Version VSD/3

EGT3
ENGINEERING TRIPOS PART IIB

Monday 25 April 2022 9.30 to 11.10

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 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. These rate constants are given by

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

$$
\begin{aligned}
g(x) &= k_r \quad && x < 0 \\
&= 0 && \text{elsewhere,}
\end{aligned}
$$

where k_f, k_r, h and x_0 are positive constants with $x_0 < h$.

(a) Determine $n(x)$ for shortening of the muscle at a constant velocity $V \equiv -dx/dt$. [35%]

(b) Determine $n(x)$ for lengthening of the muscle at a constant velocity $V \equiv -dx/dt$. [35%]

(c) Sketch the distribution of $n(x)$ under lengthening conditions and comment on whether the assumed functions f and g are appropriate choices for modelling the lengthening behaviour of a muscle. [30%]

2 Skin can be treated as a random arrangement of long straight collagen fibres, each of circular cross-section with a radius a and axial modulus E_c. The microstructure of skin is adequately represented by a cylindrical unit cell of radius $R \gg a$ and height h with fibres distributed uniformly in the cell as shown in Fig. 1.

(a) Assuming that there are N collagen fibres in the unit cell, calculate the volume fraction f of fibres in the unit cell. [20%]

(b) We wish to calculate the shear modulus $G \equiv \tau_{xy}/\gamma_{xy}$ of skin for an applied shear stress τ_{xy} that results in a shear strain γ_{xy}. The Cartesian co-ordinate system with respect to the unit cell is defined in Fig. 1.

(i) Using Mohr's circle or otherwise calculate the axial extension e in terms of γ_{xy} in a collagen fibre oriented at angle θ with respect to the x axis. [20%]

(ii) Using virtual work or otherwise, calculate the shear modulus G in terms of E_c and f. Hint:

$$\int_0^{\pi/2} \sin^2 2\theta d\theta = \frac{\pi}{2}.$$

[50%]

(iii) Briefly discuss the effect of waviness within the collagen fibres on the above estimate of the shear modulus. [10%]

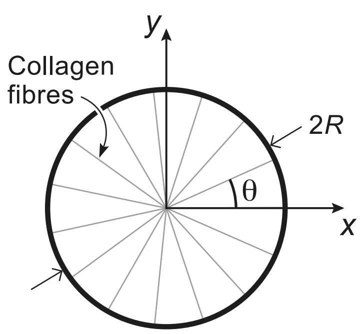

Fig. 1

3 (a) A muscle held under isometric conditions is subjected to a step change (contraction) in its length.

(i) With reference to the Huxley-Simmons model describe the process by which there is a rapid tension recovery. [30%]

(ii) Discuss in the context of the Huxley sliding filament model, the mechanism of slower tension recovery which ultimately brings the tension back to its isometric value. [25%]

(iii) Discuss the limitations of the above models for a large step change in the length of the muscle. [20%]

(b) Making reference to the role of Ca^{2+} in the activation of skeletal muscles, explain the phenomenon known as *rigor mortis*. [25%]

4 (a) Large molecules, such as glucose, must efficiently cross the cell membrane. However, the lipid bilayer of the membrane is impermeable to such molecules.

(i) Briefly describe the passive process that allows such large molecules to pass through the membrane. [20%]

(ii) Almost immediately upon entering a cell, glucose is consumed in the first step of glycolysis. Using sketches of the flux rate across the membrane as a function of the external glucose concentration explain how glycolysis affects the flux rate of glucose across the cell membrane. [30%]

(b) Explain why the cell membrane of red blood cells has a very low elastic modulus but a large strain to failure and high ultimate tensile strength. [25%]

(c) Explain why highly concentrated sugar solution is able to kill an earthworm but does not affect a plant leaf similarly. [25%]

END OF PAPER