulum in eukaryotic cells.

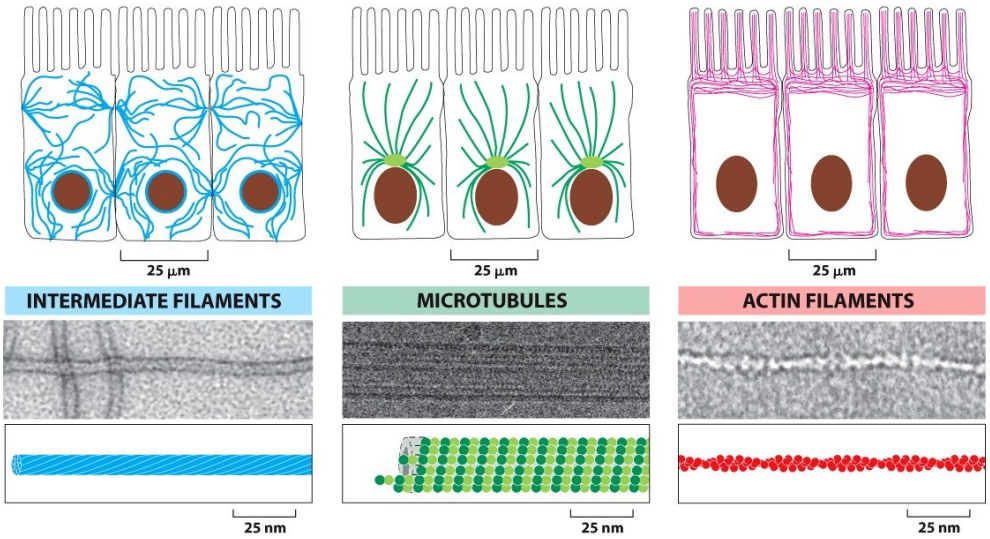
6 marks

Nucleus: The nucleus forms an internal milieu for DNA, it is the place for the synthesis of RNA (DNA transcription), and ribosomes. It controls cell activity by modulating gene expression. Nuclear pores are highly specific openings in the nuclear envelope for interacting of nuclear material with the cytoplasm.
Ribosomes: Structures where proteins are made in a process known as translation. Ribosomes have two units (small and large subunits) made of proteins and different types of RNA – ribosomal RNA (rRNA).
Endoplasmic reticulum: This is a network of membranes extending from the nuclear envelope and is often found spread throughout of the cell. There is a rough endoplasmic reticulum (RER) and a smooth endoplasmic reticulum (SER). The roughness is caused by the attachment of the ribosomes. The RER is flattened sheets, the SER is more tubular. The space between the sheets and that inside the tubes are separated from the cytosol by the ER membranes and contains the ER matrix. The SER is an extension of the RER.

Marks: 1 mark for structure and 1 mark for function of the nucleus. 1 mark for structure and 1 mark for function of the ribosome. 1 mark for structure and 1 mark for function of the endoplasmic reticulum.

b) Name two of the three main types of structure that form the cytoskeleton and indicate the protein from which each structure is made.

4 marks



Intermediate filaments are ropelike fibers with a diameter of about 10 nm; they are made of fibrous intermediate filament proteins. One type of intermediate filament forms a meshwork called the nuclear lamina just beneath the inner nuclear membrane. Other types extend across the cytoplasm, giving cells mechanical strength and distributing the mechanical stresses in an epithelial tissue by spanning the cytoplasm from one cell–cell junction to another. Intermediate filaments are very flexible and have great tensile strength. They deform under stress but do not rupture. (Micrograph courtesy of Roy Quinlan.)

Microtubules are hollow cylinders made of the protein tubulin. They are long and straight and typically have one end attached to a single microtubule-organizing center called a *centrosome*. With an outer diameter of 25 nm, microtubules are more rigid than actin filaments or intermediate filaments, and they rupture when stretched. (Micrograph courtesy of Richard Wade.)

Actin filaments (also known as *microfilaments*) are helical polymers of the protein actin. They are flexible structures, with a diameter of about 7 nm, that are organized into a variety of linear bundles, two-dimensional networks, and three-dimensional gels. Although actin filaments are dispersed throughout the cell, they are most highly concentrated in the *cortex*, the layer of cytoplasm just beneath the plasma membrane. (Micrograph courtesy of Roger Craig.)

Figure 17-2 Essential Cell Biology, 4th ed. (© Garland Science 2014)

Marks: 1 mark for naming one type of structure, and 1 mark for indicating the protein that forms this type of structure. 1 mark for naming the second type of structure, and 1 mark for indicating the protein that forms this type of structure.

Question total: 10 marks

End of the exam