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BioE 110

Biomedical Physiology for Engineers

Midterm Exam I

Spring 2012

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:		/15
Question 2:		/20
Question 3:		/20
Question 4:		/30
Question 5:		/10
Question 6:		/10
Question 7:		/25
TOTAL		/130

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Potentially useful constants and conversions

$R = 8.31\ J\ K^{-1}\ mol^{-1}$

$R = 0.0821\ L\ atm\ K^{-1}\ mol^{-1}$

$F = 96\ 485\ C\ mol^{-1}$

$N_A = 6.022 \times 10^{23}\ mol^{-1}$

$k_B = 1.38 \times 10^{-23}\ J\ K^{-1}$

1 atm = 101.325 kPa

1 atm = 760 mmHg

1 cP = 1 mPa s

1000 L = 1 m^3

ln x = 2.303 log x

Elementary charge (e) = 1.6×10^{-19} C

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1. Consider an experiment in which a 100 mM solution of neutral solute X (MW=100 g/mol) in water is separated from a 10 mM solution of X at 25˚C by a semipermeable membrane of thickness 100 µm. Assume that the viscosity of both solutions is equal to that of water (0.001 Pa-s).

A. If X has a partition coefficient of 1 and the rate of diffusion per unit area across the membrane is 400 mmol/(sec-m^2), what is the molecular radius of X (in nm)? (10)

B. Now consider a cell: If the intracellular concentration of X is very high compared to its extracellular concentration, describe a <u>secondary active transport</u> strategy involving Na+/K+ ATPase and an Na+/X antiporter that a cell could use to import X. (5)

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2. Suppose you make two solutions of the ionic salt $MgBr_2$ (MW 184 g/mol) at 25˚C : The first is made by attempting to dissolve 18 g of of $MgBr_2$ to 1 L of water, and the second is made by attempting to dissolve 6 g of $MgBr_2$ in 1 L of water.

A. Suppose you separate these two solutions by a semipermeable membrane of thickness 1 mm and area 100 cm^2, which is permeable to water and has reflection coefficients for Mg^{2+} and Br^- of 0.25 and 0.75, respectively. Assuming that $MgBr_2$ is 90% soluble under these conditions, calculate the osmotic pressure difference across the membrane (in Pa). (10)

B. Suppose you model the membrane as a parallel array of cylindrical pores each of whose effective resistance to flow is 48500 Pa L^{-1} hr. If the steady-state total flow rate of water across the membrane is 1 L/hr, estimate the total density of pores in the membrane (pores/cm^2). (10)

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3. Consider a cell at 37 ˚C with the following intracellular and extracellular ion concentrations:

Ion	Intracellular conc. (mEq)	Extracellular conc. (mEq)	Relative conductances
A^+	100	10	2
B^{+2}	5	50	1.5
C^-	40	12	3
D^-	70	98	3.5

A. Calculate the equilibrium membrane potential for this cell (in mV). (10)

B. If the cell is treated with a drug that completely blocks the transport of A^+ and C^- and the relative conductances of B^{+2} and D^- remain the same relative to one another as they are in the table above, what is the new membrane potential (in mV)? (10)

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4. Imagine a patient has a heart rate of 75 beats/min, a pulse pressure of 93 mmHg, a stroke volume of 75 mL, and an oxygen consumption rate of 250 mL/min.

A. If one models the aorta as a straight cylinder of diameter 3 cm, calculate the pressure drop per unit length along the aorta (in mmHg/cm). Assume that blood has a density of 1.0 g/cm^3 and a viscosity of 0.003 Pa-s, and that it flows in a fully-developed, laminar fashion throughout the aorta. (10)

B. Suppose blood is traveling through a 1 cm diameter artery at a flow rate of 300 mL/min, and that the artery branches into two smaller arteries whose diameters are 0.75 cm and 0.25 cm, calculate the blood flow in each of the two branches at steady-state (in mL/min). (10)

C. Sketch a representative pressure-volume loop for this patient's left ventricle (don't worry about the actual numbers). Superimposed on this PV loop, draw a new PV loop as a dashed line showing how the PV loop would eventually change if the patient developed <u>aortic stenosis</u>. Be especially clear what happens to the <u>height</u>, <u>width</u>, and <u>position</u> of the PV loop, and if one or more of these quantities change, <u>explain</u> why in a few words. (10)

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5. Suppose the hydrostatic pressures inside and outside a capillary are 50 mmHg and 25 mmHg, respectively, and the osmotic pressures inside and outside the capillary are 30 mmHg and 5 mmHg, respectively. At what net rate is fluid crossing the capillary wall (in mL/min), and is the fluid being net absorbed or secreted? (10)

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6. Suppose the active and passive components of the tension vs. initial length (T vs. L) relationship for a skeletal muscle is given by the following expressions, where lengths are in cm and tension values are in N/cm:

Passive component: $T_p(L) = -30 + 1.5L$ (for $20 \text{ cm} \leq L \leq 30 \text{ cm}$)
Active component: $T_a(L) = 40L - L^2$ (for $0 \leq L \leq 30 \text{ cm}$)

Calculate the initial length (in cm) at which the greatest tension can be generated against a given afterload <u>and</u> the maximum tension that can be generated. Assume the muscle will rupture and fail if it is stretched beyond 30 cm. (10)

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7. Answer (A)-(D) in 3 sentences or less. For (E) simply select the correct option. (5 each)

A. Explain the difference between the absolute refractory period and the relative refractory period in the neuronal action potential. In which of these periods does voltage-dependent Na+ channel inactivation play a role and how?

B. Would you expect a patient with chronic pulmonary hypertension to be more likely to develop right or left ventricular hypertrophy? How does the hypertrophy serve as an adaptive mechanism against the hypertension? Justify your answer to the latter question with an equation involving pressure and ventricular thickness.

C. We often say that at steady state, cardiac output must equal venous return. What physiologic mechanism in the ventricles ensures that this steady state is maintained and how? Your answer should include the proper name of a specific principle or relationship (e.g., Boyle's Law, Le Chatlier's Principle).

D. According to Prof. Murthy's lecture, bacteria internalize maltodextrins as a food source. For what biophysical reason are maltodextrins preferable to glucose?

E. What was the diagnosis in the case Keiko Amano presented in her guest lecture?

(1) Idiopathic pulmonary fibrosis
(2) Churg-Strauss syndrome
(3) Atrioventricular node reentry tachycardia
(4) Gallstone pancreatitis

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