4G6 – 2015

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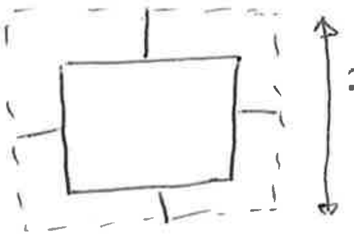
1 (a) Nodal connectivity governs whether a micro-structure is bending or stretching governed & thus controls the scaling of strength & stiffness with relative density. On the other hand randomness does not affect the deformation model.

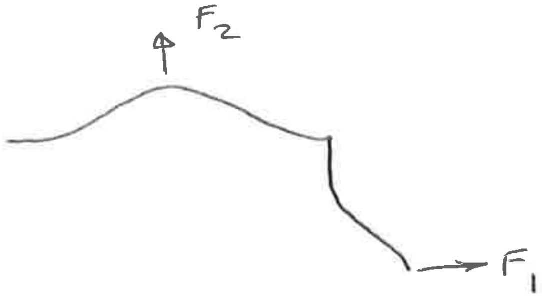
(b) (i) $\bar{\rho} = ?$



$$\bar{\rho} = \frac{2\ell t + 4\ell t}{(2\ell)^2}$$

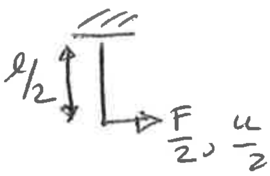
$$= \frac{3}{2}\frac{t}{\ell}$$

(ii)



$$F_1 = \Sigma_1 2\ell$$

$$F_2 = \Sigma_2 2\ell$$



$$\frac{u}{2} = \frac{\left(\frac{F}{2}\right)\left(\frac{\ell}{2}\right)^3}{3 E_s I}, \quad I = \frac{t^3}{12}$$

$$= \frac{F}{16}\frac{12\ell^3}{3E_s t^3} = \frac{3}{4}\frac{F\ell^3}{E_s t^3}$$

$$u = \frac{3}{2} \frac{F l^3}{E_s t^3}$$

$$\Sigma_1 = \frac{F_1}{2l} , \quad \varepsilon_1 = \frac{u_1}{l}$$

$$E_1 = E_2 = \frac{F_1}{2l} \frac{l}{u_1} = \frac{2}{3} E_s \left(\frac{t}{l}\right)^3$$

$$= \frac{2}{3} E_s \left(\frac{2}{3} \bar{\rho}\right)^3$$

$$= \left(\frac{2}{3}\right)^4 E_s \bar{\rho}^3$$

$$\varepsilon_1 = \varepsilon_2 = \frac{\Sigma_1}{E_1}$$

2

(a) $$v \frac{dn}{dx} = (1-n)f - ng$$

$x \geq h$

$$f = g = 0 \Rightarrow n(x) = n(h) = 0$$

$h - x_0 \leq x \leq h$

$$-v \frac{dn}{dx} = (1-n) k_1$$

with $n(h) = 0$

$$n = 1 - e^{\frac{k_1 (x-h)}{v}}$$

$0 \leq x \leq h - x_0$

$$f \,\&\, g = 0 \Rightarrow \quad n(x) = n(h - x_0) = n(0) = 1 - e^{-\frac{k_1 x_0}{v}}$$

