University of Ghana

Second semester examinations: 2014/2015

Level **400**: Bachelor of Science in Biomedical Engineering
BMEN 406: **Transport processes in living systems** (2 credits)

Answer ALL questions.

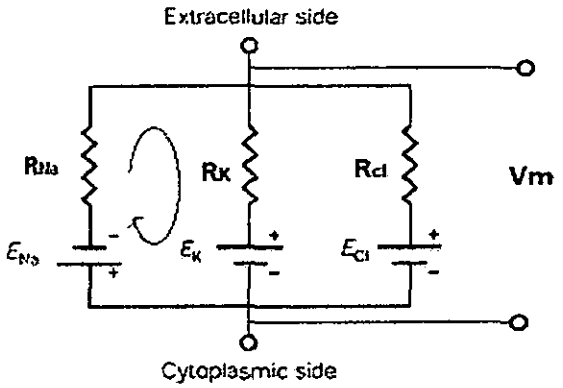
Time: Two Hours.

1. a) Write down the continuity and the momentum flux equations in one dimension in fluid dynamics and define your symbols. (6 marks)

   b) Hardening of the arteries results in a constriction of the arteries. Blood flows with a speed of 26.5 cm/sec through an aorta of radius 1 cm to a region where the aorta has constricted to a radius of 0.8 cm due to hardening of the arteries. Calculate the pressure difference between these two areas of the aorta in N/m^2. (Density of blood = 1060 kg/m^3). (9 marks)

   c) At the arterial end of the capillary, the capillary pressure P_c is about 30 Pa and at the venous end of the capillary the pressure is about 10 Pa. The interstitial fluid pressure was found to be -3 Pa. The colloid osmotic pressure for human plasma is 28 Pa and the value of the interstitial fluid is 8 Pa. Calculate the flow rates of fluid across the capillary wall at the arterial and the venous ends. Use your results to describe the net flow of fluids. (10 marks)

2. a) The diagram below is the equivalent circuit of a biological membrane in which the ion channels are modeled as resistance, the resting potentials **Vm** for each ion is modeled as the battery and the flow of ions as the current.



Find **Vm** for the frog skeletal muscle if the Cl^- channels are ignored. Comment on the ion flow.

Use $R_k = 1.7\ k\Omega$, $R_{Na} = 15.67\ k\Omega$,

$E_k = -105\ mV$, $E_{Na} = 56\ mV$. (10 marks)

b) (i) Explain the term **electrochemical gradient** as used in transport of solutes in biological systems.

(ii) Calculate the total energy released from the electrochemical gradient when one sodium ion moves down its gradient of about 140 mM outside the cell to 10 mM inside the cell.

[Assume the following: A temperature of 37°C, gas constant R to be 8.3 $JK^{-1}mol^{-1}$. Membrane potential V_m in a mammalian cell to be -70 mV]

c) The amount of energy released as one mole of charge moves down a voltage gradient of 1 volt is 96.485 kJ per volt gram equivalent. (7 marks)

(i) Give two reasons how facilitated diffusion differs from diffusion by Fick's law. (4 marks)

(ii) Explain the importance of facilitated diffusion in physiological systems and give two examples. (4 marks)

3. 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.

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

b) By considering the principle of space charge neutrality, 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. (10 marks)

c) If the total surface area of the human body is 1.20 m^2 and the surface temperature is 30°C, find the total rate of radiation of energy from the body. If the surroundings are at a temperature of 20°C, what is the net rate of heat loss from the body by radiation? Assume the emissivity of the body to be one and take Stefan Boltzman constant to be 5.67x10-8 $Wm^{-2}K^{-4}$. (9 marks)

4. a) State **three** assumptions made in mathematical modeling of heat transfer in human tissues. (6 marks)

b) The generalized boundary condition (BC) for the heat transfer occurring at the skin surface can be written as

$$-k\frac{\partial T}{\partial n}|_{skin} = h(T_\infty - T) + \in \sigma(T_\infty^4 - T) + Qe$$

where the symbols have their usual meaning. Explain the contribution of each term in the equation above. (6 marks)

c) Describe the feedback control system responsible for thermoregulation in humans when the surroundings are hot or when the body is vigorously exercising. (7 marks)

d) How is this different when the body is at rest or the surroundings are cold? (6 marks)