THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

EXAMINATION – November 2010

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

All answers must be written in ink.
Except where they
are expressly required, pencils may be used
only for drawing, sketching or graphical work.
The students provide their own calculators

$$F = 2\gamma L$$

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

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

$$\Delta P = \gamma\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

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

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

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

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

$$W = 4\pi r^2\gamma - \frac{4}{3}\pi r^3 P$$

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

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

$$Q = v_{av}A$$

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

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

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

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

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

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

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

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

$$\Psi = P - \Pi$$

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

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

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

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

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

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

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

$$I_o = 10^{-12}$$

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

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

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

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

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

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

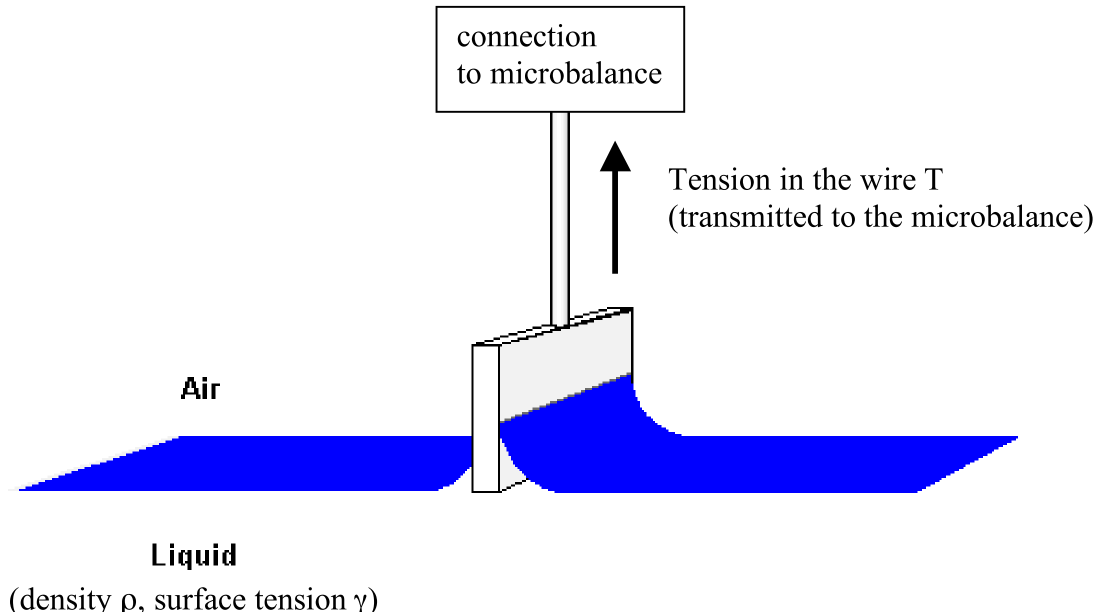
R = 0.0083143 liter MPa $mol^{-1}K^{-1}$

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

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

Question 1

(a) To measure surface tension Wilhelmy plate can be used. This is a thin plate (mass m, thickness t and width w) made from glass or platinum and roughened to ensure wetting. The plate is suspended from a microbalance and just brought into contact with the liquid at "zero depth immersion", as shown in the figure below. For the system in equilibrium, use the figure to show the forces involved. Derive equation for the surface tension γ of the liquid. How will this equation change if the plate is lowered into the liquid to depth d?



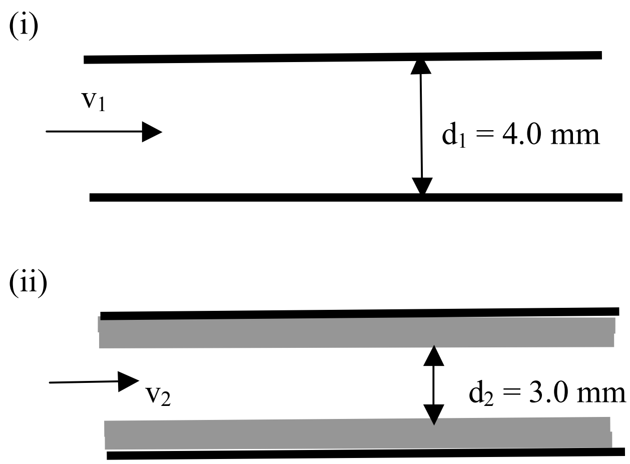
(b) Calculate the transmural pressure in the human aorta with the diameter 2.4 cm and the wall tension of 156 N/m.

