496/2024

Q1

(a) The cytoskeleton is the internal skeleton of the cell comprising 3 types of proteins. The microtubules are stiff hollow tubes made from the protein tubulin, with a persistence length of 3 mm. They emanate from the centrosome & molecular motors (dyenins & kinesins) transport their cargo of proteins to various parts of the cytoplasm.

The actin cortex sits mainly near the plasma membrane & forms a 2D network, providing support for the membrane.

Intermediate filaments are passive rope-like filaments of keratin for example. They anchor to cell junctions, and link adjacent cells together.

(b) The sarcomere is made up primarily of two types of parallel filaments designated thin & thick filaments. Viewed end on, 6 thin filaments are positioned around each central thick filament in an hexagonal

arrangement. Viewed end-on 6 thin filaments are positioned around each thick filament again on an hexagonal arrangement. Viewed along its length, there are regions where thin or thick filaments are overlapping or non-overlapping. At the end of the sarcomere is a region called the Z-line (or disc) where the thin filaments are anchored.

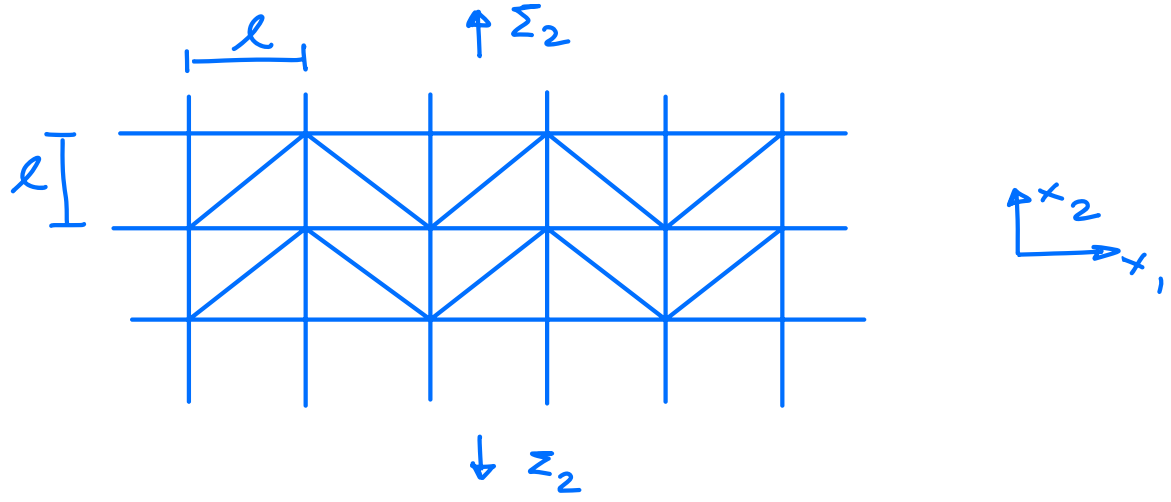
Thick filaments contain the protein myosin while thin filaments contain actin, tropomyosin & troponin. The actin & myosin together form the contractile machinery while tropomyosin acts as a mask for the actin binding sites.

(c) The persistence length $\zeta = D/kT$ is the length along a molecule at which directional correlation is lost. D = bending stiffness, k = Boltzmann's constant, T = temperature. When the contour length L of a molecule $>> \zeta$ the fibre

behaves in an entropic, rubber-like manner.
When $L << \xi$, the fibre behaves as a stiff deterministic fibre.

(d) Transport of proteins via motor proteins is an active transport mechanism that can be many orders of magnitude faster than diffusion. For example, kinesin motor proteins traverse along microtubules carrying cargo.

