THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

EXAMINATION – OCTOBER 2008

PHYS 2410
INTRODUCTORY BIOPHYSICS

Time Allowed – 2 hours

Total Number of Questions – 8

Answer **ANY FIVE** questions

The questions are of equal value

Please, write answers to questions 1 - 4 and 5 - 8 in separate books.

This paper may be retained by the candidate

Candidates may not bring their own calculators

The following materials will be provided by the

Enrolments and Assessment Section: Calculators

All answers must be written in ink. Except where they

are expressly required, pencils may be used

only for drawing, sketching or graphical work.

$$F = 2\gamma L$$

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

$$P_i - P_o = \frac{2\gamma}{r}$$

$$h = \frac{2\gamma \cos\theta_c}{\rho r g}$$

$$P = -\frac{B}{V_o}(V - V_o)$$

$$U - U_o = \frac{1}{2} B \frac{(V - V_o)^2}{V_o}$$

$$dW = 4\pi r(2\gamma + \Pr)dr$$

$$F = \eta A \frac{v}{d}$$

$$v = \frac{\Delta P}{4\eta \ell}(a^2 - r^2)$$

$$Q = v_{av} A$$

$$Q = \frac{\pi \Delta P a^4}{8\eta \ell}$$

$$N_R = \frac{\rho d v}{\eta}$$

$$F = 6\pi r \eta v$$

$$v_T = \frac{2r^2 g}{9\eta}(\rho_o - \rho_f)$$

$$F = c_D A(\frac{1}{2}\rho v^2)$$

$$N_j = N_o e^{-\frac{\varepsilon_j}{kT}}$$

$$N_j = N_o e^{-\frac{\xi_j}{RT}}$$

$$\mu_T = \mu_0 + RT \ln c + PV + zF\phi + mgh$$

$$\Psi = P - \Pi$$

$$\frac{\partial c}{\partial t} = D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} + \frac{\partial^2 c}{\partial z^2}\right) = D\nabla^2 c$$

$$c(x,t) = \sqrt{\frac{1}{4\pi Dt}} \exp\left[\frac{-x^2}{4Dt}\right]$$

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

$$\frac{1}{2} m v_{rms}^2 = \frac{3}{2} kT$$

$$v_s = \sqrt{\frac{\gamma kT}{m}}$$

$$v = \sqrt{\frac{T}{\mu}}$$

$$SL = 10 \mathrm{Log}\left[\frac{I}{I_o}\right]$$

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

$$P = \frac{1}{f} = (n - 1)\left[\frac{1}{R_1} + \frac{1}{R_2}\right]$$

$$\frac{n_1}{o} + \frac{n_2}{i} = \frac{n_L - n_1}{R}$$

$$\sin\theta \approx \theta = 1.22 \frac{\lambda}{d}$$

$$r = D\tan\theta \approx D\theta$$

Constants:

$k = 1.38 \times 10^{-23}$ J K^{-1} ,

$\varepsilon_o = 8.85 \times 10^{-12}$ F m^{-1}, $q = 1.6 \times 10^{-19}$ C

R = 0.0083143 liter MPa mol^{-1}K^{-1}

g = 9.8 m.s^{-2}

Avogadro's number = 6.02×10^{23}

Question 1

(a) The common duckweed, *lemna*, consists of a round leaf that floats on surface of fresh water ponds and a thin root (Fig.1). If the density ρ of the leaf = 1.1 x 10^3 kg/m^3 and it depresses the water surface with angle ϕ, calculate the limiting radius r of the leaf for which it can float. State whether this is a minimum or a maximum radius. Treat the leaf as a circular, horizontal disk with thickness = 1.0 mm (Fig. 2).

Explain all the principles involved in your calculation and approximations you have to make.

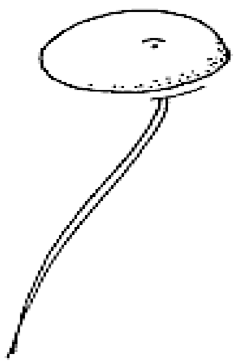


Fig. 1

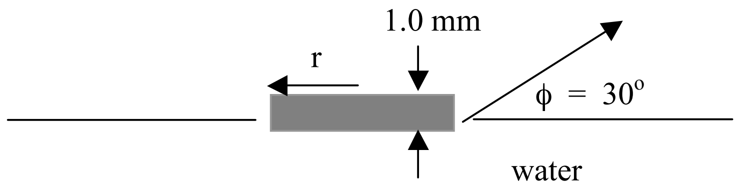


Fig. 2

Data: density of water: 10^3 kg/m^3
surface tension of water 73 x 10^{-3} N/m

(b) The figure 3 below shows two water droplets on two different materials. Explain what is happening in terms of intermolecular forces. What would you call materials shown in (i) and (ii)? State an example for each type of material.