If the small capillaries with much smaller radii had the same tension in their walls, would the pressure need to be greater or smaller? In reality is the tension in small capillaries the same as in the aorta?

Question 2

(a) In normal artery, see figure (i) below, the pressure drop per unit length is 37.2 Pa/m. Assuming that the blood flow is laminar, calculate the volume flow Q.

(b) Due to a fatty diet and not enough exercise, arteries can become clogged. Calculate the pressure drop per unit length in the narrowed artery (ii) to achieve the same blood flow as in artery (i). Can you show quantitatively that the flow is still laminar?



Data: blood density ρ = 1.0595x10^3 kg.m^{-3}, blood viscosity η = 4.0 x 10^{-3} Pa.s at 37°C

(c) A salt tolerant charophyte cell has a steady state turgor pressure P = 0.8 MPa and is in equilibrium with the medium of water potential Ψ = -1.2 MPa. What is the internal concentration of KCl?

A sudden downpour increases Ψ to -0.9 MPa. For the same internal KCl concentration, how will turgor change?

The cell senses the change in turgor, channels open and K^+ and Cl^- are effluxed until turgor returns to the steady state value. Calculate the new concentrations of KCl in the cell.

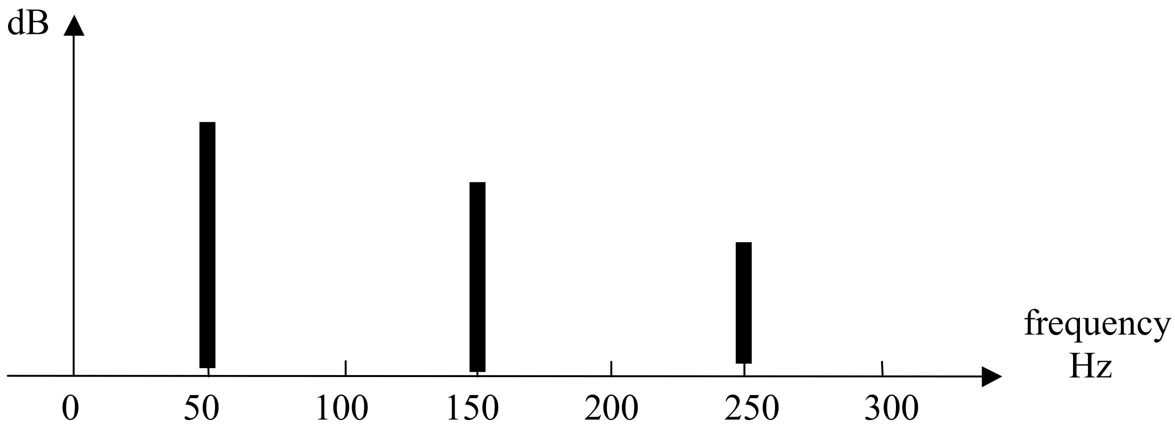
Assume K^+ and Cl^- are the main internal ions, which contribute equally to osmotic pressure of the internal solution.

Data: take the temperature as 300 K, R = 0.00831 LitreMPa/mol

Question 3

(a) A machine in a factory produces noise of 70 dB. To increase productivity, the manufacturer installs four identical machines in the same room. Will the factory still comply with occupational health and safety limit of 80 dB? Give a quantitative answer.

(b) The graph below shows three lowest frequencies recorded from a resonating air column in a pipe. What type of a pipe is it (open or closed)? Showing your reasoning and relevant diagrams, calculate its approximate length.



