UNIVERSITY OF GHANA

BSC. ENGINEERING
FIRST SEMESTER EXAMINATIONS: 2017/2018

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

INSTRUCTIONS:

Attempt all questions
All questions should be answered in the booklet provided
Calculations should be detailed and systematic. Marks are allocated to steps
All symbols used have their usual contextual meanings

TIME ALLOWED: *TWO (2) HOURS*

The preamble below is applicable to Questions 1 and 2:

A mechanical ventilator is a device used in healthcare settings to aid patients breathe by assisting or completely controlling the activity of breathing. For a patient suffering from a neuromuscular condition that prevents independent inspiration, the assist device only delivers 40% oxygen-content air at a pressure of 760.1 mmHg and rate of 18 breaths per minute. This is to maintain arterial O_2 and CO_2 partial pressures of 100 mmHg and 40 mmHg, respectively. The patient has a total functional alveolar surface area of 60 m^2 and an intra-alveolar pressure after expiration of 760 mmHg. [Density of air = 1.12 kgm^{-3}, kinematic viscosity of supplied air = $16.4\times10^{-6} m^2s^{-1}$, P_{H_2O}=47 mmHg, respiratory exchange ratio (R) = 0.8]

1.

a. Explain how the patient exhales given the above description and set-up of the ventilator.

(5 marks)

b. Given that the 1.5×10^{-4} m^3 conducting airways have a resistance of 9.9×10^4 $Pa.s.m^{-3}$ and an effective length of 300 cm, calculate

i. the effective radius of the conducting airways.

(4 marks)

ii. the pulmonary ventilation rate.

(5 marks)

iii. the tidal volume.

(3 marks)

iv. the alveolar ventilation rate.

(3 marks)

c. Determine the level (pressure) of alveolar oxygen.

(10 marks)

2. The condition does not affect the patient's cardiovascular function and the heart performs normally by perfusing the lungs at 5 L/min at a heart rate of 60 beats/min. Blood perfusing the lungs has O_2 and CO_2 pressures of 40 mmHg and 46mmHg with solubility coefficients of 0.024 $m^2s^{-1}Pa^{-1}$ and 0.57 $m^2s^{-1}Pa^{-1}$, respectively. [θ = 2000$s^{-1}Pa^{-1}$, M=32]
   a. What is the ventilation-perfusion ratio for the patient?
   (4 marks)
   b. Determine the total resistance to diffusion of oxygen from the alveoli into the pulmonary capillaries given a diffusion rate of 540 m^3s^{-1}.
   (10 marks)
   c. State the assumption made in (b).
   (3 marks)
   d. How thick is the alveolar-capillary wall?
   (8 marks)

3. The rotating cylinder viscometer is used to determine the viscosity of fluids including blood.
   a. State and briefly explain two (2) factors that affect blood viscosity.
   (5 marks)
   b. Describe with the aid of a sketch the construction of the rotating cylinder viscometer.
   (5 marks)
   c. Explain how the viscometer is used to determine the viscosity of blood indicating the associated theories/principles and how they are applied.
   (7 marks)
   d. Based on your understanding of viscosity, briefly explain the effect high blood viscosity will have on blood pressure.
   (5 marks)
   e. What effect does plasma skimming have on blood viscosity in branch vessels?
   (3 marks)

4. Pressure-volume graphs are used to describe the functioning of the heart in terms of the volume and pressure changes associated with distinct phases of the cardiac cycle. These volume and pressure changes are also linked to the length and tension generated in the cardiac muscle.
   a. With the aid of a pressure-volume graph and tension-length graph, describe the normal cardiac cycle, indicating the relationships among pressure, volume, tension and muscle length.
   (15 marks)
   b. Explain how the Frank-Starling law of the heart relates to the length-tension relationship.
   (5 marks)

Formula Bank:

$$1\,mmHg = 133\,Pa$$

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

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

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

$$F = Stress \times Area$$

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

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

$$Q = A_1 V_1 = A_2 V_2$$

$$Q_1 = Q_2 + Q_3$$

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

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

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

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

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

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

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

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

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

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

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

$$SV = EDV - ESV$$

$$CO = HR \times SV$$

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

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

$$v = \omega r$$

$$\dot{V}_P = v_R(V_T)$$

$$\dot{V}_A = v_R(V_T - V_D)$$

$$P_A O_2 = \left[(P_B - P_{H_2O}) \times F_I O_2\right] - \frac{P_a CO_2}{R}$$

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

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

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

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

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

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

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

$$\nu = \frac{\mu}{\rho}$$