UNIVERSITY OF GHANA

BSC. ENGINEERING
SECOND SEMESTER EXAMINATIONS: 2015/2016

DEPARTMENT OF BIOMEDICAL ENGINEERING

BMEN 406: TRANSPORT PROCESSES IN LIVING SYSTEMS (2 CREDITS)

INSTRUCTIONS:
ATTEMPT FOUR QUESTIONS

TIME ALLOWED: TWO (2) HOURS

1. a. Describe briefly the process of co-transportation, you may use the transport of glucose in the kidney as an example. (3 marks)

   b. i. Assume a concentration of glucose inside a cell is 0.5 mM and a concentration of glucose outside the cell is 5 mM at a body temperature of 37 °C. Calculate the energy needed to transport glucose. (5 marks)

   ii. Assume further that the plasma membrane is permeable to sodium ion with sodium ion concentration outside the cell to be 140 mM and inside the cell to be 10 mM. Given that the membrane potential is -70 mV, calculate the electrochemical energy needed to transport one mole of sodium across the membrane. (Faraday constant = $9.648\,70 \times 10^{4}$ C mol^{-1}, Molar gas constant R = 8.314 $JK^{-1}mol^{-1}$)

   (5 marks)

   iii. If the transport of glucose in (i) is to be mediated by a sodium-glucose cotransporter, how many moles of sodium would be required to transport the glucose? (2 marks)

   c. i. Explain the importance of facilitated diffusion in biological systems. (2 marks)

   ii. State three characteristics of facilitated diffusion. (3 marks)

d. i. State Fick's second law of diffusion and define your symbols. (2 marks)

ii. The molar mass of macromolecules can be calculated from the equation below where the symbols have their usual meanings:

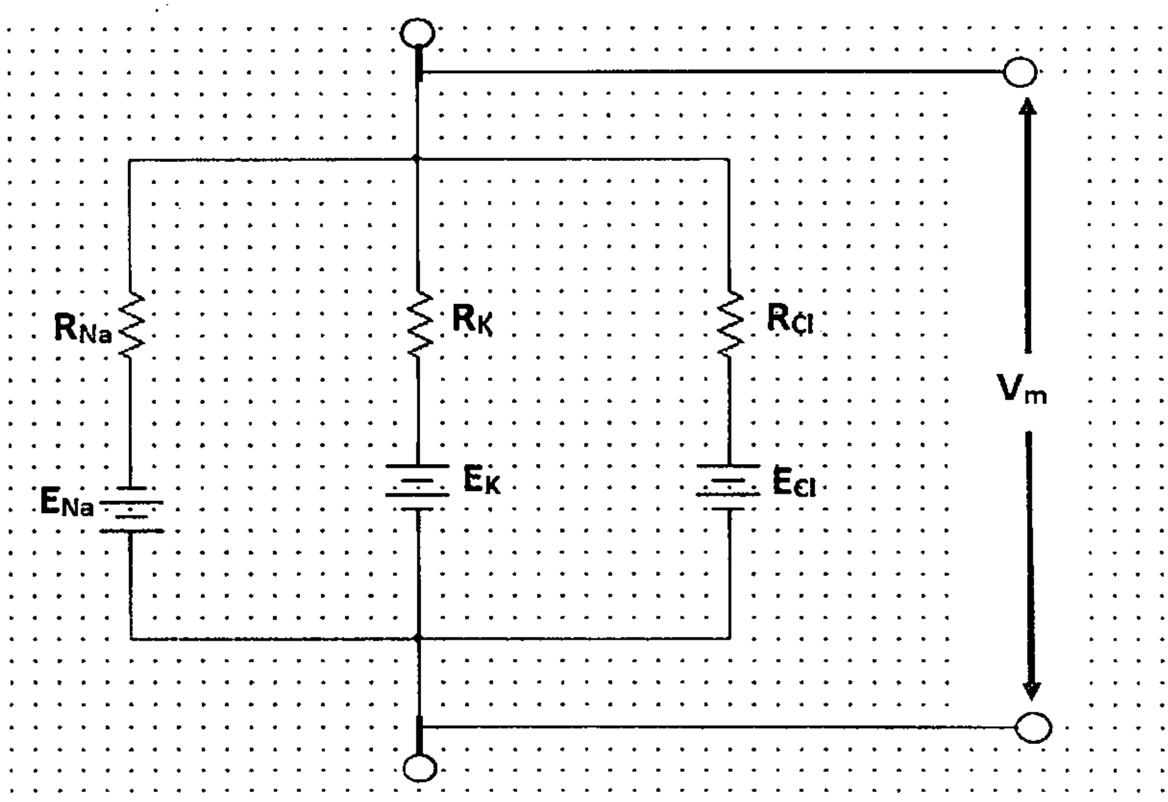
$$M = \rho \frac{4}{3} \pi \left(\frac{kT}{6\pi\eta D} \right)^3 N_A$$

