THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

EXAMINATION – NOVEMBER 2007

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.

$$F = 2\gamma L$$

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

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

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

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

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

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

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

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

$$Q = v_{av}A$$

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

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

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

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

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

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

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

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

$$\Psi = P - \pi$$

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

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

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

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

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

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

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

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

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

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

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

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

Constants:

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

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

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

$g = 9.8$ m.s^{-2}

Avogadro's number = $6.02\text{x}10^{23}$

Question 1

(a) Consider three water molecules in close proximity. What are the important factors that will determine their relative positions to each other?

Illustrate your answer with a sketch of a possible configuration and relevant molecular data. List two properties of bulk water, resulting from these molecular interactions. How are these properties important to life on Earth?

(b) If you shake a beaker of very pure water, not many bubbles will form. When detergent is added, the liquid will become frothy on shaking. Explain what is happening in terms of surface tension γ. Include definition of surface tension and any relevant equations.

(c) A beetroot cell exposed to concentrated sucrose solution, totally detached from the cell wall and formed a stable sphere with diameter of 40 μm. Describe the processes that shrunk the cell away from the wall into this new equilibrium state. Taking the membrane surface tension $\gamma = 5$ mN.m^{-1}, calculate the supporting pressure. How is this pressure related to turgor pressure?
(hint: remember the definition of turgor)

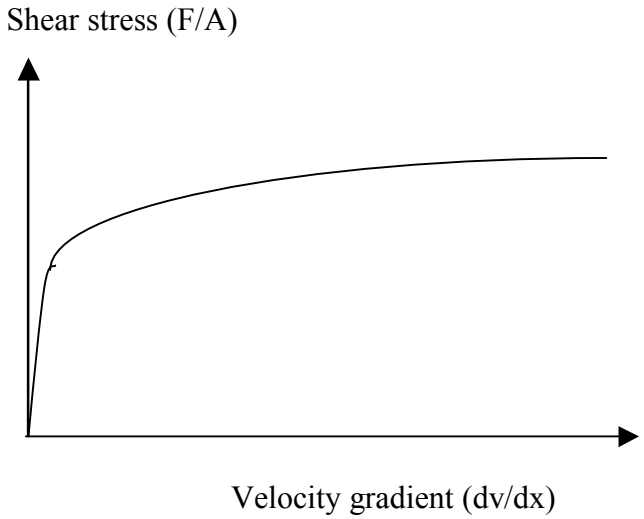
Question 2

(a) The human windpipe is a tube about 16 mm in diameter and 20 cm long before the branching into each lung. At the time of exhalation or inhalation the change in volume of the chest cavity provides the driving pressure difference $\Delta P = 134$ Pa.

(i) Calculate the volume flow Q in and out of the lungs. What assumptions do you have to make?
(ii) Calculate the average velocity of air during inhalation/exhalation. Comment on your result.
(iii) Calculate the Reynolds number for the windpipe. Can you now explain your result in part (ii)? What general conclusion can you draw about the air flow through the windpipe?

Data for air: $\eta = 18\ \mu$Pa.s, $\rho = 1.3$ kg.m^{-3}

(b) Define viscosity η and explain the difference between newtonian and non-newtonian fluid. Describe the behaviour of the viscosity of the fluid shown below and speculate on the fluid constituents.



Question 3

(a) A 50 μm plant cell with internal concentration of 60.0 mM KCl, is in equilibrium with the medium containing 1.0 mM KCl. The cell membrane is permeable to K^+, but not to Cl^-.

Calculate:

(i) The turgor pressure of the cell
(ii) The electrical potential difference across the membrane

Show all your reasoning and include the relevant equations, defining all the variables.
Assume that flows of water and ions are independent.

Data: μ_0 (medium) = μ_0 (cell)
temperature = 300 K,
R = 0.0083143 L.MPa.mol^{-1}.K^{-1} (to get pressure in MPa) or 8.3143 J.mol^{-1}.K^{-1},
F = 9.65 x 10^4 C/mol
Partial molar volume of water = 18 x 10^{-6} m^3

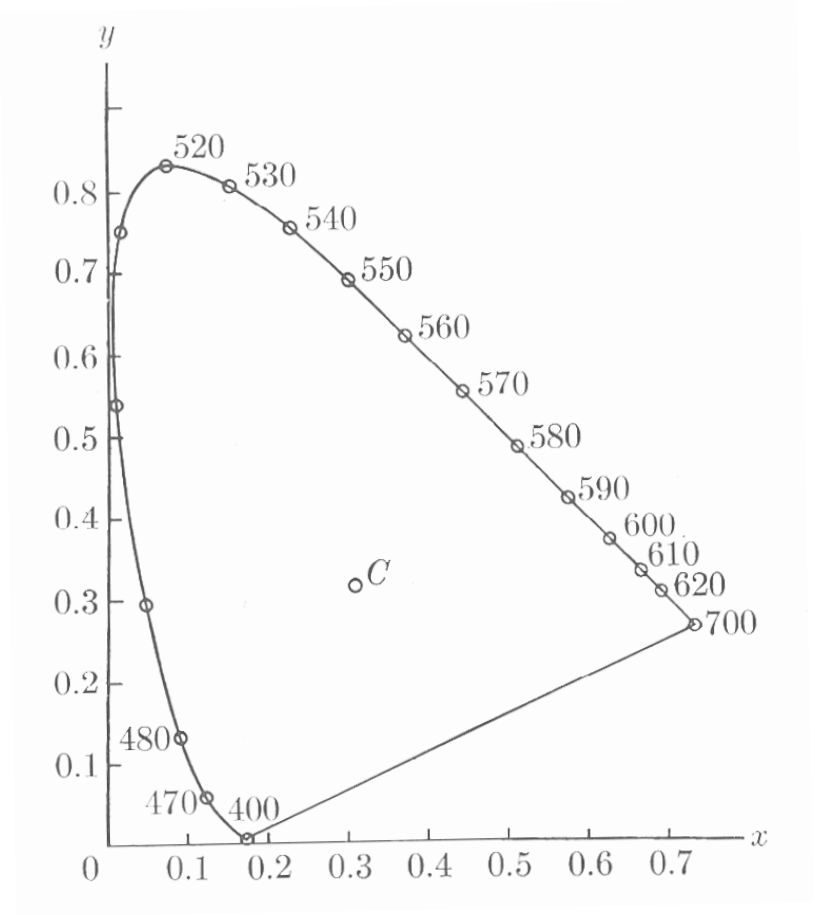
(b) If a solute diffuses through water an average distance of 10^{-2} m in 6 hours, what is its diffusion Coefficient D?

Question 4

(a) Describe the physiology of the inner ear and the transduction of the mechanical signals at the oval window of the cochlea to the perception of sound in the brain. What is meant by place or rate theory of pitch? Illustrate your answer with relevant diagrams.

(b) Using the chromaticity diagram below, describe properties of light as perceived by human eye, such as hue, saturation and brightness.

What are the mechanisms at the retina that allow us to see this wide range of colours? Illustrate your answer with relevant diagrams.



Question 5

(i) Researchers have produced a bilayer made from a new type of lipid. The initial sample has an area of 29.3 mm^2 and a thickness of 5.07 nm.

(a) The measured capacitance of the lipid bilayer sample is 153 nF. Calculate the relative dielectric constant of the material that forms this lipid bilayer.

(b) Calculate the expected concentration of K^+ ions within this bilayer when bathed in a aqueous solution of 60.0 mole m^{-3}. Assume that the radius of a K^+ ion is 0.13 nm, the relative dielectric constant of water is 78.5 and the temperature is 25 ^oC.

(c) Calculate the expected conductance of the above bilayer to K^+ ions. You may assume the diffusion constant for K^+ ions is $1.5x10^{-9}$ m^2 s^{-1}.

(ii) Explain why charged molecules or ions find it impossible to travel across a lipid bilayer. Discuss the various mechanisms that have evolved in biological systems to overcome this problem. You should include equations where appropriate.

(iii) Explain what is meant by 'patch-clamping' and how it can confirm the presence of channels in biological membranes.

Constants: $k = 1.38x10^{-23}$ J K^{-1}, $\varepsilon_o = 8.85x10^{-12}$ F m^{-1}, $q = 1.6x10^{-19}$ C,

Avagadro's number = $6.02x10^{23}$, temperature = 298 K

Question 6

(i) Biophysicists are trying to decide between two possible models responsible for producing the voltage between the inside and outside of a cell.

Model A: the cell has internal fixed charges.

Model B: the cell has a fixed internal concentration of K^+ ions and is surrounded by a membrane that is permeable only to K^+ ions.

The results of experiments which measured V_m (the voltage of the cell interior with respect to the exterior) as a function of K_o (the external concentration of K^+ ions) are:

K_o (mM)	0.5	1	2	5	10	20	50	100	200
V_m (mV)	-112.7	-94.9	-77.19	-53.9	-37.1	-22.7	-10.0	-5.1	-2.6

(a) Decide which Model (A or B) best explains the experimental data. Briefly explain your reasoning.

(b) If you think Model A is appropriate, calculate the concentration and sign of the fixed charges. If you think Model B is appropriate, calculate K_i, the internal concentration of K^+ ions.

(ii) The membrane of a nerve cell has ionic permeability ratios given by $\alpha = P_{Na}/P_K = 0.08$ and $\beta = P_{Cl}/P_K = 0.10$. The external solution contains 110 moles m^{-3} NaCl and 5 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 potential of the interior of this nerve cell with respect to the potential of the external solution.

Question 7

(i) Describe, with the aid of equations and diagrams, the ionic processes associated with the nerve impulse.

(ii) Briefly describe and distinguish between the terms ‘space-clamping’ and ‘voltage-clamping. Briefly explain the role each played in determining the mechanism 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 detect electric fields. Describe these abilities and then explain some situations in which these abilities would be an advantage.