Version NAF/4

EGT3
ENGINEERING TRIPOS PART IIB

Friday 5 May 2023 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.

(a) Determine the steady-state $n(x)$ in terms of $f(x)$ and $g(x)$ for a muscle in isometric tension. [20%]

(b) Determine $n(x)$ for shortening at a velocity $V = -dx/dt$ given that

$$\begin{aligned} f(x) &= 0; \quad g(x) = g_1; \quad x < 0; \\ f(x) &= f_0; \quad g(x) = g_0; \quad 0 \le x \le h; \\ f(x) &= 0; \quad g(x) = g_0; \quad x > h, \end{aligned}$$

where g_1, g_0, f_0 and h are constants. [50%]

(c) Explain, using equations as appropriate, how one might use the Huxley crossbridge dynamics model to calculate the response of a muscle in Hill's quick-release experiment (step change in tension). [30%]

2 The square lattice shown in Fig. 1 is a good representation of the reinforcement network sourounding the cell nucleus. The periodic lattice comprises squares of size L and struts of cross-section $t \times t$. The parent material of the lattice is a solid 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) Determine the effective Young's modulus E_1 of the lattice in the x_1 direction in terms of $\bar{\rho}$. [30%]

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

(d) In reality the struts in this biological network are not perfectly bonded but tied together by elastic fibres at the nodes. Discuss the effect of this on the values of E_1 and σ_{12}^Y calculated above. [15%]

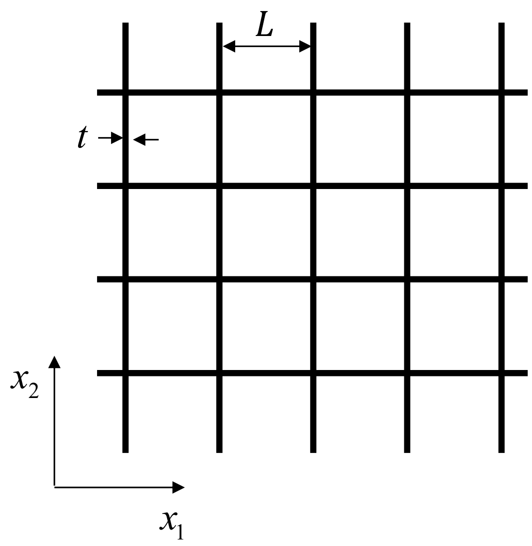

Fig. 1

3 Consider the muscle model sketched in Fig. 2. The model comprises a dashpot, a spring and an active force generating element. The dashpot has a force F versus velocity v (v is positive for extension of the dashpot) relation $F = \eta v$, while the spring is assumed to be linear with a spring constant k . The muscle is always held under isometric conditions and at time $t < 0$ all elements of the model are unstressed. At time $t = 0$ the force generating element is activated such that it exerts a constant contractile force T_0 for all times $t > 0$ while the muscle still remains under isometric conditions.

(a) Derive the governing differential equation for the isometric response of the muscle in terms of the change in length x of the spring element. [20%]

(b) Determine the force T versus time t response of the muscle for all times $t > 0$. [30%]

(c) Sketch the force T versus time t response derived in part (b) and discuss whether the model is appropriate for predicting the isometric response of a muscle. [20%]

(d) 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%]

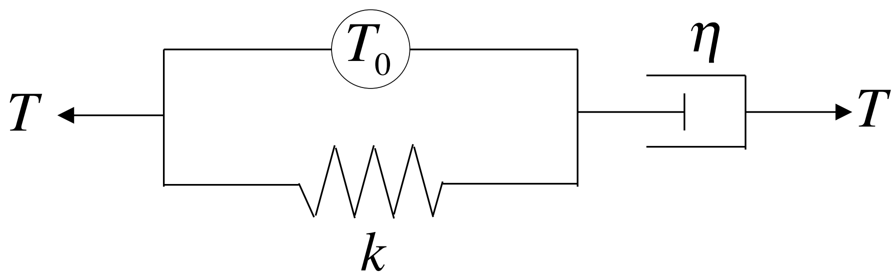

Fig. 2

4 (a) Explain why a highly concentrated solution of sugar or salt is able to kill bacteria but not affect a plant leaf. [15%]

(b) Explain why skin which comprises a network of collagen fibres has a modulus that is several orders of magnitude lower than that of collagen. [25%]

(c) 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. [35%]

(d) Almost immediately upon entering a cell, glucose is phosphorylated in the first step of glycosis. With the aid of a diagram explain how this rapid and nearly unidirectional reaction affects the flux rate of glucose across the membrane. [25%]

END OF PAPER

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