Hemoglobin has an accepted molar mass of 68,000 units but using the equation above yields a value of 89,000. What can you then deduce about the shape of the hemoglobin molecule? (3 marks)

2. a. Explain how biological membranes exhibit the following equivalent properties:

i. Resistive properties (2 marks)
ii. Capacitive properties (3 marks)
iii. Electrical potential difference (2 marks)

b. Consider the equivalent circuit diagram below:



Find the membrane potential Vm for the frog skeletal muscle and comment on the ion flow if the Cl^- channels are ignored given that:

[R_k = 1.7 k ohms and R_{Na} = 15.67 k ohms, E_k = -105 mV, E_{Na} = 56 mV, E_{Cl^-} = -89 mV].

(10 marks)

c. i. Distinguish between Intensive and Extensive transport properties. (2 marks)

ii. Classify the following transport properties as intensive or extensive:

viscosity, heat, mass, thermal conductivity, diffusivity, momentum, pressure, volume, temperature, electrical charge. (5 marks)

3. a. The mean velocity in an artery of internal diameter 5 mm is 0.5 ms^{-1}. It may be assumed that blood has a viscosity of 0.004 Pa s and a density of 1000 kg m^{-3}. Calculate the Reynolds number and deduce whether the flow is laminar or turbulent. (6 marks)

b. The diffusion coefficient for a potassium ion crossing a biological membrane 10 nm thick is 1.0×10^{-16} m^2s^{-1}. What flow rate of potassium ions would move across an area 100 nm x 100 nm if the concentration difference across the membrane is 0.5 mol dm^{-3}?

(5 marks)

c. Blood with constant density ρ kg/m^3 is flowing at an unknown velocity V_1 m/s through a blood vessel of cross-sectional area A_1 m^2 at a pressure P_1 N/m^2, and then passes to a section of the blood vessel where there is a constriction reducing the area to A_2 m^2 and changing the pressure to P_2. Assuming no friction losses, if the pressure difference ($P_1 - P_2$) is measured use the mass balance continuity equation to show that the velocity V_2 is given by:

$$V_2 = \sqrt{\frac{2(P_1 - P_2)}{\rho\left[1 - \left(\frac{A_2}{A_1}\right)^2\right]}}$$

State the assumption made with regards to the nature of the blood vessel. (6 marks)

d. State three reasons why using Bernoulli's equation to calculate blood flow in humans is only an approximation. (6 marks)

e. Explain the Fahraeus-Lindquist effect. (2 marks)

4. a. Explain the statement "the Sodium – Potassium pump is electrogenic". (2 marks)

b. Describe briefly how the pump works. (5 marks)

c. Consider a membrane in which there is an active K^+ pump, passive channels for K^+ and Cl^- and non-equilibrium initial concentration of KCl on both sides of the membrane.

i. Write the flow equations for the passive channels (K^+ and Cl^-) and define your symbols. (6 marks)

ii. Show that the expression for the active potassium pump is:

$$J_p = \frac{2kT\mu_k([K^+]_o - [K^+]_i)}{q\delta}$$

where δ is the membrane thickness. (12 marks)

5. a. Heat transfer in human beings can be modelled by the Pennes' bio heat equation below, where the symbols have their usual meaning.

$$\nabla k_t \nabla T - W_b c_b (T - T_a) + M = c_t \rho_t \frac{\partial T}{\partial t}$$

i. Explain each term in the equation. (4 marks)
ii. What does the solution of the equation mean qualitatively? (2 marks)
iii. State three assumptions made when developing a mathematical model for heat transfer in humans. (3 marks)

b. Describe the process of thermoregulation in humans (you may use diagrams for illustrations). (10 marks)

c. Describe the transport mechanisms involved in the exchange of CO_2 in the lung. (5 marks)