data: take velocity of sound in air as 340 $m.s^{-1}$

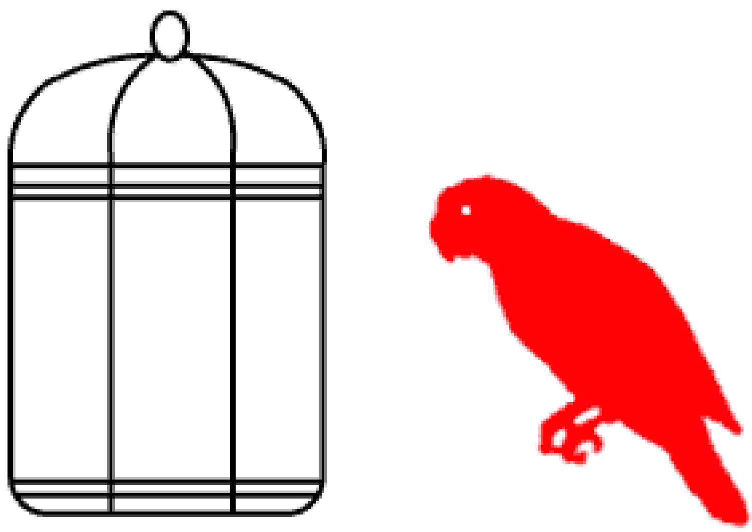
(c) Describe the anatomy of the cochlea in the inner ear. Which part of the cochlea will be excited by the first three harmonics of the pipe from part (b)?

Question 4

(a) Outline the anatomy of human eye. Use the camera analogy in describing the functions of various structures in controlling the amount of light admitted, focusing and perceiving of the image at the back of the eye.

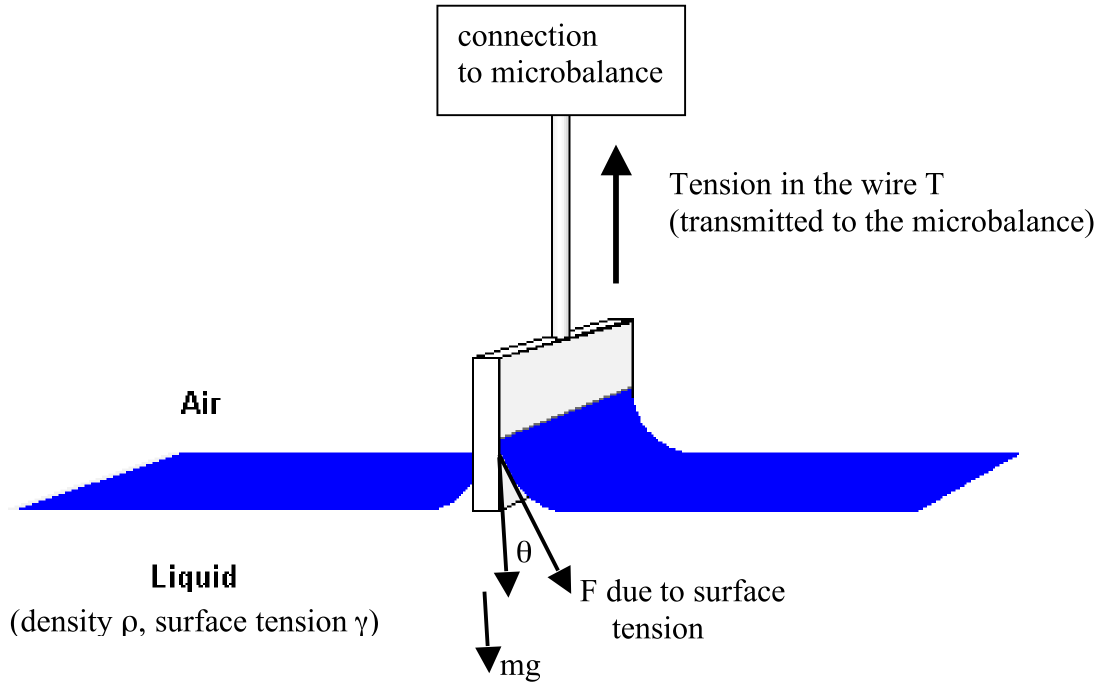
(b) In the vision laboratory, a figure containing black and white stripes of equal width of 0.2 mm is shown to a human subject at a distance of 4 m in bright daylight. The subject is a young student with normal vision. Show quantitatively, whether she will be able to resolve the stripes. Illustrate with a diagram and relevant equations.

(b) Explain "the parrot in the cage" illusion as shown below. If the parrot is colored red, what color afterimage will a person with normal color vision see in the cage? Why?



Answers: Question 1 (12 marks)

(a) Balancing forces:



In equilibrium tension $T = mg + F\cos\theta = mg + \gamma\,(2w + 2t)\cos\theta$

$$\gamma = \frac{T - mg}{(2w + 2t)\cos\theta}$$

where T is given by the reading on the balance. The balance can be zeroed before plate touches the liquid surface and cosθ is close to 0 for platinum and many liquids, so the readout can be simply divided by the perimeter of the plate.

