Version VSD/2

EGT3
ENGINEERING TRIPOS PART IIB

Monday 27 April 2015 9.30 to 11.00

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
Attachment: 3C7 datasheet (2 pages).
Engineering Data Book

10 minutes reading time is allowed for this paper.

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

1. (a) Explain why the effective modulus and strength of a cellular solid are sensitive to nodal connectivity but are relatively insensitive to the degree of randomness of the microstructure. [30%]

(b) The transverse microstructure for wood can be represented by a periodic assembly of square tubes and connecting plates, each of side length ℓ and thickness t, as shown in Fig. 1.

(i) Obtain an expression for the relative density $\bar{\rho}$ in terms of t and ℓ, assuming that $t/\ell \ll 1$. [20%]

(ii) The microstructure is subjected to a transverse equi-biaxial macroscopic stress $\Sigma_1 = \Sigma_2$ which is sufficiently low for the cell walls to remain elastic. Calculate the corresponding macroscopic in-plane strain components ε_1 and ε_2 in terms of $\bar{\rho}$ and Young's modulus E_s of the cell walls. [50%]

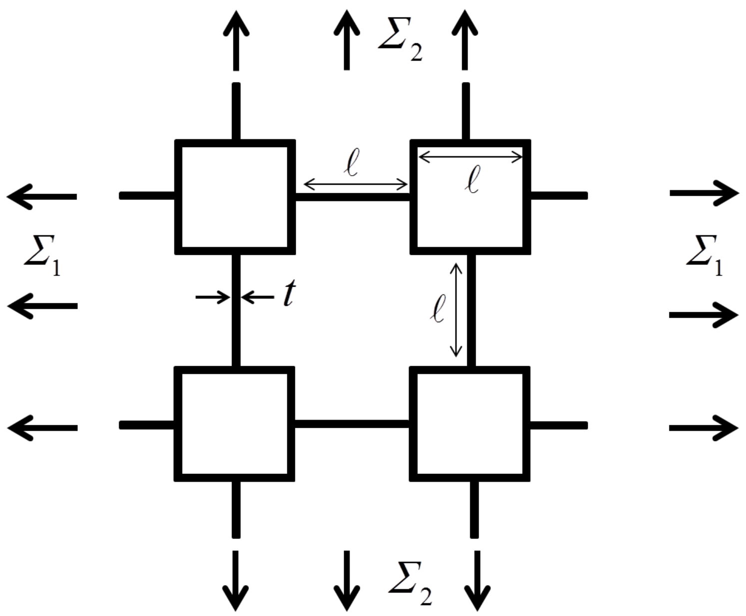

Fig. 1

2 In the Huxley crossbridge model for a muscle, $n(x)$ is the fraction of attached crossbridges, where x is the position of an actin binding site measured from the equilibrium position of a myosin head located at $x = 0$. Assume that the attachment and detachment of the crossbridges is governed by a first order kinetic scheme with attachment and detachment rate constants $f(x)$ and $g(x)$, respectively.

(a) Given that:

$$\begin{aligned} f(x) &= k_1 \qquad & h - x_0 < x < h \\ &= 0 & \text{elsewhere} \end{aligned}$$

$$\begin{aligned} g(x) &= k_2 \qquad & x < 0 \\ &= 0 & \text{elsewhere} \end{aligned}$$

determine $n(x)$ for shortening at a constant velocity $V = -dx/dt$. Here k_1, k_2, h and x_0 are constants. [50%]

(b) Briefly describe "shortening heat" in muscles and the associated Fenn effect. [20%]

(c) With the aid of a diagram, briefly describe the concepts of "unfused tetanus" and "tetanus" with reference to skeletal muscles. To which of these states does the Huxley model apply? [30%]

3 (a) Discuss the role of ATPase's in animal cells with reference to:

(i) the regulation of cell pressure [25%]

(ii) the transport of organelles within cells. [25%]

(b) Consider a large molecule with molecular weight M and diffusion coefficient D. Using scaling arguments briefly describe why $DM^{1/3}$ is approximately a constant. [40%]

(c) Why does the scaling relation specified in part (b) not apply to smaller molecules such as those of respiratory gases? [10%]

4 (a) Briefly discuss the differences between the isotonic shortening and lengthening responses of muscles. [25%]

(b) When the length of the muscle is decreased suddenly (quick-release experiment), two time constants govern the recovery of the tensile forces. Discuss the sources of these time constants with reference to cross-bridge dynamics. [40%]

(c) Explain why ion pumps are essential to maintain cell pressure in animal cells but plants cells can survive without such pumps. [20%]

(d) Briefly discuss the role of the Ca^{2+} ATPase in controlling the contraction of skeletal muscles. [15%]

END OF PAPER

Numerical answers

1. (b)(i) $\bar{\rho} = 1.5\, t/l$

   (b)(ii) $\varepsilon_1 = \frac{\Sigma_1}{E_1}$ where $E_1 = \left(\frac{2}{3}\right)^4 E_s\, \bar{\rho}^3$

2. (a)

$$n = 0 \quad x \geq h$$

$$n = 1 - \exp\left(\frac{k_1(x-h)}{v}\right) \qquad h - x_0 \leq x \leq h$$

$$n = 1 - \exp\left(\frac{k_1 x_0}{v}\right) \qquad 0 \leq x \leq h - x_0$$

$$n = \left[1 - \exp\left(\frac{k_1 x_0}{v}\right) \qquad \right] \exp\left(\frac{k_2 x}{v}\right) \qquad x \leq 0$$