$x \leq 0$

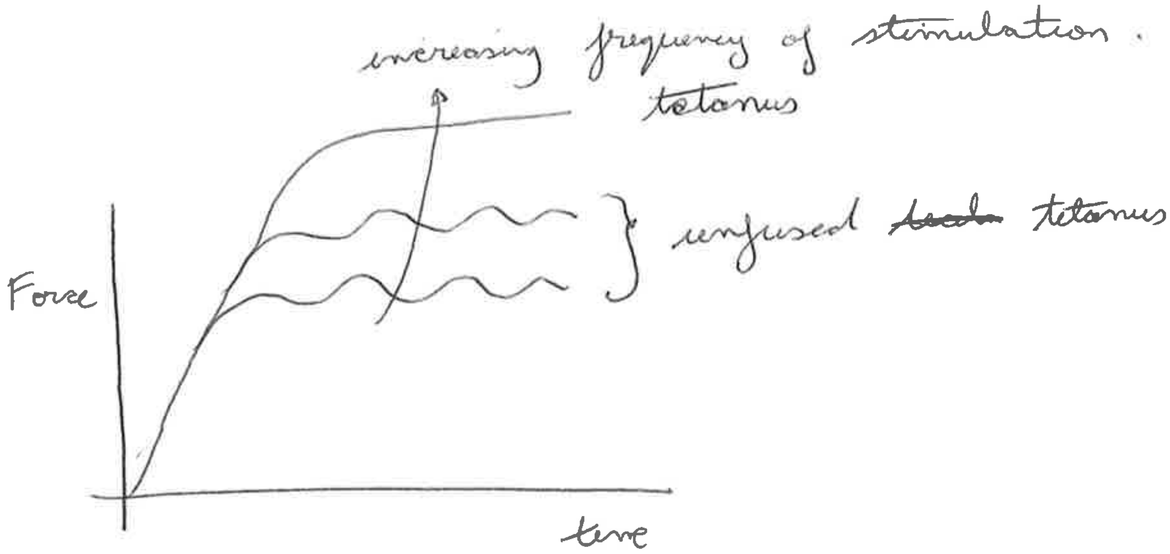
$$-v \frac{dn}{dx} = -k_2 n$$

$$n(0) = 1 - e^{-\frac{k_1 x_0}{v}}$$

$$n = \left(1 - e^{-\frac{k_1 x_0}{v}}\right) e^{\frac{k_2 x}{v}} .$$

(b) Shortening heat is the additional heat released by a muscle when shortening compared to under isometric conditions.

(c)



Huxley model applies to ~~the~~ tetanus.

3(a)

(i) Animal cells have a semi-permeable cell membrane with concentrations of certain ions eg Na^+, K^+ that is different from the environment. This creates an osmotic pressure & ~~[illegible]~~ protein pump on the cell membrane help regulate this pressure.

(ii) Proteins & organelles are synthesised near the nucleus of the cell & are transported by motor proteins such as kinesins to different parts of the cell.

(b) Einstein formula $D = \dfrac{kT}{6\pi\eta a}$

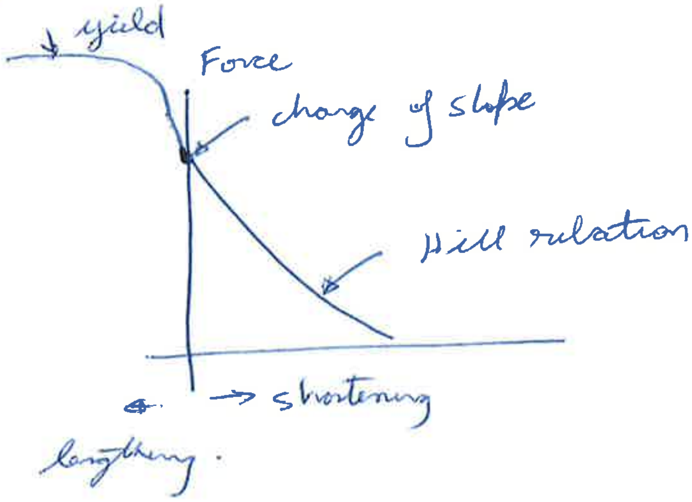
$$M = \frac{4}{3}\pi a^3 \rho$$

$$\Rightarrow D = \frac{kT}{3\eta}\left(\frac{\rho}{6\pi^2 M}\right)^{1/3}$$

$$\Rightarrow DM^{1/3} = \text{constant}$$

(c) The Einstein formula is based on a calculation of ~~a~~ the drag force on a sphere in a liquid using a continuum assumption. When the solute molecules are of comparable size to that of the liquid this assumption fails.

4(a) Under isotonic shortening the force decreases with increasing contractile velocity but under isotonic lengthing the force initially rises & then plateus out.



(b) The long time constant is governed by cross-bridge dynamics as described by the Huxley model. The short time constant is governed by the bound myosin head dynamics as described by the Huxley - Simmons model.

(c) Plant cells have a cell wall that is strong & helps build turgour pressure to balance the osmotic pressure while no cell wall in animal cells implies the cell wall can burst under osmotic pressure & requires ion pumps to maintain the pressure.

(d) Ca^{2+} initiates a process in which the troponin draws the tropomyosin chain aside & desmasks the actin binding sites & permits the cross-bridge cycling process to commence.

Comments on questions

Q1 Modulus of a cellular solid

A question that was well-attempted. Most students explained the role of connectivity well and calculated the relative density correctly. Only a small fraction of the students were able to correctly calculate the biaxial modulus.

Q2 Huxley cross-bridge model

Generally the students had no problems with this question with some candidates making errors in the boundary conditions for the Huxley differential equations. Candidates attempted the qualitative parts of the question well.

Q3 Qualitative question on cellular transport

The most unpopular question. Students generally did not explain the role of ATPases controlling cell pressure in animal cells well.

Q4 Qualitative question on muscles and ion pumps

Generally well attempted other than part (c). In part (c) only a handful of candidates connected the question to turgor pressure.