Once the plate is submerged below the liquid surface, there will be a buoyant force directed upwards

F_B = weight of volume of displaced liquid = $\rho V g = \rho\,(t \times w \times d)\,g$

(b) Using Young-Laplace eqn for a cylinder:

$$\Delta P = \frac{\gamma}{r} = \frac{156}{1.2\times10^{-2}} = 13\times10^{3}\text{Pa}$$

With the same wall tension and smaller radius the pressure difference will increase.
In reality the tension in capillaries is smaller and the pressure difference is also smaller.

Question 2 (12 marks)

(a)

$$Q = \frac{\pi r^4}{8\eta}\frac{\Delta P}{\ell} = \frac{3.1416 \times (2.0 \times 10^{-3})^4 \times 37.2}{8 \times 4.0 \times 10^{-3}} = 58.4 \times 10^{-9}\,m^3 s^{-1}$$

Using the same volume flow:

$$\frac{\Delta P}{\ell} = \frac{Q \times 8\eta}{\pi \times (1.5)^4} = \frac{58.4 \times 10^{-9} \times 8 \times 4.0 \times 10^{-3}}{\pi \times 15.9 \times 10^{-12}} = 117.54 \text{ Pa/m}$$

The average velocity in the narrowed artery:

$$\bar{v} = \frac{Q}{\pi r_2^2} = \frac{58.4 \times 10^{-9}}{7.1 \times 10^{-6}} = 8.2 \times 10^{-3}\,ms^{-1}$$

To check for turbulence, calculate Reynolds number N_R:

$$N_R = \frac{\rho d v}{\eta} = \frac{1.059 \times 10^3 \times 3.0 \times 10^{-3} \times 8.2 \times 10^{-3}}{4.0 \times 10^{-3}} = 6.5$$

This is well below the 2500, which indicates the onset of turbulence. So, flow far from turbulent.

(c)

Initially:

$\Psi = P - \pi$
$\pi = 0.8 - (-1.2) = 2.0$ MPa $= RTc_i$

$RT = 2.493$
$c_i = 2.0/2.493 = 0.8$ M
As each ion contributes to osmotic pressure, 0.4 M KCl

After rain: $-0.9 = x - 2.0$, new turgor pressure: 1.1 MPa, 0.3 MPa greater than the steady state turgor
Need to decrease π by 0.3 MPa
$2 - 0.3 = 1.7 = RTc_f$
$c_f = 1.7/2.493 = 0.68$ M (both ions together)

KCl concentration in the cell needs to decrease to 0.34 M

Qustion 3 (12 marks)

(a) The decibel scale is logarithmic and compares an intensity I ($W.m^{-2}$) to a threshold of human hearing $I_0 = 10^{-12}$ $W.m^{-2}$

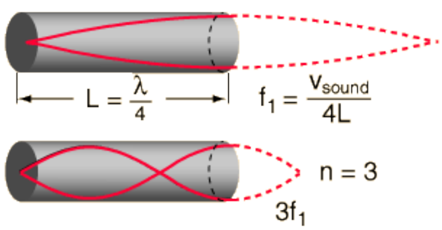
$$\beta = 10\log\frac{I}{I_0} \text{ in decibels (dB)}$$

For 4 machines:

$$\beta = 10\log\frac{4I_{machine}}{I_0} = 10\log 4 + 10\log\frac{I_{machine}}{I_0} = 6 + 70 = 76\text{dB}$$

The factory is still compliant with OHS, but only just.

(b) The fundamental frequency f_o is 50 Hz, the next harmonic is $3f_o$ and the next is $5f_o$.
The odd numbered harmonics indicate a pipe closed at one end, as shown below for the first two modes.



