Carleton University, Systems and Computer Engineering

BIOM 5100/SYSC 5302: Final Exam: December 10, 2008

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Instructions:

- This exam has **3** pages and **3** questions. Answer any **two (2)** of them. Marks are indicated
- You have **180 minutes** to complete this exam.
- This is a closed book exam; however, you are permitted to bring one 8.5" × 11" sheet of notes.
- Write your answers on an examination booklet. You may take this examination paper with you
- You may use the following equations and constants:

$E = mc^2$	$R_c = (8\eta L)/(\pi r^4)$	$E = E_0 + \frac{RT}{nF}\, ln\, a_c$	Charge e^-: 1.6×10^{-19} Coul
$c = 3 \times 10^8 \frac{m}{s}$	$L_c = (\rho L)/(\pi r^2)$	$R = 8.31$ J/(K·mol)	$P_{atm} = 101.3$ kPa $= 760$ mmHg
$F = ma$	$C = (\Delta V)/(\Delta P)$	$F = 9.65 \times 10^4 \frac{Coul}{mol}$	1 mol $= 6.02 \times 10^{23}$ particles
$P = \dot{V}R$	$P(\frac{V}{N})^\alpha =$Const	$dV + \frac{V}{\alpha P}dP = \frac{1}{\rho}dN$	Resistivity: $\rho_{\text{blood}} = 450\Omega$·cm
$\rho_{\text{air}} = 1.21\frac{kg}{m^3}$	$\rho_{\text{blood}} = 1060\frac{kg}{m^3}$	$\eta_{\text{air}} = 1.8 \times 10^{-6}$ Pa·s	$\eta_{\text{blood}} \approx 3.0 \times 10^{-3}$ Pa·s

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1. **ECG Measurement**

   We would like to monitor the heart rate of a subject while she is exercising. Exercise causes three main difficulties for measurement of the ECG: a) movement artefacts, b) sweat on the electrodes, and c) artefacts from the EMG in the ECG.

   We consider two different electrodes systems to measure the ECG. #1) we place two Ag/AgCl electrodes each shoulder of the subject, and #2) we ask the subject to hold onto stainless steel handles which act as electrodes.

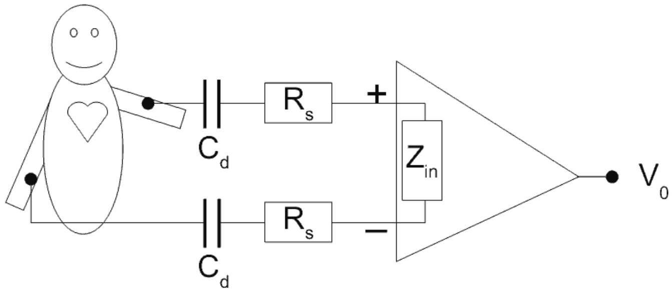
   (a) (5 points) **Briefly describe the origin of movement artefacts.** Use an equation or diagram if necessary. **Do movement artefacts differ for electrodes #1 and #2?** Explain (≤ 50 words).

   (b) (5 points) **Briefly describe the effect of sweat on the electrodes.** Show equivalent electrical models of the electrodes. **Does sweat affect electrodes #1 and #2 differently?** Explain (≤ 50 words).

   (c) (5 points) **Briefly describe how artefacts from the EMG affect the ECG. Can a filter be used to clean the signal?** Use a diagram if necessary. **How is the effect different on electrodes #1 and #2 different?** Explain (≤ 50 words).

   (d) (5 points) **Draw a diagram of the ECG waveform. Label the P,Q,R,S, and T events.** In a segment of the ECG, R waves occur at the following times (after the start of measurement) 9.95s, 10.49s, 11.23s, 11.61s, and 12.45s. **Estimate the heart rate (in beats/min).**

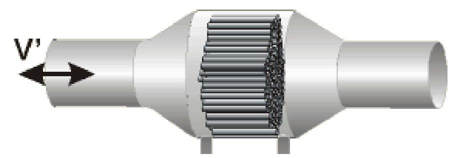
   (e) (10 points) Consider the circuit diagram shown. The amplifier is configured so that the differential gain is 100. From the specifications of the amplifier, it has a common mode rejection ratio of 80 dB and an input impedance, Z_{in}, of 1 MΩ. Two stainless steel electrodes are attached with electrode model parameters $C_d = 0.3\ \mu$F and $R_s = 1$ kΩ. The common mode voltage due to power-line interference is 3.0 V and the differential voltage is 3.0 mV (which can can consider to be at 10 Hz). **What is the ratio of the differential to common mode signal at the amplifier output, V_0?**



(f) (10 points) Consider a standard Ag/AgCl electrode where the electrode gel is modified by sweat from the subject. When fresh out of the package, the electrode gel has a concentration [Cl$^-$]$= 0.1\frac{\text{mol}}{\text{L}}$. Sweat has approximately [Cl$^-$]$\approx 0.01\frac{\text{mol}}{\text{L}}$, and thus will reduce the concentration in the gel. **Calculate the change in electrode voltage when [Cl$^-$] changes from $0.1\frac{\text{mol}}{\text{L}}$ to $0.05\frac{\text{mol}}{\text{L}}$.** Assume skin temperature is 30°C. **In practice, will sweat show up as a fast or slow contribution to the signal, and as a differential or common mode effect?**

2. **Breathing Measurement**

We wish to measure breathing parameters patient from a patient using a Fleisch-type pneumotach as shown at right and a fast gas analyzer. (Image reproduced from `spirxpert.com/technical2.htm`)



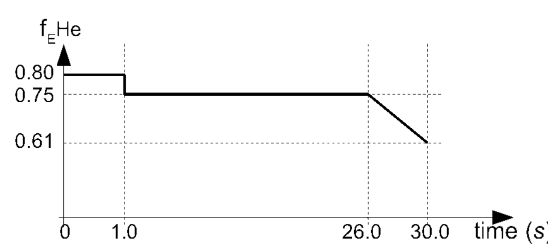
(a) (5 points) **How does such a pneumotach work?** Sketch a diagram showing how it is connected to a patient, and what measurements are made on it. Briefly (≤ 30 words) describe how the pneumotach can measure air flow.

