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BioE 110
Biomedical Physiology for Engineers
Final Assignment
Spring 2011

Name	
SID	
Signature* (required)	

SCORE (for instructors only)

Question 1:		/30
Question 2:		/35
Question 3:		/55
Question 4:		/30
Question 5:		/50
Question 6:		/40
Question 7:		/15
Question 8:		/30
TOTAL		/285

*Your signature affirms that you understand and have followed the rules listed on page 2, and that you have worked completely independently on this assignment.

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RULES FOR FINAL ASSIGNMENT

- To facilitate grading, please print out this assignment and write your answers in the spaces provided, similar to the midterm exams. If you need additional pages, feel free to attach them.

- As always, show your work and clearly mark your final answer.

- A hard copy of the assignment will be due to the Bioengineering office (306 Stanley Hall) by **4:30 pm on Monday, May 9**.

- The assignment is "open book, open notes," which means you may freely consult your textbook, notes, problem sets, exams, and online resources and databases. Note that this does not include personal communications of any kind, including email, with anyone inside or outside of this class (the sole exception is that you may email Prof. Kumar and/or the GSIs for clarification).

- All answers must be expressed in your own words and show reasoning and calculations. For example, if you are given a circuit and asked to calculate total current, it is unacceptable to say that you arrived at your answer by plugging the circuit into a piece of software. Similarly, unit conversions must be carried through manually. As a rule: when in doubt, show your calculations.

- Revised versions of the exam will be posted as corrections and clarifications come to light, so please monitor your email and BSpace for these announcements and postings. You are responsible for keeping up with these updates, but it is not necessary to reprint the exam every time a revision or clarification is posted.

- **No consultation of any kind with others is permitted.** This includes but is not limited to discussing strategies to solve problems, discussing interpretations of questions, and comparing solutions.

- The assignment is designed to take 3-4 hours from beginning to end, but you may spend as much time working on it as you wish prior to the deadline. I would recommend clearing off a block of time in your schedule to complete the assignment in one sitting.

Good luck!

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1. Consider an experiment in which a solution of an ionic salt AX and a solution of a second ionic salt BX_2 are each housed in a separate chamber at temperature T and that the two chambers are divided by a membrane that is freely permeable to water. Suppose the molar concentrations of AX and BX_2 are C_{AX} and C_{BX2}, respectively, the reflection coefficients of the ionic species are σ_A, σ_B, and σ_X, respectively, and both salts dissociate completely into their constituent ions (A^+, B^{+2}, and X^-)under these conditions.

A. Derive an expression for the equilibrium osmotic pressure difference across the membrane. (10 pts)

B. Now suppose the reflection coefficient of each ion is 1. What must be the ratio of concentrations in the two chambers (C_{AX}/C_{BX2}) to ensure no osmotic flow of water across the membrane? (10 pts)

C. One way to model water flow though a semipermeable membrane is to think of each pore in the membrane as a tiny cylindrical pipe that enables water to flow in a laminar fashion from one side of the membrane to another. With this model in mind, consider two membranes that both have the same number of pores per unit area. One membrane is 50 μm thick and has an average pore radius of 10 μm, whereas the other membrane is 10 μm thick and has an average pore radius of 50 μm. For a given osmotic pressure, which membrane would support faster flow? What would be the ratio of the two flow rates? (10 pts)

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2. Consider a lipid vesicle that has a radius of 100 nm and wall thickness of 10 nm that is filled with 20 mEq/L Ca^{+2}, 40 mEq/L K^{+}, and 80 mEq/L $Cl^{-}$and bathed in a solution that contains 50 mEq/L Ca^{+2}, 20 mEq/L K^{+}, and 140 mEq/L Cl^{-}. The temperature is 37 C and the viscosity and density of both solutions are 1 cP and 1 g/cm^3, respectively.

