ENGINEERING TRIPOS PART IIB
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Friday 5 May 2006 2.30 to 4

Module 4C14

MECHANICS OF BIOLOGICAL SYSTEMS

*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.*

There are no attachments.

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

1 (a) With the aid of a sketch, briefly describe the concepts of "twitch", "unfused tetanus" and "tetanus" for skeletal muscle. [25%]

(b) Sketch a typical passive and tetanized tension versus length relationship of a skeletal muscle. Briefly discuss the reasons for the local maximum in the tetanized tension versus length curve. [25%]

(c) Explain the composition and functions of the cell wall in animal cells and plant cells. [25%]

(d) Sketch and label the cycle of pressure versus volume for the heart over a heartbeat cycle. With reference to this sketch derive an expression for the *stroke volume.* [25%]

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 from the equilibrium position of a myosin head. Assume that attachment and detachment of the crossbridges are governed by a first order kinetic scheme, with attachment and detachment constants $f(x)$ and $g(x)$, respectively.

(a) Given that:

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

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

determine $n(x)$ for shortening at a constant velocity $V = -\mathrm{d}x/\mathrm{d}t$. Here, k_1, k_2, h and x_0 are constants. [60%]

(b) Briefly describe "shortening heat" in muscles and the associated Fenn effect. [40%]

3 Strands of spectrin form a fully-triangulated, periodic 2D network on the surface of a red blood cell, as idealised in Fig. 1. The network can be treated as a periodic assembly of elastic struts made from a solid of Young's modulus E_S. The struts have a length l and a circular cross-section of diameter d.

(a) A representative strand can be treated as a wavy beam, made from a solid of axial modulus E. The beam has an initial waviness described by a sine wave of wavelength λ and amplitude a, as shown by the insert of Fig. 1. Calculate the effective axial stiffness of the beam k as defined by the ratio of axial force P to extensional strain e. [30%]

(b) Apply the method of sections to relate the applied normal stress Σ_{11} in the x_1-direction to the tensions in the bars A to F as labelled in Fig. 1. [30%]

(c) Hence obtain an expression for the macroscopic modulus E_1 in the x_1-direction. [40%]

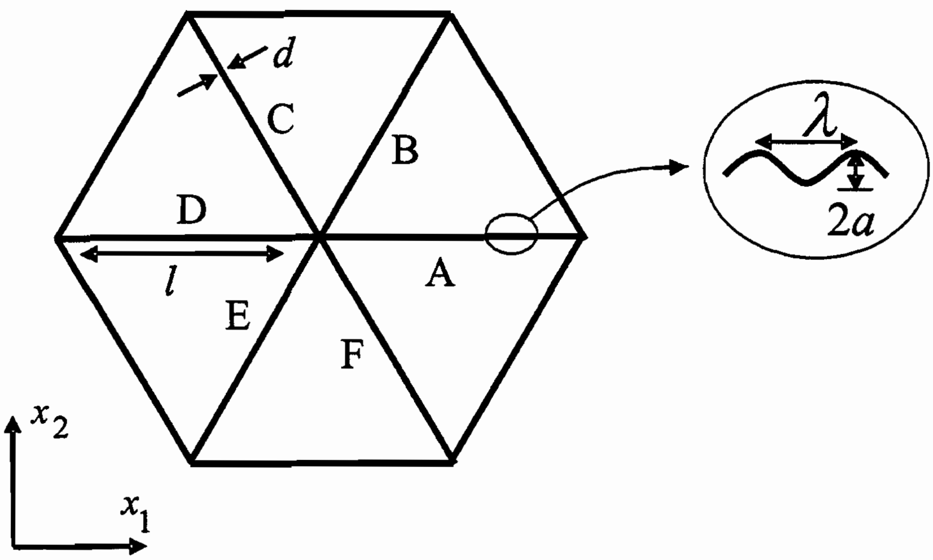

Fig. 1

(TURN OVER

4 (a) Describe the two sides of the blood circulatory system in the body, and the changes of blood composition during circulation. Define systolic pressure and diastolic pressure. [20%]

(b) Explain why it is the veins, not the arteries, which are often called the storage area of blood. [15%]

(c) When leaving the lungs, blood is 97% saturated with oxygen. Explain how this is achieved. [15%]

(d) A simple model of capillary-alveolar transport gives the following concentration U of a gas dissolved in blood:

$$U(x) = \sigma P_g + \sigma(P_0 - P_g)\exp(-Dx/v)$$

where x is the axial coordinate along the capillary, P_g is the partial pressure of the gas in the alveolar space (which may be taken as a constant), P_0 is the partial pressure at $x = 0$, σ is the solubility of the gas, D is the membrane exchange rate, and v is the blood flow velocity.

(i) Calculate the flux of gas through the walls of the capillary of length L and constant cross-sectional area A. [10%]

(ii) By considering the effects of blood chemistry, explain briefly why the above model for capillary-alveolar transport can be improved upon, for both the removal of carbon dioxide and the uptake of oxygen. [40%]

END OF PAPER