(b) (5 points) A Fleisch-type pneumotach with 100 channels is used, each has a diameter of 1 mm and a length or 3 cm. **Estimate the flow resistance of the pneumotach in units of $\frac{\text{kPa}}{\text{L/s}}$** .

(c) (5 points) **Explain one of the following problems with a pneumotach, and discuss a way to address the problem**: (1) Pneumotachs give a different signal level for the same quantity of air flowing into and out of the lungs, due to heating and humidification of the air; (2) Pneumotachs tend to get full of condensation because of humid expired air.

(d) (10 points) We ask a patient to perform a vital capacity manouevre. Starting at FRC, he (a) slowly breathes out (at 200 ml/s for 6.0 s), then (b) rapidly breathes in (at 1000 ml/s for 4.5 s), then (c) holds his breath for 2.0 s, then (d) slowly breathes out (at 150 ml/s for 30.0 s). **Calculate expiratory reserve volume (ERV), Inspiratory Capacity (IC), and Vital Capacity (VC) for this patient.** If the patient has a lung resistance, $R_L = 2.0\ \frac{\text{kPa}}{\text{L/s}}$, and lung compliance, $C_L = 1.2\ \frac{\text{L}}{\text{kPa}}$, **sketch time curves of flow $\dot{V}_L$, volume V_L, and muscular pressure P_{mus} required to perform this manouevre.** Remember to account for the resistance of the pneumotach.

(e) (10 points) In the previous question, during inspiration (b), the patient inspired heliox gas (80% He, 20% O_2). The fraction of He in expired gas f$_E$He as a function of time during expiration (d) is shown at right. **Calculate residual capacity (RC).** Assume gas remaining in the lungs has He concentration of



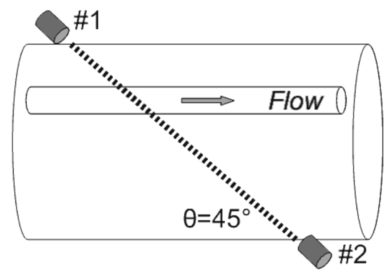
f_EHe= 0.61, and that the patient was breathing atmospheric air (use 80% N_2, 20% O_2) before the experiment. Ignore water vapour for your calculations.

(f) (5 points) One widely used way to measure the concentration of O_2 in arterial blood is with a pulse oxymeter. **How does a pulse oxymeter work?** Sketch a diagram if necessary. Explain why it measures arterial, and not venous blood oxygenation, or tissue oxygenation. Note that there is much more venous blood and tissue than arterial blood.

3. **Blood Pressure and Flow**

(a) (5 points) A time-of-flight Doppler ultrasound system measures blood flow by placing two ultrasound transducers at an angle θ on either side of a blood vessel. First, one transducer transmits a pulse while the other receives, and then the roles are switched. **Describe how flow can be measured from such an ultrasound system.**

(b) (10 points) A Doppler ultrasound system is shown at right, where blood flows through a 0.5 cm diameter artery in the arm at 2 ml/s. Assume the flow profile is uniform (blood flows at the same speed at any position in the artery). An ultrasound transducer transmits a 3.0 MHz pulse which travels at 1500 m/s through the tissue. The distance between transducers is 15 cm.



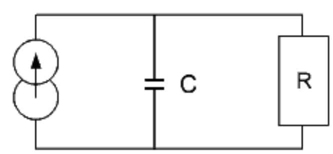
Calculate the transmit-receive delay from transducer #1 to #2. How different is this from the delay when the flow is zero? **Comment briefly on any difficulties measuring changes in a delay of this size.**

(c) (5 points) A photoplethysmography (PPG) system can be used to monitor peripheral blood flow. **Sketch a PPG system, and discuss briefly how it works.** PPG measures relative changes in flow, but not the absolute flow level. **Discuss why?**

(d) (5 points) If a PPG system breaks, it could potentially become a shock hazard. **Sketch the current pathways for a possible failure mode, and briefly discuss what damage it could cause to the subject.**

(e) (5 points) The compliance of the aorta is a key factor in determining the level of systolic blood pressure. Stiffening of the aorta with age can result in increases in blood pressure. **Calculate the compliance of the aorta**, assuming the aorta length is 30 cm with 3 cm diameter, and the aorta diameter increases 1mm per kPa of blood pressure.

(f) (10 points) A simple model of the circulatory system is shown at right. The heart is a current source which pushes blood into a resistance, R, representing the systemic circulatory system. The aortic compliance is C.



Assume a heart rate of 60 beats per minute; systole lasts 200 ms and the heart ejects 70 ml. The diastolic pressure is 80 mmHg, and $R = 25\frac{\text{kPa}}{\text{L/s}}$. **Calculate the RC time constant and sketch the blood pressure waveform for this model. Discuss briefly** (≤ 50 words) **how this pressure waveform compares to that of a normal subject.**