University of Ghana

BSc. Engineering

First semester examinations: 2015/2016

Department of Biomedical Engineering

BMEN 401: Engineering Principles in Human Physiology and Anatomy (2 credits)

INSTRUCTION:

ANSWER QUESTION ONE AND ANY OTHER TWO QUESTIONS

TIME: 2 HOURS

Q1. The Proportional Integral Derivative(PID) controller based on the input/output model used to control type 1 diabetes is given as

$$PID(t) = k_p(G(t) - G_B) + \frac{k_p}{T_1}\int_0^t (G(t) - G_B)dt + k_pT_D\frac{dG(t)}{dt}$$

Where, the symbols have their usual meanings.

i, Explain each term in the PID equation above. (6 marks)

ii. Define the symbols kp, T_1 and T_D. (6 marks)

b. What is feedback mechanism? Explain its importance in human physiology. (6 marks)

ii. Describe the feedback mechanism in glucose control. (10 marks)

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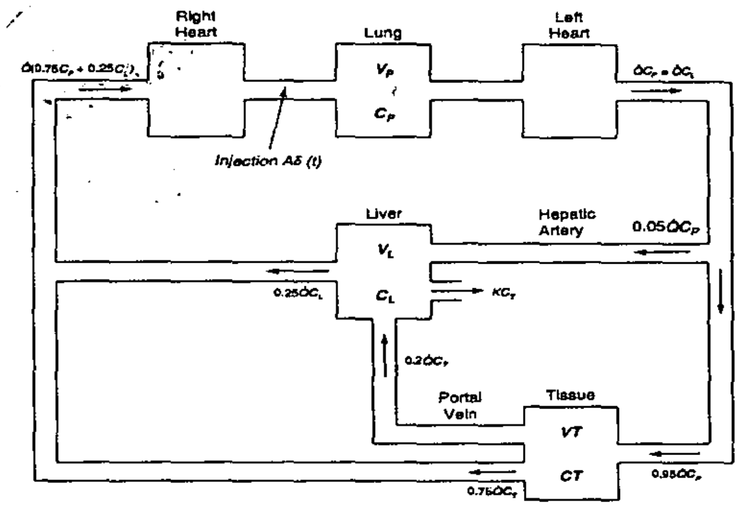
c.



Given in the diagram above is a three compartment (the Lung, the Liver and the Tissue) model used to describe the time course of steroid concentration in the arterial and venous blood. The steroid is injected as a bolus into the pulmonary artery. Assume all metabolisms of steroids takes place in the liver, and that the metabolic rate of steroids is directly proportional to the concentration of steroids in the tissue compartment and Q is the cardiac output. If 5% of the total cardiac output flows into the hepatic artery and 20% of the cardiac output flows into the portal vein, write the differential equations that describe the system. (12 marks)

2a. What is autoregulation? (3 marks)

b. By means of diagrams, illustrate the following results from both data and model during autoregulation. Briefly comment on the curves in each case.

i. Effect of arterial pressure on blood flow (6 marks)

ii. Blood flow and arterial oxygen deficiency (5 marks)

iii. Blood flow and metabolism. (5 marks)

c. A simple model of autoregulation considered oxygen consumption and blood flow via the following equations

$$([O_2]_a - [O_2]_2\ )Q = M$$

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$$P_a - P_v = RQ$$

Where $[O_2]_a$ and $[O_2]_v$ are the arterial and venous oxygen concentrations respectively and **M** is the metabolic rate. $\mathbf{P_a}$ and $\mathbf{P_v}$ are the arterial and venous pressures driving the flow **Q** through tissue with total resistance **R**. Assuming that there is a linear relationship between arterial resistance and venous oxygen content by

