EGT3
ENGINEERING TRIPOS PART IIB

Friday 3 May 2024 14.00 to 15.40

Module 4G6

CELLULAR AND MOLECULAR BIOMECHANICS

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

You may not remove any stationery from the Examination Room.

1 (a) Summarise the main mechanical functions of the cytoskeleton within a cell making reference to microtubules, actin filaments and intermediate filaments. [30%]

(b) Outline the structure of a sarcomere and explain the role of the thick filaments, thin filaments and Z-discs. [30%]

(c) What is the significance of the persistence length in dictating the properties of biological fibres? [20%]

(d) Explain how proteins are transported within cells faster than diffusion can provide. [20%]

2 The micro-structure of a two-dimensional biological network is shown in Fig. 1. We approximate it as a periodic assembly of elastic ideally-plastic struts with a cell wall Young's modulus E_s and yield strength σ_s. The struts are of uniform thickness t.

(a) Obtain an expression for the relative density $\bar{\rho}$ in terms of t and the cell size ℓ marked in Fig. 1. [15%]

(b) Calculate the effective modulus E_2 and strength σ_2^Y of the network in the x_2-direction. You may neglect the contribution from the bending stiffness and strength of the struts. [30%]

(c) The strength in the x_1-direction is dictated by the plastic bending of the hinges at the ends of the inclined struts. Obtain an expression for the strength σ_1^Y in the x_1-direction in terms of the relative density $\bar{\rho}$ and cell wall strength σ_s. [35%]

(d) Calculate the nominal strain in the x_1-direction at which the strength of the network in that direction switches from being bending to stretching dominated. [20%]

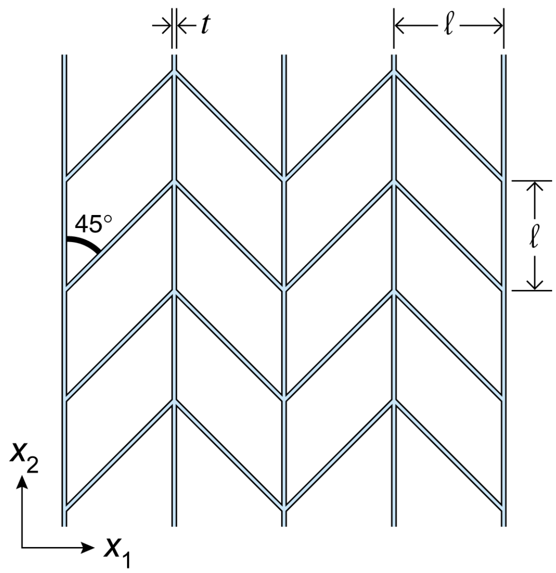

Fig. 1

3 (a) Briefly describe the main assumptions of the Huxley-sliding filament model. [30%]

(b) In the Huxley sliding filament model for a muscle, the fraction $n(x)$ of attached crossbridges is given by

$$n(x) = \begin{cases} n_0 \exp(kx/v) & x < 0 \\ n_0 & 0 \leq x \leq h \\ 0 & x > h \end{cases}$$

where n_0 and k are constants, x is the position of an actin binding site from the equlibrium position of a myosin head and $v \equiv -dx/dt$ is the velocity of the muscle. The muscle has a cross-sectional area A, sarcomere length s and m crossbridges per unit volume while the linear spring stiffness of the connection of the myosin head to the thickness filament is λ.

(i) Determine the tension-velocity relation for the muscle assuming that both the myosin and actin binding sites are spaced a distance $\ell \gg h$ apart. [40%]

(ii) Sketch the tension-velocity relation predicted by the model and discuss its agreement with the measurements under both isotonic stretching and shortening conditions. [30%]

4 (a) Briefly describe the mechanism of glucose transport across the cell membrane and in this context discuss how insulin affects the transport of glucose across the cell membrane. [30%]

(b) Almost immediately upon entering a cell, glucose is phosphorylated in the first step of glycosis. With the aid of a skectch describe how this rapid and nearly unidirectional reaction affects the flux rate of glucose across the membrane. [30%]

(c) Explain why a highly concentrated solution of sugar is able to kill bacteria but not damage a plant leaf. [20%]

(d) Explain why the cell membrane of red blood cells is highly compliant despite the fact that it is a fully triangulated network. [20%]

END OF PAPER

THIS PAGE IS BLANK