Fig. 3 (i)

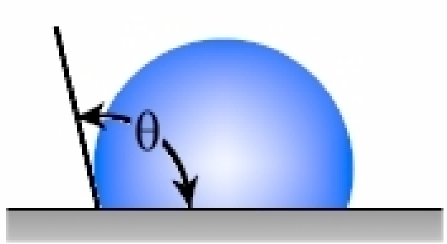
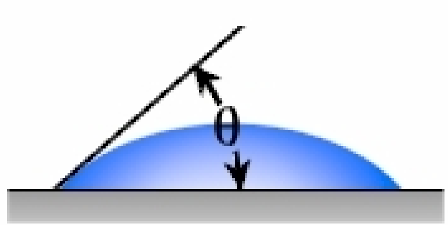
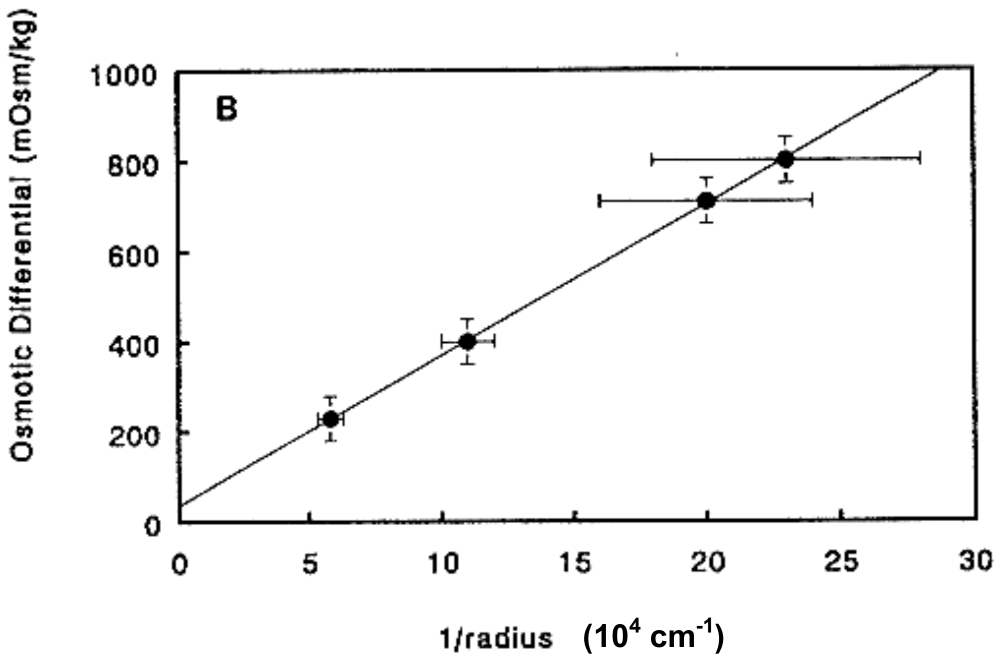


Fig. 3 (ii)



Question 2

(a) In an experiment, single layer (uni-lamellar) spherical lipid vesicles with radii ranging from 45 to 170 nm were exposed to progressively larger osmotic pressure differences until they burst. The "bursting pressures" were plotted as function of the radii below. The experimenters were happy to find that the results confirmed a well-known biophysical equation. Showing your reasoning, use the graph below to calculate the maximal membrane tension.



(from Mui et al, 1993, *Biophysics Journal* 64: 443 – 453)

You might find following conversions useful: 1 mosmol/kg = 1 mol/m^3 (if solvent is water)
Pressure = RTc (R = 8.314 J/K.mol, T absolute temperature = 300 K, c concentration in mol/m^3)

(b) State Poiseuille's equation, defining all the terms.

If one large artery of r_L = 0.75 cm divides into two arteries with r_S = 0.5 cm, find the ratio of the pressure change/unit length between large and small arteries.

Question 3

(a) The oral cavity can be modeled by a pipe 17 cm long, open at the mouth end and nearly closed at the vocal cords.

Calculate the first three resonant frequencies. Show your reasoning and illustrate with diagrams. Discuss how this spatial arrangement reflects human speech sounds and the sensitivity of human hearing.

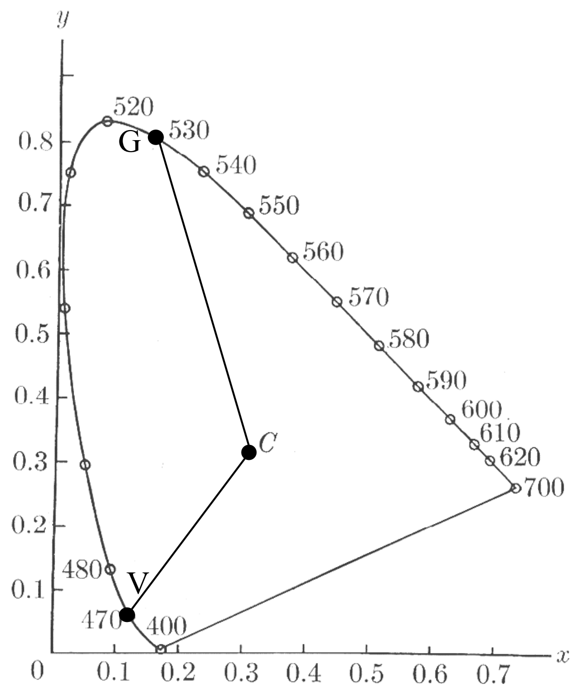
(b) Describe how the middle ear transmits the vibration of the eardrum to the cochlea. Greater sound power is transmitted to the cochlea when the middle ear is present (and functional) than in its absence. How does the middle ear achieve this greater power transmission? Illustrate with relevant diagrams.