A. Calculate the equilibrium potentials of Ca^{+2}, K^{+}, and Cl^{-} across the membrane of the vesicle. (10 pts).

B. If a drug is added that renders the membrane completely impermeable to Cl^{-}, the resting membrane potential under these conditions is -10 mV, calculate the ratio of the conductance of Ca^{+2} to that of K^{+} (i.e., g_{Ca2+}/g_{K+}). (10 pts)

C. Now consider a separate experiment in which a single vesicle of the same dimensions as above contains a sucrose solution of initial concentration of 100 mM and is placed in a large volume of 10 mM sucrose solution. Assuming sucrose has a molecular radius of 10 A and a partition coefficient of 1, derive an expression for the concentration of sucrose in the vesicle as a function of time (and no other parameters/variables). Assume the volume of the vesicle remains constant and ignore all effects of osmotic flow. (15 pts)

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3. A 52-year old man presents to your emergency room with a 6-hour history of crushing substernal chest pain. He had recently eaten a spicy meal and initially thought this was acid reflux but became concerned when the pain persisted even after two doses of antacids. On physical examination he is found to have a heart rate of 102 beats per minute, blood pressure of 155/90 (in mmHg), respiratory rate of 17 breaths per minute, and an oxygen saturation of 92% on room air. He is also noted to be sweating profusely, breathing in a labored fashion, and bearing a slightly blue complexion on his lips.

A. Calculate this patient's pulse pressure and mean arterial pressure. (10 pts)

B. Suspecting an ongoing myocardial infarction (heart attack), you obtain an EKG. Based on the results you place this man on supplemental oxygen, aspirin, sublingual nitroglycerin, and a dose of atenolol. Identify which one (or ones) of these 4 therapeutic interventions directly affect the following (1) left ventricular afterload; (2) myocardial oxygenation. Briefly justify each answer. (10 pts)

C. Imagine a thought experiment in which you are able to isolate a healthy cardiomyocyte from this patient's sinoatrial (SA) node and a second cardiomyocyte from his atrioventricular (AV) node. Draw three sets of axes and label each of them as membrane potential vs. time. On the first set of axes, sketch a few action potentials for the SA node cardiomyocyte, and on the second set of axes do the same for the AV node cardiomyocyte. Suppose you treat the SA node cardiomyocyte with a drug that inhibits but does not completely block T-type calcium channels. On the third set of axes, sketch the action potential for the drug-treated cardiomyocyte. Be clear on what the differences between the 3 curves are. (10 pts)

D. Imagine that this patient has cardiac and vascular function curves (CFC and VFC) that can be described by the following equations for a right atrial pressures (RAP) between 0 and 6 mmHg:

CFC: CO [cardiac output, L/min] = 2*RAP
VFC: VR [venous return, L/min] = 6 – 2.5*RAP

Calculate: (1) the combined flow rate of blood entering the pulmonary arteries at steady state; (2) the mean systemic pressure; and (3) A new equation for the CFC if a patient is treated with a drug that doubles ventricular contractility. (15 pts)

E. As part of his workup, you schedule the patient for cardiac echocardiography (ultrasound) to evaluate his left ventricular function. This reveals that during the cardiac cycle, the left ventricle contains 155 mL of blood when maximally filled (dilated) and has an ejection fraction of 0.55. Calculate the stroke volume and cardiac output. (10 pts)

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4. Consider a 25-year old woman undergoing a spirometry study. Suppose she has a tidal volume of 600 mL, an inspiratory capacity of 3700 mL, and a vital capacity of 5000 mL. Suppose that each tidal breath requires 4 seconds from beginning to end.

A. Calculate the inspiratory and expiratory reserve volumes. (10 pts)

B. Given the following lab values, calculate the alveolar ventilation rate, assuming the heart rate is 72 beats/min and the patient has an overall V/Q ratio of 0.75. When these values were obtained, the woman was breathing dry room air at 37C. (10 pts)

Arterial blood gas: P_aCO_2 = 35 mmHg, P_aO_2 = 100 mmHg, HCO_3^- = 25 mEq/L
Venous blood gas: P_vCO_2= 51 mmHg, P_vO_2 = 85 mmHg, HCO_3^- = 25 mEq/L
Exhaled breath sample: P_ECO_2 = 32 mmHg, P_EO_2= 105 mmHg

C. Calculate the partial pressure of this woman's alveolar oxygen (P_AO_2). Assume that the patient is consuming oxygen at a rate that is 20% higher than the rate at which she is producing carbon dioxide. (10 pts)

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5. Consider a 75 kg man for whom approximately 60% of his weight is composed of water. Suppose he has the following plasma electrolyte values, complete blood count.