Q2



(a) $$\bar{\rho} = \frac{(1+\sqrt{2})tl}{l^2} = (1+\sqrt{2})\frac{t}{l}$$

(b) Wall stress $$\sigma_2 = \frac{\Sigma_2 l}{t}$$

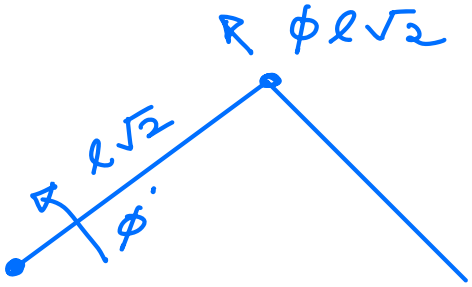
$$\varepsilon_2 = \frac{\sigma_2}{E_s}$$

$$\Rightarrow E_2 = \frac{\Sigma_2}{\varepsilon_2} = \frac{t}{l}\frac{\sigma_2}{\varepsilon_2} = E_s\frac{t}{l}$$

$$\frac{E_2}{E_s} = \frac{\bar{\rho}}{1+\sqrt{2}}$$

$$\sigma_2^{Y} = \frac{t}{l}\sigma_s = \frac{\sigma_s\,\bar{\rho}}{1+\sqrt{2}}$$

(c)



$$\dot{\varepsilon}_1 = \frac{\dot{\phi}\ell}{\ell} = \dot{\phi}$$

$$\sigma_1^Y \ell (\dot{\varepsilon}_1 \ell) = 2 M_p \dot{\phi} \quad \therefore \; M_p = \frac{1}{4}\sigma_s t^2$$

$$\sigma_1^Y = \frac{1}{2}\left(\frac{t}{\ell}\right)^2 \sigma_s = \frac{1}{2}\left(\frac{\bar{P}}{1+\sqrt{2}}\right)^2 \sigma_s$$

(d)

St becomes stretching dominated when inclined struts become horizontal

$$\Rightarrow \varepsilon_1^d = \frac{\sqrt{2}\ell - \ell}{\ell} = \sqrt{2} - 1$$

$$= 41\%$$

Q3

(a) The main assumptions in the Huxley sliding filament model are

- passive elastic elements of muscle neglected
- population of crossbridges taking part is fixed so only applicable on plateau of tension - length curve
- The muscle is fully activated
- The velocity is constant
- Each crossbridge which is attached goes through a full cycle of force development, detachment & ATP splitting.

(b)

(i) The number of crossbridges in $\frac{1}{2}$ a sarcomere = $\frac{mAS}{2}$. Allow the sarcomer to change length by l. Since $l >> h$ all crossbridges have an opportunity to go through one cycle. Let T be force per

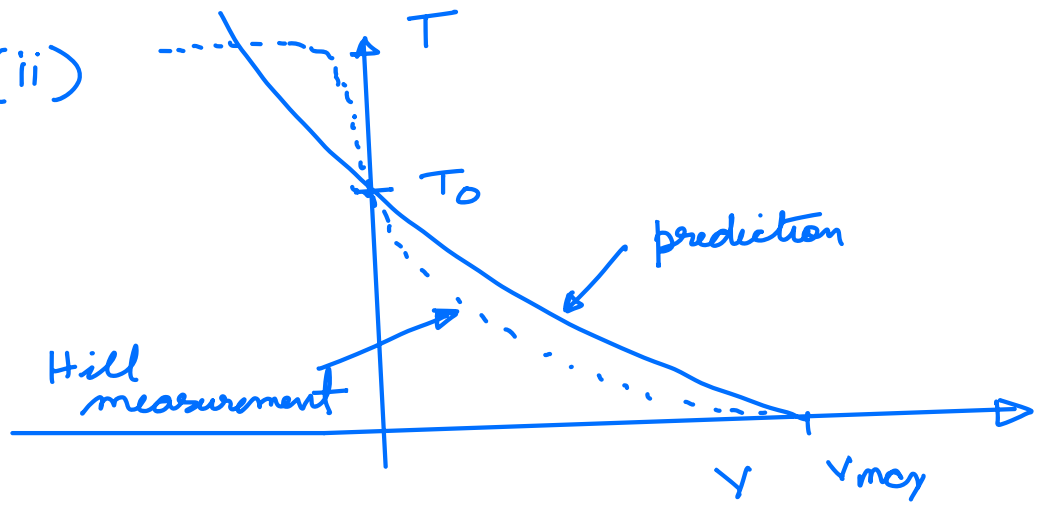
unit cross-section $\Rightarrow$ work done is

$$Tl\,A = \int_{-\infty}^{\infty} \left(n(x)\, \frac{m A s}{2} \right) x\, \lambda\, dx$$

$$T = \frac{m s \lambda}{2l} \left[\int_{-\infty}^{0} n_0 e^{\frac{kx}{v}} x\, dx + \int_{0}^{h} n_0 x\, dx \right]$$

$$T = \frac{n_0 s \lambda m}{2l} \left[\frac{h^2}{2} - \frac{v^2}{k^2} \right]$$

(ii)



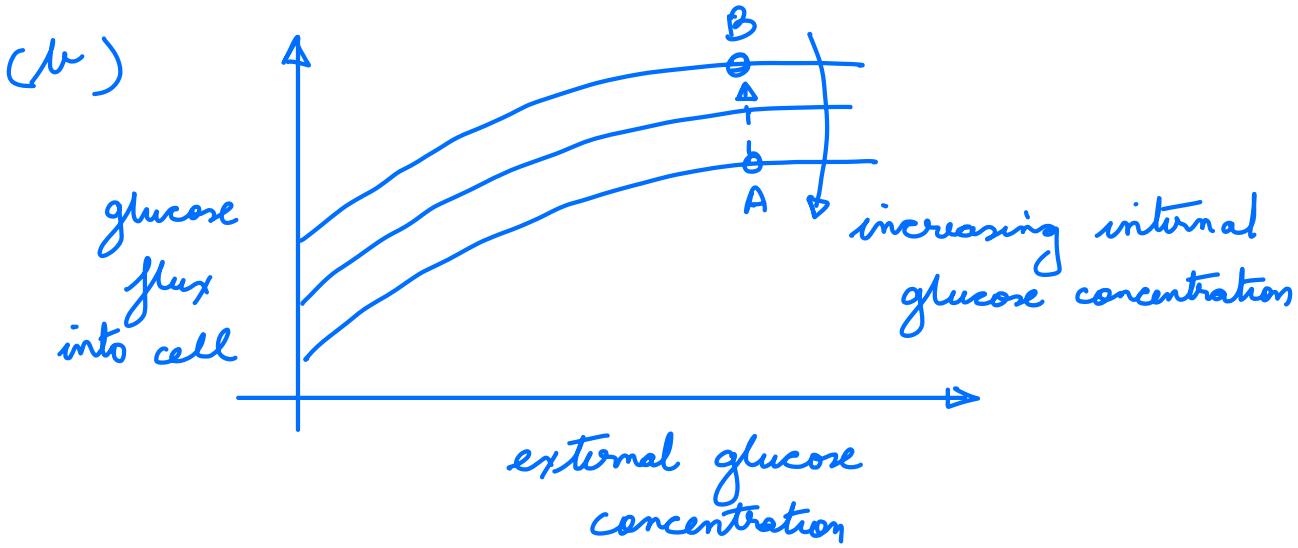
For shortening the model is in reasonable agreement although model is quadratic in v while Hill is hyperbolic. In stretching there

is significant disagreement as seen in sketch including the change in slope at $V=0$ & the yielding behaviour.

Q4

(a) Glucose transport across the cell membrane occurs by carrier mediated transport via uniports. The carrier molecule alternatively exposes its binding site first on one side & then the other side of the membrane capturing & releasing glucose. Insulin affects the binding affinity of the glucose to the carrier thus controls the flux of glucose

(b)

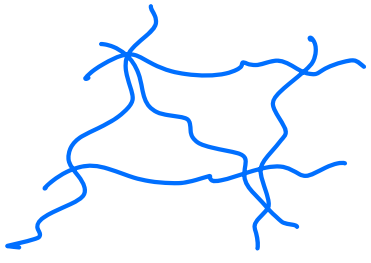


The phosphorylation of glucose decreases the internal concentration of glucose & thereby the operating

point moves from A → B on the above graph. This increases the flux of glucose into the cell.

(c) Animal (bacteria) cells only have a semi-permeable cell membrane. When placed in a highly concentrated sugar solution osmosis drives the pressure inside the cell up & results in the bursting of the cell. Plant cells (leaf) have a strong cellulose cell wall that can sustain the osmotic pressure & prevents the bursting of the cell.

(d) The cell membrane of red blood cells comprises a triangulated network of spectrin



However, the spectrin fibres are weary & thus

even though the triangulated topology is stretching governed, the wavy fibres deform by bending & hence the cell membrane of red blood cells is very compliant.