UNIVERSITY OF GHANA

BSC. ENGINEERING
FIRST SEMESTER EXAMINATIONS: 2016/2017

DEPARTMENT OF BIOMEDICAL ENGINEERING
BMEN 407: HAEMODYNAMICS (2 CREDITS)

INSTRUCTIONS:

Attempt all questions
All questions should be answered in the booklet provided (no graph sheets)
Calculations should be detailed and systematic. Marks are allocated to steps
Relevant formulae are provided at the end of the question sets
All symbols used have their usual contextual meanings

TIME ALLOWED: TWO (2) HOURS

1. An increased venous return affects the preload hence the volume of blood flowing into the aorta.
    a. What is preload?

    (3 marks)

    b. What effect does this increased venous return have on the preload?

    (3 marks)

    c. How does the change in the preload affect the force generating capacity of the heart? Which law explains this behaviour?

    (4 marks)

    d. With the aid of well-labelled pressure-volume graphs, briefly explain how this change in preload affects the stroke volume.

    (10 marks)

2. A patient is admitted to the hospital with a case of blood acidosis due to decreased responsiveness to hypoxia. As the biomedical engineer in charge, you are tasked to design a simple ventilation assist device to replace a recently broken down one. The P_{CO_2} and P_{O_2} of the patient's blood has been determined to be 55 mmHg and 31 mmHg, respectively.

    a. Briefly explain blood acidosis.

    (5 marks)

    b. State any two (2) causes of blood acidosis aside the one mentioned.

    (5 marks)

    c. Given that the alveoli have a functional surface area of 70 m^2 and alveolar-capillary thickness of 2μm,

i. What percentage of oxygen would the 800 mmHg gas supply of your device need in order to establish an oxygen diffusion rate of 600 m^3s^{-1}? [O_2 solubility = $0.024 m^2s^{-1}Pa^{-1}$, M = 32]

(10 marks)

ii. Calculate the total resistance offered by the lungs to the diffusion of oxygen if the rate of oxygen-haemoglobin combination is 2000 $s^{-1}Pa^{-1}$. [Volume of blood in pulmonary capillary is 70 ml].

(5 marks)

3. The radius of the aorta in a test subject determined by MRI is 1.5 cm. During exercise, he has an end diastolic volume of 150 mL. This corresponds to a diastolic pressure of 80 mmHg and a measured systolic pressure of 125 mmHg. The cardiac cycle starts at the opening of the mitral valve which closes after 0.3 s, filling the left ventricle at a rate of 267 mL s^{-1}. All the blood supplied to the left ventricle is ejected into the aorta during systole which lasts for 0.65 s. If the density of blood is 1050 kgm^{-3} and its viscosity is 3.0×10^{-3} Pa s,
   a. Calculate the mean arterial pressure.

   (2 marks)

   b. Determine the stroke volume of the subject during exercise.

   (2 marks)

   c. Calculate the end systolic volume.

   (2 marks)

   d. Determine the exercise heart rate to the nearest whole number.

   (3 marks)

   e. Calculate the cardiac output.

   (2 marks)

   f. Determine the systemic vascular resistance if you assume a central venous pressure of 0 mmHg.

   (3 marks)

   g. What is the average speed of blood in the aorta?

   (4 marks)

   h. What is the Reynolds number for the flow of blood during ejection?

   (2 marks)

   i. Is blood flow in the aorta laminar or turbulent? Why?

   (2 marks)

   j. What is the kinetic energy of the ejected blood?

   (3 marks)

4. Haematocrit plays a very important role in determining the viscosity of blood. One effect of Haematocrit behaviour in blood has been described by the Fahræus-Linqvist effect.
   a. Briefly explain the Fahræus-Linqvist effect and how it applies to blood flow in the smaller blood vessels.

   (8 marks)

b. An experiment to determine the viscosity of blood by measuring the shear stress at different shearing rates produces the following results:

Shearing rate ($\frac{dv}{dr}$)/s^{-1}	**Wall shear stress (τ_{xy})/Pa**
0.0	20.0
10.0	20.5
20.0	21.0
40.0	22.0
60.0	23.0
80.0	24.0
100.0	25.0
120.0	26.0

i. Plot a graph of shear stress against shearing rate. Use an appropriate scale.

(6 marks)

ii. Based on the graph you have drawn, what model of fluid flow behaviour would you conclude this blood follows? Explain your choice?

(6 marks)

iii. What does the intercept on the y-axis represent?

(2 marks)

iv. Calculate the apparent viscosity of this blood.

(4 marks)

v. Deduce a mathematical expression relating the shear stress (τ_{xy}) to the shearing rate ($\frac{dv}{dr}$).

(4 marks)

Formula Bank:

$$T = F \times moment\ arm$$

$$F = Stress \times Area$$

$$\tau = \mu \frac{dv}{dr}$$

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

$$Q = A_1 V_1 = A_2 V_2$$

$$Q_1 = Q_2 + Q_3$$

$$F = Q\rho(v_2 - v_1)$$

$$P_1 + \frac{1}{2}\rho {v_1}^2 + \rho g z_1 = P_2 + \frac{1}{2}\rho {v_2}^2 + \rho g z_2$$

$$\Delta P = \frac{8\mu L Q}{\pi R^4}$$

$$\frac{X_E}{D} = 0.06Re$$

$$Re = \frac{\rho v d}{\mu}$$

$$h_L = f \frac{L}{D}\frac{v^2}{2g}$$

$$f_{lam} = \frac{64}{Re}$$

$$f_{turb} = \frac{0.316}{Re^{1/4}}$$

$$c = \sqrt{\frac{Et}{2r\rho}}$$

$$Z = \frac{\rho c}{A}$$

$$a = \frac{1}{Z}$$

$$SV = EDV - ESV$$

$$CO = HR \times SV$$

$$MAP = DP + \frac{SP - DP}{3}$$

$$MAP = (CO \times SVR) + CVP$$

$$\rho(blood) = 1050 kgm^{-3}$$

$$g = 9.81\ ms^{-2}$$

$$1mmHg = 133\ Pa$$

$$v = \omega r$$

$$c = \sqrt{\frac{Et}{2r\rho}}$$

$$D = \frac{\Delta P A s}{\Delta x \sqrt{M}}$$

$$D_a = \frac{\dot{V}_{gas}}{P_a - P_c}$$

$$R = \frac{1}{D_a}$$

$$R = \frac{1}{\theta V_c}$$

$$\Gamma = \frac{a_0 - (a_1 + a_2)}{a_0 + (a_1 + a_2)}$$

$$\mathrm{T} = \frac{2a_0}{a_0 + (a_1 + a_2)}$$

$$\mathrm{T} - \Gamma = 1$$

$$\frac{E_t}{E_i} = \frac{a_t T^2}{a_i}$$