Blood
Na^+: 140 mEq/L
K^+: 4 mEq/L
Cl^-: 35 mEq/L
HCO_3^-: 25 mEq/L
Glucose: 95 mg/dL
Blood urea nitrogen: 14 mg/dL
Creatinine: 1.2 mg/dL
Berkeleic oxide*: 1 mg/dL
Hematocrit: 0.46
White Blood Cell count: 4500 cells/mm^3
Hemoglobin: 15 g/dL
Platelet count: 200,000 per mm^3

Urine
Osmolarity: 300 mOsm/L
Creatinine: 240 mg/dl
24-hour urine output: 500 mL/day
Berkeleic oxide*: 500 mg/dL

*Note; Berkeleic oxide is an inert food additive that this man has been ingesting and excreting at a steady level for many years. Berkeleic oxide has an interesting property: all Berkleic oxide arriving at the kidney via the renal artery during a given time interval is excreted into the urinary stream, through a combination of filtration and secretion.

A. Estimate this man's intracellular and extracellular fluid (ICF nad ECF) volume. State and justify any assumptions you make in arriving at these values. (10 pts)

B. Estimate this man's glomerular filtration rate and renal blood flow. (10 pts)

C. Estimate this man's clearance of free water. (10 pts)

D. If this man eats a bag of 20 potato chips, where each chip contains 2.5 mg of NaCl and negligible amounts of glucose, estimate the ECF and ICF volumes and osmolarities following equilibration. Ignore all effects of urine, sweat, and metabolism. (10 pts)

E. If, after eating the potato chips, the patient then drinks 500 mL of water, calculate the new ICF and ECF volumes and osmolarities following equilibration. Ignore all effects of urine, sweat, and metabolism. (10 pts)

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6. Answer the following questions in 1-3 sentences each.

A. Consider a cation R+ that is secreted into the tubular fluid in the proximal tubule of the nephron. Propose a plausible mechanism for R+ secretion that involves Na+/K+ ATPase activity and an Na+/R+ antiporter. (10 pts)

B. Conisder two identical animals, one of which you treat with a drug that stops all blood flow in the vasa recta, the other of which is an untreated control. If you deprive each animal of water, which one will have a higher urine osmolarity and why? (10 pts)

C. Suppose a patient is administered a drug that specifically inhibits the brush border carbonic anhydrase. Predict what will happen to urinary and blood pH and explain why. (10 pts)

D. A 13-year old boy suffers a severe bee sting and is treated with an intramuscular injection of a newly-developed epinephrine analog. While this rapidly reverses the allergic reaction, within 2 hours the boy begins to develop an arrhythmia (irregular heartbeat), palpitations, and muscle weakness. Provide a plausible explanation for the adverse drug reaction that involves levels of a specific blood electrolyte. (10 pts)

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7. Imagine that you are working at a biotechnology company, where you are developing an artificial blood substitute to be used for transfusions. Suppose you decide to buffer this blood substitute with the bicarbonate buffering system and include some recombinant carbonic anhydrase. Due to the presence of some additives needed to maintain sterility, the bicarbonate buffering system operates somewhat differently than in the body. Specifically, the K_a of carbonic acid under these conditions is 2.51×10^{-7} M and the solubility of CO_2 is 38 mmol/L/atm. Derive an equation that relates the pH of the blood substitute to $[HCO_3^-]$ (in mEq/L) and pCO_2 (in mmHg). (15 pts)

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8. For patients with each of the following lab values, identify:

(1) His/her ongoing primary acid/base disorder, if any (your choices are acidosis, alkalosis, or no acid/base disorder).

If a primary acid/base disorder is present, also determine:

(2) The anion gap (and state whether this is elevated)

(3) Whether the primary acid/base disorder is likely respiratory or metabolic in origin.

Normal ranges are as follows:

P_aCO_2: 35-45 mmHg
P_aO_2: 80-100 mmHg
pH: 7.35-7.45
$[HCO_3^-]$ = 21-28 mEq/L
$[Na^+]$: 135-145 mEq/L
$[Cl^-]$: 98-108 mEq/L
Anion gap: 8-12 mEq/L

A. P_aCO_2 = 55 mmHg; P_aO_2= 100 mmHg; pH = 7.33; $[HCO_3^-]$ = 28 mEq/L; $[Na^+]$= 135 mEq/L; $[Cl^-]$ = 104 mEq/L (10 pts)

B. P_aCO_2= 35 mmHg; P_aO_2= 95 mmHg; pH = 7.08; $[HCO_3^-]$ = 10 mEq/L; $[Na^+]$= 142 mEq/L; $[Cl^-]$ = 108 mEq/L (10 pts)

C. P_aCO_2= 42 mmHg; P_aO_2= 98 mmHg; pH = 7.43; $[HCO_3^-]$ = 27 mEq/L; $[Na^+]$= 140 mEq/L; $[Cl^-]$ = 102 mEq/L (10 pts)

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