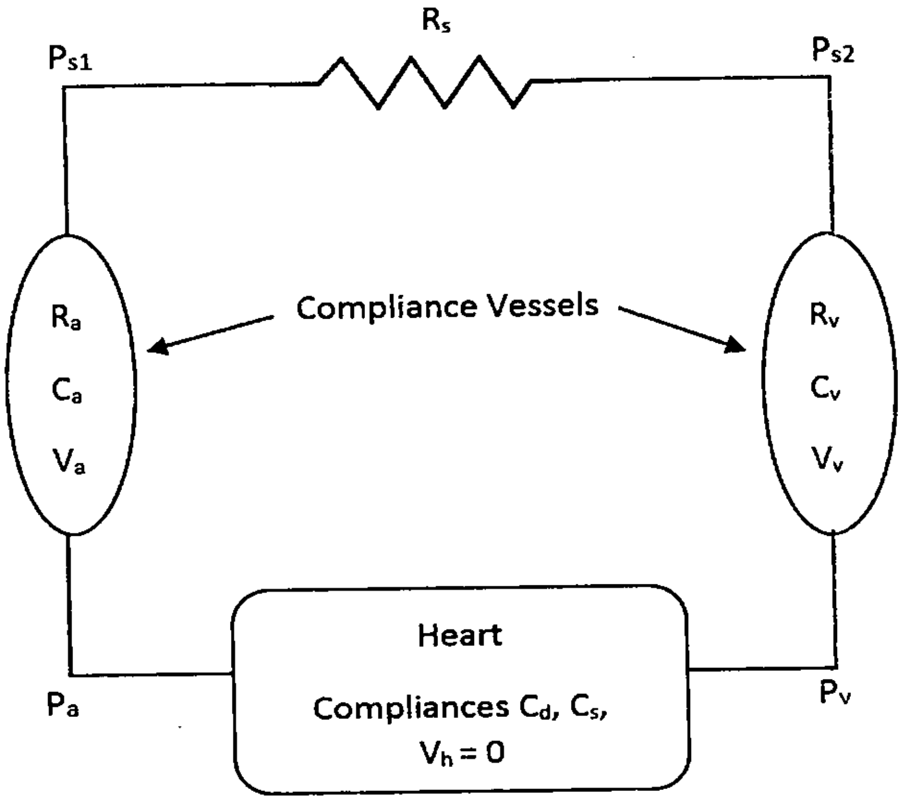
$$R = R_o\left(1 + A[O_2]_V\right)$$

Where **A** is the sensitivity to Oxygen resistance, show that

$$Q = \frac{\left(MA + \frac{P_a}{R_o}\right)}{1 + A[O_2]_a}$$

(11 marks)

3a. A simple linear model by (Guyton in 1963) describes the circulatory system as a closed loop with two compliance vessels and one pure resistive vessel as shown.



If $\mathbf{P_a}$, $\mathbf{P_v}$ and $\mathbf{Q}$ are found to be

$$P_a = \left(\frac{(1 + FC_d R_s)V_t}{C_v + (1 + FC_d Rs)Ca} (\right)$$

$$P_v = \left(\frac{V_t}{C_v + (1 + FC_d R_s)C_a} \right) \text{ and}$$

$$Q = \frac{FC_d V_t}{C_v + (1 + FC_d R_s)C_a}$$

Where F is the heart rate and the other symbols have their usual meaning.

State the qualitative features that can be deduced from the above solutions if

i. The heart rate increases (5 marks)
ii. The heart rate decreases (5 marks)
iii. Use your deductions in (i and ii) or otherwise explain how heart failure occurs. (6 marks)

b. The circulatory system can be viewed as a set of compliance vessel connected by valves and resistive vessels. Write the expressions for the flow **Q** in

i. The compliance vessels (4 marks)

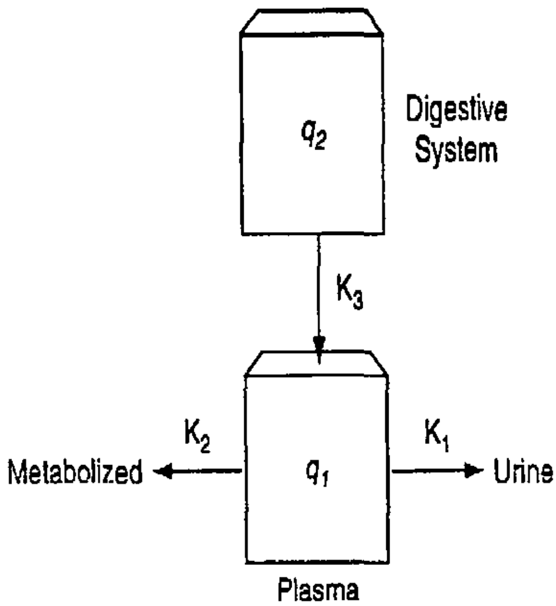
ii. The resistive vessels and define your symbols. (4 marks)

c. The flow through the two valves connecting the left ventricle can be modelled as

$$Q_{in} = \frac{S_{mi}(P_{sv} - P_{lv})}{R_{mi}} \text{ and } Q_{out} = \frac{S_{ao}(P_{lv} - P_{sa})}{R_{ao}}$$

Assuming that the left ventricle is a compliance vessel, write the flow equation for the left ventricle. (6 marks)

4a. Consider a two compartmental model in which a solute is injected in the digestive system and the solute is slowly released into the plasma and is later removed via metabolism and excretion in the urine shown in the diagram below.



a. Write the differential equations that describe the transfer of solute in the compartments. (6 marks)

b. Show that the complete solution is
$q_1 = B_1 e^{-(k_1+k_2)t} + B_2 e^{-kt_3}$ (10 marks)

c. If B_1 and B_2 are given by the equations $B_1 = \dfrac{-q_2(0)k_3}{k_1 + k_2 - k_3}$ and $B_2 = \dfrac{q_2(0)k_3}{k_1 + k_2 - k_3}$ respectively show that the time when maximum solute is in compartment one is

$$t_{max} = \frac{\ln\left(\frac{k_1 + k_2}{k_3}\right)}{k_1 + k_2 - k_3}$$ (8 marks)

d. Suppose 100 g of solute is ingested in the digestive system. Find the maximum amount of solute in the plasma if the compartment model above is used with $k_1 + k_2 = 0.01$ /min. and $k_3 = 0.04$ /min. (6 marks)