EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 1 May 2019 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.

1 (a) It is commonly accepted that the shortening velocity v of a muscle is related to the tension T via the Hill relation

$$(T+a)v = b(T_0 - T),$$

where a and b are constants and T_0 is the isometric tension. Derive an expression for the velocity at which the power output of the muscle is maximised. Discuss the implications for the selection of suitable gear ratios by a cyclist in a race. [50%]

(b) Explain the physical basis for the "persistence length" in a biological fibre, and give examples where the structural length scale is much greater and much less than the persistence length. [30%]

(c) Why is the cell wall dominant in dictating the mechanical properties of plant cells whereas the cytoskeleton dictates the response of animal cells? [20%]

2 Strands of the protein spectrin form a fully triangulated, periodic 2D network on the surface of a red blood cell as sketched in Fig. 1. Strands of spectrin have a Young's modulus E_s and can be idealised to have a circular cross-section of diameter d. Each strut in the triangulated network has length ℓ as shown in Fig. 1.

(a) A representative strand can be treated as a wavy beam with an initial waviness described by a sine wave of amplitude a and wavelngth λ as shown in the inset of Fig. 1. Calculate the effective axial stiffness k of the beam defined as the ratio of the axial force to the axial extensional strain. [30%]

(b) A macroscopic normal stress Σ_{11} is applied in the x_1-direction to the network. Using method of sections or otherwise, relate Σ_{11} to the tensions in the struts labelled A through F in Fig. 1. [30%]

(c) Obtain an expression for the macroscopic modulus E_1 of the network of wavy struts in the x_1-direction. [40%]

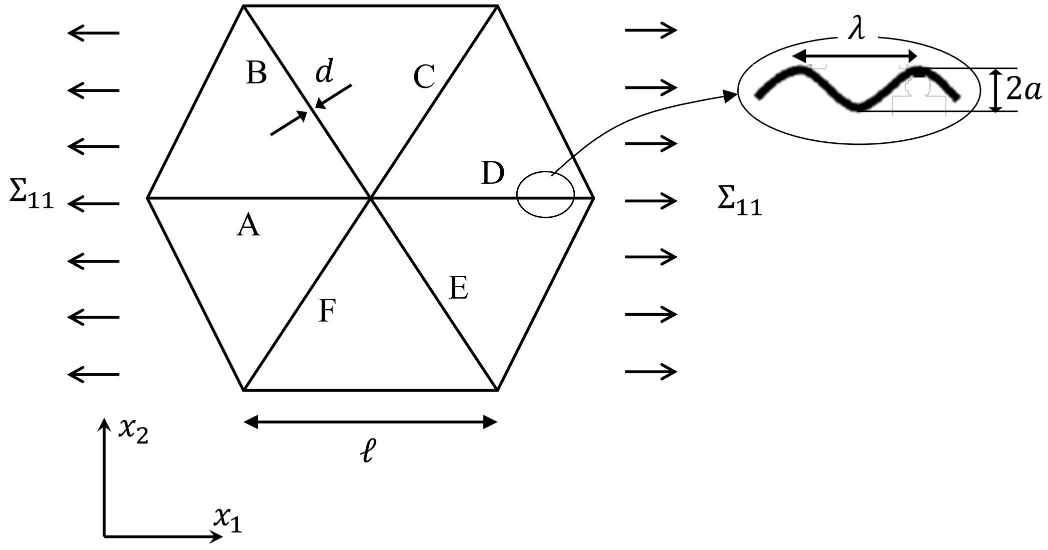

Fig. 1

3 Consider the three element muscle model sketched in Fig. 2a that comprises a dashpot, spring and an active force generating element. The dashpot has a force F versus velocity v relation $F = Bv$, while the spring is assumed to be linear with a spring constant k. The muscle is held under isometric conditions, and at time $t = 0$ all elements of the model are unstressed. Two stimuli are applied to the muscle and the force generator develops a maximum tension T_0 according to the schedule sketched in Fig. 2b.

(a) Determine the tension T as a function of time t for $0 \leq t \leq C$ and hence determine the maximum tension T_1 developed by the muscle for $t \leq C$. [20%]

(b) Using your answer in (a) extend the solution for T as a function of time over the range $0 \leq t \leq C+A$. [30%]

(c) Employing linear superposition determine the tension developed by the muscle over the range $C+A \leq t \leq 2C+A$ and hence calculate the maximum tension T_2 developed by the muscle after the application of the second stimulus. [40%]

(d) Briefly discuss whether such a model is expected to qualitatively predict the differences in tension due to a single twitch versus the tetanic tension developed in a muscle. [10%]

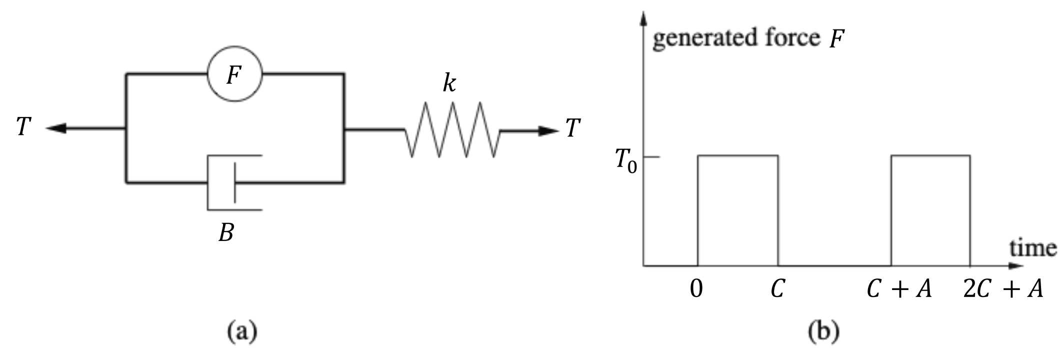

Fig. 2

4 (a) 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%]

(b) 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%]

(c) (i) Briefly describe the working of the sodium-potassium pump in animal cells. [20%]

(ii) How does the concentration of ATP affect the rate of the sodium-potassium pump? [20%]

END OF PAPER

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