(data: take velocity of sound in air as 344 $m.s^{-1}$)

Question 4

(a) In the eye of the bald eagle, the separation of the cones on the fovea is 1.3 x 10^{-6} m. The eye diameter is similar to that of humans, 2 cm, but the pupil can dilate up to 9.2 mm diameter. Using this information, estimate the theoretical acuity of the eagle's eye. Is diffraction a limiting factor? Document your answer with diagrams and calculations. Take wavelength of light as 500 nm.

(b) In the vision laboratory, a sequence of light flashes specified by points G, C and V on the chromaticity diagram below is directed into the human subjects' eyes so as to fall upon the fovea.



(i) What physical properties of the light flashes can be determined from the chromaticity diagram?

(ii) If the light flashes are sufficiently bright and long to be visible, but not damaging, there will be physiological responses at the subject's retina. Describe these responses and illustrate your answer with relevant diagrams.

(c) One of the greatest challenges in robotics design is to translate the two-dimensional image formed on a robots 'camera-like' eye into three-dimensional space. Our brain uses 'learnt' visual cues to interpret the 2-dimensional images formed on the retina in 3-dimensional space. Describe 3 examples (with the aid of a diagram if necessary) of learnt distance perception cues that our brain uses to determine when one object appears closer to us than another object.

Constants: $k = 1.38 \times 10^{-23}$ J K^{-1}, $\varepsilon_o = 8.85 \times 10^{-12}$ F m^{-1}, $q = 1.6 \times 10^{-19}$ C,
Avogadro's number = 6.02×10^{23}, temperature T = 298 K

Question 5

(i) A new type of artificial membrane, made from material with a relative dielectric constant of 4.06, has an area of 45.2 mm^2 .

(a). Calculate the thickness of this membrane if its measured capacitance is equal to 15.2 nF.

(b) A research team has managed to construct a new ionic channel for this membrane that only allows the passage of uranium ions X-ray studies show that these channels have a diameter of 2.91 nm and are 10.7 nm in length. Calculate the expected concentration of U^{3+} ions within these channels when they are embedded in the membrane described in part (a) and bathed in water containing 123 mole m^{-3} of U^{3+} at a temperature of 25 ^oC.

(c) Calculate the unit conductance of one of these channels if the diffusion constant for U^{3+} ions is 3.57×10^{-10} m^2 s^{-1}.

(d) The researchers wish to use these channels to separate the isotope ^{235}U, which is preferentially present as the U^{4+} ion, from the isotope ^{238}U, which is preferentially present as the U^{3+} ion. Calculate the ratio of U^{4+} / U^{3+} ions within the channel if their ratio in the outside solution was 0.0072.

(ii) Describe and explain how patch-clamping provides evidence for the presence of channels in biological membranes.

Question 6

(i) The interior of a cell contains immobilised fixed negative charges at a concentration of 100 mM. The external solution contains a 39 mM KCl solution. Assuming the Donnan equilibrium is applicable, calculate the internal concentrations of K^+ and Cl^- ions, and calculate the potential of the cell interior with respect to the external solution.

(ii) The membrane of a nerve cell has ionic permeability ratios given by $\alpha = P_{Na}/P_K = 0.1$ and $\beta = P_{Cl}/P_K = 0.05$. The external solution contains 95 moles m^{-3} NaCl and 3 moles m^{-3} KCl, whereas the cell interior contains 15 moles m^{-3} NaCl, 12 moles m^{-3} KCl and 105 moles m^{-3} KA, where A represents the aspartate anion. The aspartate anions are too large to pass through the cell membrane. No other ions are present. Use the Goldmann-Hodgkin-Katz equation to calculate the membrane potential (i.e. the potential of the interior of this nerve cell with respect to the potential of the external solution).

(iii) The sodium permeability P_{Na} of the nerve cell in (ii) increases by a very large amount. Calculate the new value of the membrane potential

Question 7

(i) Describe briefly how experimenters were able to determine the ionic species are involved in the nerve impulse and their behaviour.

(ii) Describe the role played by the cable properties of a nerve cell in the propagation of the nerve impulse

(iii) Describe and explain any advantages afforded by the myelin sheath around myelinated nerves. Provide at least one diagram.

Question 8

(i) Describe and explain how the electrical signals of an electrocardiogram are related to the processes that occur in the human cardiac cycle. Your answer should include appropriate sketches and perhaps explain how some various abnormal conditions might be detected.

(ii) Several animals have developed the ability to produce and/or detect electric fields. Describe and explain some situations in which these abilities would be an advantage.