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BioE 110
Biomedical Physiology for Engineers
Final Exam
Spring 2010

Name	
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:		/40
Question 2:		/35
Question 3:		/35
Question 4:		/30
Question 5:		/35
Question 6:		/25
Question 7:		/30
Question 8:		/30
Question 9:		/20
TOTAL		/275

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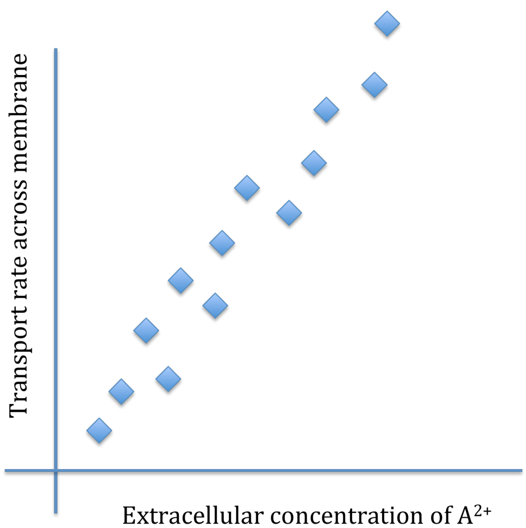
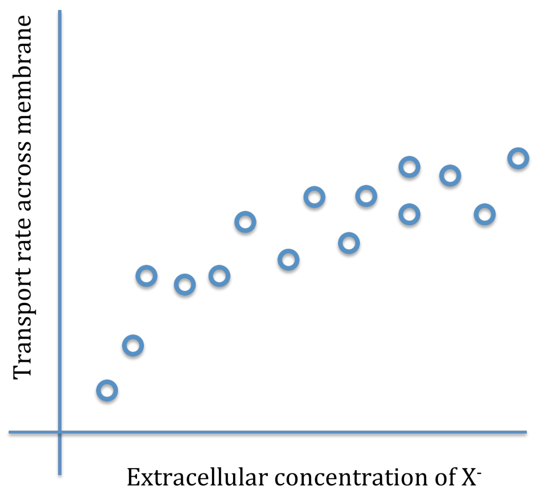
1. Consider a membrane that separates two chambers each containing solutions of the ionic salt AX_2, which completely dissociates to form the ions A^{2+} and X^- in the appropriate stoichiometry.

A. Suppose that A^{2+} has a molecular radius that is 1.3 times that of X^- and a partition coefficient that is 0.85 times that of X^-. Calculate the ratio of the diffusion coefficient (D) and permeability (P) of A^{2+} to X^- in water at 37C. (10 pts)

B. Suppose one chamber contains a 100 mM AX_2 solution and the other chamber contains a 15 mM AX_2 solution (both at 37 C), and the membrane is permeable to water but only partially permeable to A^{2+} and X^-. If A^{2+} has a reflection coefficient of 0.8 and X^- has a reflection coefficient of 0.9, how much pressure would need to be applied (and to which solution) to stop osmotic flow? (10 pts)

C. Suppose you treat a cell culture with varying external concentrations of AX_2 and have a way of measuring the transport rate of each ion across the plasma membrane (results below). For each ion explain whether the data are more consistent with an ion channel-based transport mechanism or a pump-based transport mechanism. (10 pts)





D. As George Costanza famously noted on *Seinfeld*, "These pretzels are making me thirsty!" Describe what happens to (1) extracellular fluid (ECF) volume and osmolarity; (2) intracellular fluid (ICF) volume and osmolarity; and (3) total body water (TBW) after one eats a bag of pretzels without drinking any water, and incorporate the concept of osmosis into your answer. Neglect all effects of sweat and urination. Which of these five properties (TBW, ICF/ECF volume and osmolarity) is the thirst response most sensitively tuned to? (10 pts)

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2. Consider a lipid vesicle that is filled with a 10 mM solution of NaCl and bathed in a solution of 100 mM NaCl. The temperature is 37 C, and NaCl is completely soluble under these conditions.

A. Calculate the equilibrium potentials of Na^+ and Cl^- across the membrane of the vesicle. (10 pts).

B. If the resting membrane potential is -1.2 mV, derive a linear equation that expresses the conductance of Na+ in terms of the conductance of Cl- and no other unknown quantities. Which ion has the greater conductance? (10 pts).

C. A very simple way to model the repolarization phase of the action potential would be with first-order kinetics, i.e. to say that the membrane potential [E(t)] starts at some initial value E_{max} and falls with a rate $dE/dt = -t/\tau$, where τ is a constant. Derive an equation that expresses E(t) in terms of t, τ, and E_{max}. (10 pts)

D. Action potentials typically only propagate in one direction along the axon, yet individual ion channels have no way of "knowing" which direction points towards the cell body and which points to the synapse. Explain this directionality, incorporating a specific molecular mechanism in your answer. (5 pts)

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3. Consider a physical examination and cardiac ultrasound that give the following results:

Heart rate: 80 beats per minute
Left ventricular end diastolic volume: 120 mL
Left ventricular end systolic volume: 75 mL

A. Calculate the stroke volume, the ejection fraction, and the cardiac output. (10 pts).

B. The process of ventricular contraction involves both "internal work" and "pressure-volume work." Distinguish between these two terms and explain which component grows to the greater degree in the setting of systemic hypertension. (5 pts)

C. Suppose blood from the aorta is distributed in parallel to the brain, heart, kidneys, GI tract, skeletal muscle, and skin. At rest, the relative resistances of these systems are given by the following ratio: R_{brain}: R_{heart}: $R_{kidneys}$: R_{GI}: R_{muscle}: R_{skin} = 1: 2: 3: 5: 7: 10. If R_{heart} = 0.02 mmHg min ml^{-1}, calculate the total resistance of the system. (10 pts)

D. Imagine a scenario in which it was critical to supply the kidneys the same flow rate of blood received by the brain in problem C. If the arteriolar resistances remain the same as they were in C, how much harder would the heart have to pump to achieve this renal flow rate, i.e., by what factor would aortic pressure need to increase? (5 pts)

E. Consider a 77 year old man with benign prostatic hyperplasia, which forces him to strain significantly when urinating. One day his wife brings him into the emergency room because for the past week he has been "fainting" while going to the bathroom. Incorporating the concepts of the Valslava maneuver and the Frank-Starling relationship, explain why this man is having these fainting spells. (5 pts)

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4. Imagine a study in which in which you are capable of measuring action potentials from single cells at various anatomical locations in the heart.

A. Sketch what an action potential would look like for 3 representative heartbeats at the following locations: (1) the sinoatrial node; (2) the Purkinje fibers; and (3) the atrial intranodal tracts. (10 pts)

B. Neuronal action potentials have stable resting membrane potentials, whereas the pacemaking cells of the heart do not. What accounts for this difference? (5 pts)

C. Which of the following interventions would <u>not</u> be expected to increase cardiac contractility and why: (1) inhibition of a Ca^{++} pump in the sarcoplasmic reticulum; (2) administration of a drug that decreases heart rate, and (3) inhibition of cardiac Na^{+}/K^{-} ATPase. (5 pts).

D. In general, increasing cardiac contractility increases cardiac output. Explain why this is the case using cardiac function curves (cardiac output vs left atrial pressure) and vascular function curves (venous return vs. right atrial pressure). (10 pts)

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5. Consider a patient with the following physiologic values. Assume all measurements are taken at atmospheric pressure (760 mmHg) and at so-called "body temperature pressure saturated" (BTPS) conditions. Note that the vapor pressure of water at BTPS is 47 mmHg and that the mole fraction of oxygen in inhaled air is ~0.21.

Pulmonary function tests:
Tidal volume (V_T) = 0.6 L
Vital Capacity (VC) = 7 L
Inspiratory Capacity (IC) = 4 L
Forced expiratory volume after 1 sec (FEV_1) = 1.8 L
Breathing rate: 12 breaths/min
Fraction of CO2 in expired air (F_{ECO2})= 0.04

Arterial Blood Gas:
pO2 = 90 mmHg
PCO2 = 40 mmHg
pH = 7.38
[HCO3-] = 26 mEq/L

A. Calculate this patient's expiratory reserve volume. (5 pts)

B. Calculate this patient's alveolar ventilation rate (mL/min). (10 pts)

C. Calculate the partial pressure of this patient's alveolar oxygen (P_{AO2}). Assume that the patient is consuming oxygen at 1.3 times the rate at which she is producing carbon dioxide. (10 pts)

D. Seasonal allergies often include an asthma-like component, in which the smooth muscle cells of the airways become highly contractile. Sketch this patient's forced expiration curve (FEV vs time) before and after developing such an asthma-like condition. (10 pts)

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6. Consider a 25-year old patient who arrives at the emergency room with a stab wound to the left chest wall. In addition to the bleeding, he presents with rapid, shallow breathing and a barrel-chested appearance. The history, physical exam, and chest x-ray are consistent with a right-sided pneumothorax.

A. Using the concepts of lung and chest wall compliance, explain why this condition has led to the collapsed right lung and the barrel chested appearance. (10 pts)

B. Given this diagnosis, what would you expect to be the most striking findings on (1) auscultation (stethescopy), and (2) the chest x-ray? In both cases be clear on what you would expect to see/hear on the right and left sides of the chest. (10 pts)

C. Suppose this patient is given a chest tube and eventually recovers from his pneumothorax. Consider an alveolus within one of his lungs with a diameter of 50 μm. What wall tension (in N/m) would be needed to sustain a pressure drop of 1 Pa? (5 pts)

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7. Consider a patient with the following laboratory values [normal range in brackets]:

Blood solutes:
Na+: 145 mEq/L [135-145]
Cl-: 95 mEq/L [98-106]
Glucose: 95 mg/dl [70-110]
BUN: 14 mg/dl [7-18]

Arterial Blood Gas:
pO2 = 100 mmHg [80-100]
pCO2 = 21 mmHg [35-45]
pH = 7.5 [7.35-7.45]
[HCO3-] = 16 mEq/L [18-23]

A. Classify this patient's primary acid-base status. The choices are normal, respiratory acidosis, respiratory alkalosis, metabolic acidosis, and metabolic alkalosis. Justify your answer. (5 pts)

B. Assuming the bicarbonate ion concentration remains constant, what pCO_2 would this patient need to have to return to a normal pH of 7.35? (5 pts)

C. Calculate this patient's serum osmolarity. If the urine osmolarity is 90 mOsm/L and the urine output is 500 mL/day, calculate the clearance of free water. (10 pts)

D. Suppose that the glucose level was 100 mg/dl and the arterial blood gas values changed to pO2 = 95 mmHg, pCO2 = 30 mmHg, pH = 7.3, and [HCO3-] = 17 mEq/L. Reclassify the primary acid-base status and determine whether the anion gap is elevated [the normal range is 8-16 mEq/L]. Name 2 substances (e.g., drugs, medications) whose overdose could account for these values (10 pts)

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8. Consider a patient who receives an IV infusion of inulin and para-aminohippuric acid (PAH), and then 24 hours later is subject to urine and blood collection. Suppose those tests reveal the following values:

<u>Urinalysis</u>
Urine output over 24-hour period: 1200 ml
Urine concentration of PAH: 60 mg/dL
Urine concentration of inulin: 350 mg/dL
Urine concentration of K+: 40 mEq/L
Urine concentration of Na+: 30 mEq/L
Urine osmolarity: 900 mEq/L
Urine concentration of glucose: 0.1 mg/dL

<u>Blood work</u>
Plasma concentration of inulin: 12 mg/dL
Plasma concentration of PAH: 0.8 mg/dL
Plasma concentration of K+: 3.8 mEq/L
Plasma concentration of Na+: 129 mEq/L
Plasma concentration of BUN: 15 mg/dL
Plasma concentration of Glucose: 100 mg/dL
Hematocrit: 0.5

A. Calculate the clearance <u>ratio</u> of Na+. How would you expect this value to change in someone who begins to take hydrochlorothiazide (HCTZ) and why? (1-2 sentences) (10 pts)

B. Determine the filtered load of glucose (in mg/hr), the rate of elimination of glucose through the urine (mg/hr), and the % of glucose that is reabsorbed. (10 pts)

C. Calculate the osmolarity of this patient's blood (mOsm/L) and determine the clearance of free water (mL/min). (10 pts)

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9. Provide 1-3 sentence short answers to the following questions (5 pts each):

A. Na^+ has a much smaller ionic radius than K^+, yet in general Na^+ ions cannot pass through K^+ channels. Why?

B. Define the Single Effect and explain how it contributes to the corticopapillary osmotic gradient.

C. The compliance curve (volume vs pressure) of an air-filled lung shows hysteresis, whereas that of a saline-filled lung does not. Why?

D. Angiotensin converting enzyme (ACE) inhibitors are often prescribed to treat hypertension in patients that have renal disease because these drugs are thought to "protect" the glomerular filtration rate. How might an ACE inhibitor maintain or increase the GFR?