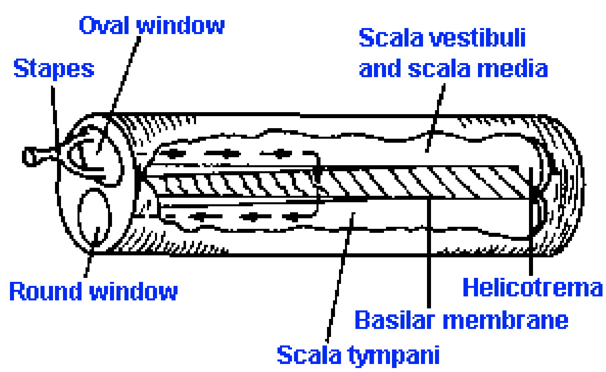
The fundamental node consists of approximately one quarter of a wavelength (neglecting end corrections).

$$\lambda = \frac{v}{f} = \frac{340}{50} = 6.8\text{m}$$

$$L = \frac{\lambda}{4} = 1.7\text{m}$$

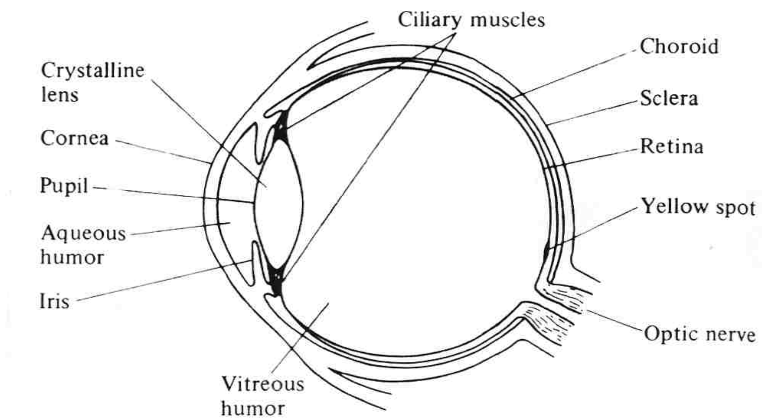
(c) The inner ear: cochlea

The above frequencies are near the low frequency limit of the ear and will vibrate the cochlea near helicotrema.



Question 4 (12 marks)

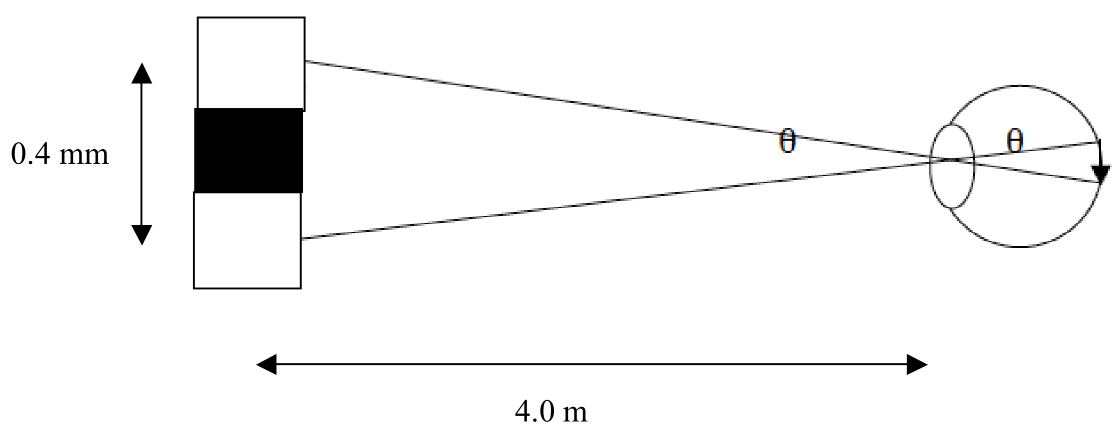
(a) Anatomy of human eye:



Camera analogy:

(1) pupil surrounded by iris controls the amount of light similar to camera adjustable aperture
(2) Cornea and crystalline lens (which can change shape, especially in young people) are similar to the camera lens system, which produces a sharp image on the film or at the back of the eye.
(3) Light sensitive film that captures the upside down image in the camera and rods and cones in the retina of the eye that translate the image into spatial array of electrical impulses for the brain to interpret.

(b) The experiment is testing the acuity of the subject:



The angle θ can be approximated by $0.4 \times 10^{-3} / 4.0 = 1 \times 10^{-5}$ rad: much less than normal acuity of human eye of 5×10^{-4} rad. The subject will not resolve the stripes.
Alternatively, the size of the two bright stripes image can be worked out and compared to the spacing of the cones on the fovea.

(c) The afterimage will be blue green. Due to the fatigue of the red cones red is subtracted from the reflected white light from the empty cage.