NAME: SID:

BioE 110

Biomedical Physiology for Engineers

Final Exam

Spring 2009

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SID	

Write your name and SID on the top of each page!
If you need extra space, use the back of the sheet.
No computers or electronic communications devices allowed.

SCORE (for instructors only)

Question 1:		/25
Question 2:		/30
Question 3:		/30
Question 4:		/30
Question 5:		/30
Question 6:		/20
Question 7:		/15
Question 8:		/20
TOTAL		/200

NAME: SID:

1. Consider two neutral solutes, A and B, that are capable of diffusing through a semipermeable membrane.

A. Suppose A has a molecular radius that is 2.5 times that of B and a partition coefficient that is 1.5 times that of B. If the permeability of A through the membrane under a specific set of conditions is 10 cm/sec, what is the permeability of B (in cm/sec) through the same membrane under the same conditions? (10 pts)

B. Consider a chamber that consists of pure water and a solution of A of unknown concentration, with the two liquids separated by a semipermeable membrane. If the application of 3 atm of pressure to the solution of A is just sufficient to stop osmotic flow of water at room temperature (20 C), what is the concentration of A (in mM) in solution? Assume that A dissolves completely and without dissociating into multiple soluble particles, and that its reflection coefficient is 0.5. (10 pts)

C. Suppose you are studying the import of B into living cells and wish to determine whether B enters the cell by passive diffusion or via carrier-mediated transport (i.e. facilitated diffusion). Assuming you have a way of measuring the import rate of B across the membrane, describe a simple experiment you could do to distinguish between these two possibilities (some simple plots may help). (5 pts)

NAME: SID:

NAME: SID:

2. Consider the axon of a neuron that has the following intracellular and extracellular ion concentrations:

Intracellular: Na^+: 15 mEq/L; K^+: 120 mEq/L; Ca^{++}: 0.0001 mEq/L; Cl^-: 10 mEq/L
Extracellular: Na^+: 135 mEq/L; K^+: 5 mEq/L; Ca^{++}: 3 mEq/L; Cl^-: 100 mEq/L

A. Based on the information above, the concentration of intracellular cations far exceeds the concentration of intracellular anions. Yet, the interior of the cell is essentially electroneutral. Explain this discrepancy; i.e., what are the "missing" intracellular anions? (5 pts)

B. Calculate the equilibrium potentials of Na+ and Cl-. (10 pts)

C. If under some condition the ratio of the conductances of Na^+ and Cl^- is 3:1, and the conductance of Cl^- is 500 times those of K+ and Ca++, estimate the membrane potential. (10 pts)

D. Suppose this axon conducts an action potential using the mechanisms discussed in class and in the text. Suppose you inserted a micropipet at some position along the axon and depolarized it at that point. Would you expect the resulting action potential to be bidirectional (i.e., propagating in both directions simultaneously along the axon) or unidirectional, and why? (5 pts)

NAME: SID:

NAME: SID:

3. Consider a 75-year old man who presents to the emergency room with a two-week history of shortness of breath. He has a longstanding history of poorly-controlled hypertension, and he suffered a myocardial infarction due to coronary artery disease five years ago for which he received balloon angioplasty. Physical exam reveals a heart rate of 75 beats per minute, blood pressure of 150 mmHg/85 mmHg, and a respiratory rate of 30 breaths/min.

Chest x-ray reveals an enlarged heart and bilateral pulmonary edema (fluid). Cardiac ultrasound reveals a left ventricular end-diastolic volume of 120 mL and a left-ventricular end-systolic volume of 80 mL.

The patient's condition dramatically improves following 2-3 days of treatment with supplemental oxygen, furosemide (lasix), and digoxin (digitalis, a Na^+/K^+ ATPase inhibitor).

A. Calculate the ejection fraction prior to treatment. (5 pts)

B. Calculate the total peripheral resistance (in mmHg/mL/min) prior to treatment. (10 pts)

C. Using terms in the Starling Equation for capillary transport, explain why the furosemide helps resolve the patient's pulmonary edema. (5 pts)

D. Ignoring the effects of the other drugs, sketch the Frank-Starling curve (cardiac output vs left ventricular end-diastolic volume) before and after administration of the digoxin, and explain in molecular terms how the digoxin gives rise to this effect. (10 pts)

NAME: SID:

NAME: SID:

4. Consider a 60 year-old woman who presents with a history of wheezing and coughing that started 6 months ago and has been getting worse. Her past medical history is notable for a 30 year, 2 pack/day history of smoking, and on physical exam she appears blue-colored and barrel-chested (i.e., her chest volume appears unusually large and expanded). An arterial blood gas reveals a pCO_2 of 50 mmHg.

Chest x-ray reveals hyperinflation in both lungs, but no evidence of any masses. Pulmonary function tests reveal that the FEV_1/FVC ratio is 50% of the value that would normally be expected for a person of her age and weight.

