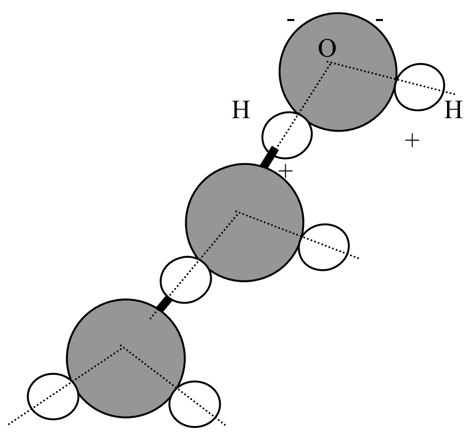
Answers

Question 1 (10 marks)

(a)



In water molecule the two hydrogens are placed at angle of ~105°. The molecule is slightly polar, with charge distribution as shown in the diagram. The positive charges near the hydrogen atoms are attracted to negative charges on the oxygen molecules, forming hydrogen bonds (black lines). Many different combinations are possible. The diagram above is just one example.

Some life-supporting properties:

The hydrogen bonding results in high specific heat and high latent heat of vaporization. Thus presence of water in an organism stabilizes its temperature and provides cooling by evaporation in high outside temperatures.

Polar nature of water makes it a good solvent for ionic solutes, which are important for living organisms.

The tensile strength of water is high, making it possible for columns of water to assent to the top of high trees.

(b) Work is zero for moving molecules in the bulk of liquid. At water/air interface there is an attractive force pulling molecules into the liquid. Energy is needed to create new surface against this force. Surface tension γ is defined as ratio of energy input ΔE needed to create new surface ΔA.

$$\gamma = \frac{\Delta E}{\Delta A}$$

Pure water has a high surface tension. The addition of detergent lowers γ. So, for the same amount of energy input (shaking), large ΔA can be created: stable bubbles.

(c) The cell was exposed to sucrose solution with water potential much less than the water potential of the cell. Water flowed out of the cell, making the turgor pressure = 0. However, the outflow continued, detaching the membrane from the wall. The inward collapse stopped, when the pressure difference between inside and outside just balanced the membrane surface tension, as described by Young-Laplace equation.

Taking membrane as single surface

$$\Delta P = \frac{2\gamma}{r} = \frac{2x5x10^{-3}}{20x10^{-6}} = 0.5x10^{3}Pa$$

This pressure is not related to turgor, as there is no cell wall.

Question 2

(a) (i) assuming laminar flow, use Poiseuille's equation:

$$Q = \frac{\pi \Delta P a^4}{8\eta\ell} = \frac{3.1416 \times 134 \times (8 \times 10^{-3})^4}{8 \times 18 \times 10^{-6} \times 20 \times 10^{-2}} = \frac{172.4}{2880} = 0.06 m^3/s$$

(ii) To calculate the Reynolds number, we need the average velocity of air in the windpipe:

$$v = \frac{Q}{\pi r^2} = \frac{0.06}{3.1416 \times 8^2 \times 10^{-6}} = \frac{8.04}{18} = 298 m/s$$

This seems impossibly large and will give us large Reynold number:

(iii) $N_R = \frac{\rho v d}{\eta} = \frac{1.3 \times 298 \times 16 \times 10^{-3}}{18 \times 10^{-6}} = 344 \times 10^3$

This is well over the limit of 2500 for onset of turbulence! This explains why the velocity is impossibly high: Poiseuille's equation does not hold. The resistance to flow will be large making the actual Q much lower for the given pressure difference.

(b) $\eta = \frac{F/A}{dv/dx}$

where F/A is applied force per area A, v is velocity and x is a spatial dimension, dv/dx is a velocity gradient.

Newtonian fluids have a constant η, regardless of shear stress applied, while in non-newtonian fluids, η is variable with velocity gradient.

The fluid described in the graph, shows little increase in velocity gradient until the shear stress reaches some threshold magnitude. The viscosity then decreases with velocity gradient. The fluid is probably composed from large molecules or particles. A certain level of stress is needed to initiate flow. As the velocity gradient increases, the molecules/particles align to the flow gradient and the viscosity decreases. This is called thixotropy.

Question 3

(a) (i) For the plant cell to be in equilibrium with the outside medium, its water potential must be equal to that of the medium, so there must be turgor pressure.

The water potential equation:

$$\Psi = P - \pi$$

$$\pi = RTc$$

c molar concentration (gram mole/litre)

P turgor pressure in MPa

$\Psi_{cell} = \Psi_{medium} = -RTc_{medium} = -0.0083143 \times 300 \times 0.002 = -0.005$ MPa

remember that both K^+ and Cl^- contribute to the osmotic pressure

$\Psi_{cell} = -0.005 = P - RTc_{cell} = P - 0.0083143 \times 300 \times .12 = P - 0.299$

$P = 0.299 - 0.005 = 0.294$ MPa

(ii) In equilibrium the total chemical potentials inside and outside the cell must be equal:

$$\tilde{\mu}_{cell} = \tilde{\mu}_{medium}$$

$$\mu_{0cell} + RT\ln c_{cell}^{K} + z_K F\phi_{cell}^{K} + P_{cell}\overline{V} + Mgh_{cell} = \mu_{0medium} + RT\ln c_{medium}^{K} + z_K F\phi_{medium}^{K} + P_{medium}\overline{V} + Mgh_{medium}$$

For a small cell the Mgh term can be neglected and μ_0 terms cancel. The only ion which contributes to the concentrations and trans-membrane potential difference is the K^+. $z_K = 1.0$

$$(\phi_{cell}^{K} - \phi_{medium}^{K}) = \frac{RT}{F}(\ln c_{medium}^{K} - \ln c_{cell}^{K}) + \frac{\overline{V}}{F}(P_{medium} - P_{cell})$$

$$= \frac{8.314 \times 300}{9.65 \times 10^4}\ln\left[\frac{c_{medium}^{K}}{c_{cell}^{K}}\right] + \frac{18 \times 10^{-6}}{9.65 \times 10^4}(-0.294 \times 10^6)$$

$$= -105.6 \times 10^{-3} - 0.05 \times 10^{-3} = -106\text{mV}$$

Note that $R = 8.3143$ $J.mol^{-1}.K^{-1}$ is used in the total chemical potential equation.

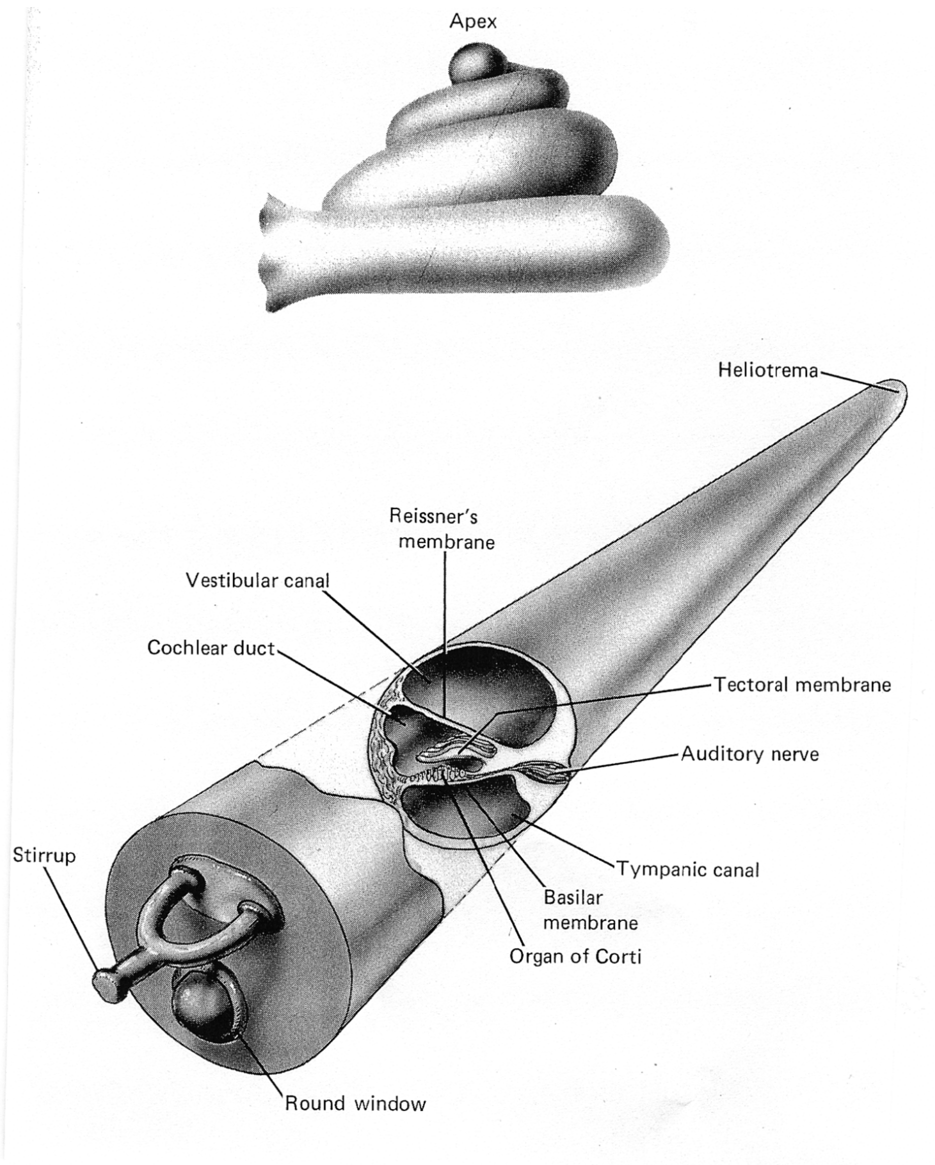
(b) using equation for characteristic diffusion time

$$t = \frac{x^2}{4D}$$

$$D = \frac{x^2}{4t} = \frac{(10^{-2})^2}{4 \times 6 \times 60 \times 60} = \frac{10^{-4}}{86400} = 1.2 \times 10^{-9} m^2.s^{-1}$$

Question 4

(a)

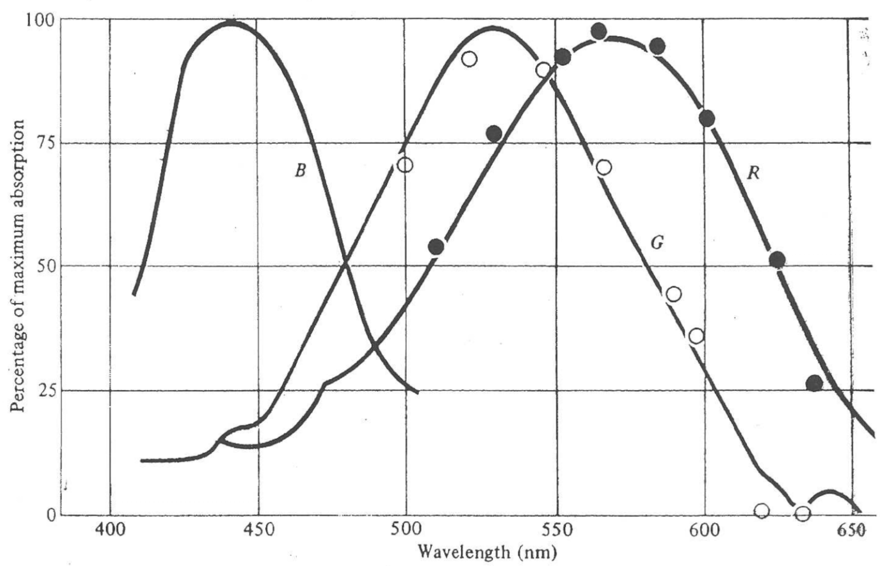


Vibration caused by the stirrup on the oval window cause waves on the basilar membrane. The high frequencies vibrate the cochlea near the oval window, the low frequencies near the helicotrema. The vibration sets off action potentials along the nerves into the brain. The brain relates the perceived pitch (frequency) to the excited place on the cochlea. This is called the place theory of pitch. However, the resolution of the ear seems too good to explain by this mechanism, so the frequency of the action potentials is thought to be correlated to the frequency of perceived sound (rate theory of pitch). However, the action potentials cannot repeat fast enough at the high end of the perceived frequency range. Thus the perception must be achieved by the combination of the two mechanisms.

(b) (i) The 100% saturated spectral colours are found on the tong-shaped curve in the diagram. Hue changes from blue and violet at 400 nm through to green at 500 nm to red at 700 nm. Mixture of all colours produces white light at point C. Non spectral colours are mixtures of red and blue (contained in triangle defined be 400 nm, C and 700 nm). Drawing a line from a saturated colour to C shows de-saturation. The triangle drawn with blue, green and red at the vertices contains greatest range of colors.

(ii) The cone cells at the retina contain red, green and blue wavelengths sensitive pigments.

The percentage of maximum absorption versus wavelength for each of three cone pigments. The curves are the results of measurements on single cones taken from human and monkey retinas. The open and filled circles are data obtained by studies of the absorption of light in the living human eye. (Adapted from W. A. H. Rushton, Visual Pigments and Color Blindness, *Scientific American*, vol. 232, March 1975.)



The cone sensitivity peaks at particular wavelengths and drops off on both sides. Consequently the flashes of light of same intensity will appear less bright at wavelengths, where the cones are less sensitive.