ENGINEERING TRIPOS PART IIB

Monday 23 April 2012 9.00 to 10.30

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.*

Attachments:
3C7 datasheet(s) (2 pages).

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

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

vsd03

1 (a) Briefly describe *shortening heat* in muscles and the associated Fenn effect. [40%]

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

$$n(x) = \begin{cases} n_o \exp\left(\dfrac{kx}{v}\right) & x < 0 \\ n_o & 0 \le x \le h \\ 0 & x > h \end{cases} .$$

where n_o and k are constants, x is the position of an actin binding site from the equilibrium position of a myosin head and $v \equiv -\mathrm{d}x/\mathrm{d}t$ is the shortening velocity of the muscle. The muscle under consideration has a cross-sectional area A, sarcomere length s, and m crossbridges per unit volume. Assume that a linear spring with stiffness λ connects the myosin head to the thick filament.

(i) Determine the tension-velocity relation for this muscle. You may assume that the myosin sites (M) and actin sites (A) are spaced a distance $l >> h$ apart. [40%]

(ii) Sketch the tension-velocity relation determined above and briefly discuss the quality of the agreement of this model with the Hill equation. [20%]

Hint: $\int x e^{qx} \mathrm{d}x = \dfrac{1}{q^2}\left[qxe^{qx} - e^{qx} \right]$

2 (a) Physiologists have long known that muscle speed v decreases with increasing load T according to the Hill equation

$$(T+a)v = b(T_o - T)$$

where a and b are constants and T_o the isometric tetanic tension.

(i) Derive an expression for the power output of the muscle as a function of the muscle load T. [10%]

(ii) Determine the speed at which the muscle power is maximised and hence explain how you might better climb a hill on a bicycle with gears. [30%]

(b) With reference to the dual role of myoglobin as an oxygen store and an oxygen transporter, explain how the diffusion rate of oxygen is enhanced in the presence of myoglobin. [40%]

(c) Large molecules, such as glucose, must efficiently get across the plasma membrane. However, the lipid bilayer of the membrane is virtually impermeable to these molecules. Briefly describe the process that allows large molecules such as glucose to pass through the plasma membrane. [20%]

3 (a) Explain the following:

(i) the cell membrane of red blood cells has a very low elastic modulus, but a large lock-up strain and a high ultimate strength; [25%]

(ii) wood is strongly anisotropic, with a compressive strength along the grain an order of magnitude greater than that across the grain; [25%]

(iii) plant and animal cells have different strategies for harvesting energy. [25%]

(b) Describe the tension versus length curve of a single muscle fibre. Suppose that the tension decreased nonlinearly with increasing length for striation spacings greater than 2.5 μm. Would this invalidate the theory that the crossbridges working independently generate the tension? [25%]

4 The square lattice structure shown in Fig. 1 represents the two-dimensional reinforcement network surrounding a cell nucleus. The lattice is periodic and comprises squares of side l and struts of square cross-section $t \times t$. You may assume that the struts are slender such that $t \ll l$. The lattice may be assumed to be made from an elastic perfectly plastic material with Young's modulus E_S and tensile yield strength Y.

(a) Calculate the relative density $\bar{\rho}$ of the lattice in terms of t and l. [15%]

(b) Calculate the effective Young's modulus E_1 of the lattice in the x_1 direction and the corresponding Poisson's ratio ν. [30%]

(c) Calculate the tensile strength σ_{11}^{Y} in the x_1 direction and the in-plane shear strength σ_{12}^{Y} of the lattice. [40%]

(d) Typically, the struts in a biological network are tied together by elastin fibres at the nodes. Explain in qualitative terms the effect of this feature upon the values of E_1 and σ_{12}^{Y} as calculated above. [15%]

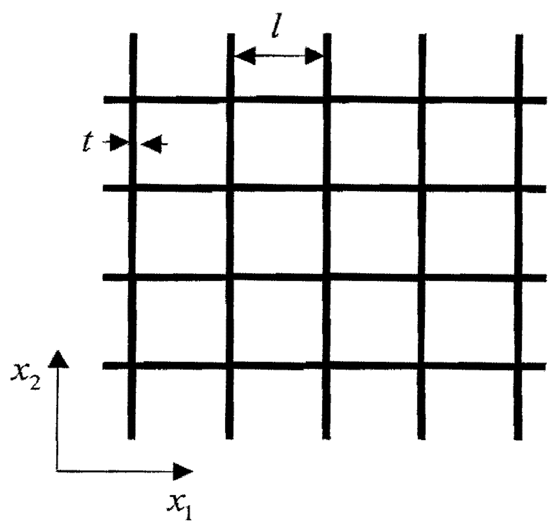

Fig. 1

END OF PAPER

Numerical answers

4. (a) $\bar{\rho} = \frac{2t}{l}$

(b) $E_1 = 0.5\bar{\rho}E_s$

(c) $\sigma_{11}^{Y} = 0.5\bar{\rho}Y$

$\sigma_{12}^{Y} = \frac{1}{16}\bar{\rho}^2 Y$