Based on this, the patient is diagnosed with pulmonary emphysema.

A. Why is the patient barrel-chested? Explain your answer in terms of the mechanical properties of the lung and chest wall. (10 pts)

B. If this patient is breathing air at 37C and 760 mmHg (1 atm), estimate the partial pressure of O_2 in the alveoli. Assume that the vapor pressure of water at 37C is 47 mmHg, the mole fraction of oxygen in air is ~0.2, and the respiratory exchange ratio is 0.8. (10 pts)

C. The low FEV_1/FVC ratio and hyperinflation imply that the patient cannot effectively expel air from her lungs, and the wheezing implies that this is due to collapse of the airways upon expiration. Explain how the patient's emphysema is leading to airway collapse. (5 pts)

D. Would the alveolar-arterial (A-a) oxygen gradient in this patient be higher or lower than normal and why? Would supplemental oxygen help normalize this defect? (5 pts)

NAME: SID:

NAME: SID:

5. Consider a patient with the following laboratory values:

Urinalysis
Urine output over 24-hour period: 1500 ml
Urine concentration of K^+: 50 mEq/L
Urine concentration of Na^+: 25 mEq/L
Urine concentration of creatinine: 20 mg/dL
Urine osmolarity: 800 mEq/L

Blood work
Plasma concentration of K^+: 4.0 mEq/L
Plasma concentration of Na^+: 140 mEq/L
Plasma concentration of BUN: 17 mg/dL
Plasma concentration of creatinine: 1.0 mg/dL
Plasma concentration of Glucose: 90 mg/dL
Hematocrit: 0.45

A. Using only the information above, estimate the glomerular filtration rate. (10 pts)

B. Assuming a filtration fraction of 0.20, calculate the renal blood flow. (10 pts)

C. Calculate the clearance of free water. Given your answer, does the patient likely have high or low circulating levels of anti-diuretic hormone (ADH)? (10 pts)

NAME: SID:

NAME: SID:

6. Consider a patient with the following laboratory values:

Plasma: Na^+: 140 mEq/L, K^+: 4 mEq/L, $HCO3^-$: 18 mEq/L, Cl^-: 100 mEq/L
Arterial Blood gas: pO_2: 100 mmHg, pCO_2: 33 mmHg, pH: 7.2

A. Classify this patient's primary acid-base disorder (e.g., respiratory acidosis, metabolic alkalosis). (5 pts)

B. In determining the cause of this acid-base disorder, you learn the patient consumed a large amount of aspirin a few hours before presenting at the hospital. Is this a plausible cause of his acid-base disorder? Support your answer with an anion gap calculation. (10 pts)

C. On presentation, would you expect this patient's respiratory rate to be higher than normal, normal, or lower than normal, and why? (5 pts)

NAME: SID:

NAME: SID:

7. Short-answer questions about acid-base physiology.

A. Suppose you are working at a biotechnology company and developing a plasma substitute for bioreactor-based expansion of human T cells. Suppose this plasma substitute is buffered by HCO_3^-/CO_2 system (like blood) but that under the conditions used in the bioreactor, the pKa of the buffer is 7.2 and the solubility of CO_2 is 0.07 mmol/L/mmHg. Write an equation that shows how pH depends on $[HCO_3^-]$ and pCO_2 and contains no other variables (a derivation is not needed here as long as you can justify your answer). (5 pts)

B. The metabolic alkalosis developed by patients with chronic vomiting is often more severe than can be accounted for by the loss of stomach acid. What other major mechanism contributes to alkalosis in these patients? (5 pts)

C. Acetazolamide (diamox) is a carbonic anhydrase inhibitor used in the treatment of glaucoma. One of the side effects of this drug is metabolic acidosis. Why? (5 pts)

NAME: SID:

NAME: SID:

8. Short-answer questions about endocrine physiology

A. Hashimoto's thyroiditis, in which the thyroid gland fails due to autoimmune destruction of thyroid tissue, is virtually always accompanied by elevated levels of TSH. Why? (5 pts)

B. When insulin is released into the bloodstream, it takes minutes to reduce plasma glucose levels. Conversely, release of cortisol takes hours to days to stimulate gluconeogenesis. Invoking the mechanisms of action of insulin and cortisol, explain why these hormones' kinetics are so different. (5 pts)

C. Suppose a tumor destroys the nerve tracts (but not the blood vessels) that connect the hypothalamus and pituitary. Would you expect to see a larger abnormality in plasma oxytocin or LSH levels, and why? (5 pts)

D. The first trimester of pregnancy is sometimes accompanied by high circulating levels of thyroid hormone, in spite of the fact that TSH levels are lower than normal. What might account for this finding? (5 pts)

NAME: SID: