Key

BioE 110
Biomedical Physiology for Engineers
Midterm Exam I
Spring 2019

Name	

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

SCORE (for instructors only)

PART I		
Question 1:		/25
Question 2:		/30
Question 3:		/35
Question 4:		/25
PART II		
Questions 1-10		/50
TOTAL		/165

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Potentially useful constants and conversions

$R = 8.31\ J\ K^{-1}\ mol^{-1} = 0.0821\ L\ atm\ K^{-1}\ mol^{-1}$

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

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

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

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

For a sphere of radius R:

Volume = $4/3 * \pi R^3$

Surface area = $4 * \pi R^2$

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PART I: QUANTITATIVE PROBLEM SOLVING

1. Consider a cell membrane at 37C with ionic concentration gradients that give rise to the following equilibrium potentials (for the purposes of this question, ignore all other ions):

E_{Na+} = +65 mV
E_{K+} = -95 mV
E_{Cl-} = -90 mV
E_{Ca++} = +120 mV

A. If the extracellular chloride ion concentration is 100 mEq/L, calculate the intracellular chloride ion concentration (in mEq/L). (10 pts)

2 pts	Identify the equilibrium potential equation $E_X = \frac{-60\ mV}{z} log_{10}(C_{intracellular}/C_{extracellular})$
2 pts	z = -1
2 pts	Calculate equation E_x = 60 mV (log (C_{in} /C_{out})) -90 mV = 60 mV (log (C_{in} /C_{out})) -3/2 = log (C_{in} /C_{out}) 10^(-3/2) = C_{in}/C_{out}
1 pt	Plug in C_{out} = 100 mEq/L 10^(-3/2) = C_{in}/(100)
1 pt	Solve for C_{in} C_{in} = 10^(0.5)
2 pts	Final Answer C_{in} = sqrt(10) = 3.16 mEq/L

B. Suppose the membrane potential is -75 mV. Derive a linear equation that relates the conductances (g) of the four ions to one another. Your equation should be in the form

$$Ag_{Na+} + Bg_{K+} + Cg_{Cl-} + Dg_{Ca++} + E = 0$$

where g_i is the conductance of ion i and A, B, C, D, and E are constants. (10 pts)

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2 pts	Identify chord conductance equation $E_M = (g_{Na+}/g_{tot})E_{Na+} + (g_{K+}/g_{tot})E_{K+} + (g_{Cl-}/g_{tot})E_{Cl-} + (g_{Ca++}/g_{tot})E_{Ca++}$
2 pt	Write total conductance in this system $g_{tot} = g_{Na+} + g_{K+} + g_{Cl-} + g_{Ca++}$
3 pts	Shift total conductance to other side $E_M(g_{Na+} + g_{K+} + g_{Cl-} + g_{Ca++}) = g_{Na+}(E_{Na+}) + g_{K+}(E_{K+}) + g_{Cl-}(E_{Cl-}) + g_{Ca++}(E_{Ca++})$
3 pts	Subtract both sides by all $E_M * g_x$ $0 = g_{Na+}(E_{Na+} - E_M) + g_{K+}(E_{K+} - E_M) + g_{Cl-}(E_{Cl-} - E_M) + g_{Ca++}(E_{Ca++} - E_M)$ A = 140 , B = -20 , C = -15 , D = 195 , E = 0 *Note: all the above negated is also correct (must be ALL or none)*

C. Suppose you add a drug that blocks all chloride and calcium channels and you hold the membrane potential constant at 0 mV. What will be the ratio of the K+ conductance to the Na+ conductance (g_{K+}/g_{Na+})? (5 pts)

1 pt	Use the equation from 1B: $0 = g_{Na+}(E_{Na+}/g_{tot}) + g_{K+}(E_{K+}/g_{tot}) + g_{Cl-}(E_{Cl-}/g_{tot}) + g_{Ca++}(E_{Ca++}/g_{tot}) - E_M$
1 pt	Set $g_{Cl-} = 0$, $g_{Ca++} = 0$, and $E_M = 0$ $0 = g_{Na+}(E_{Na+}/g_{tot}) + g_{K+}(E_{K+}/g_{tot})$
2 pts	Solve for g_{K+} / g_{Na+} $- g_{Na+}(E_{Na+}/g_{tot}) = g_{K+}(E_{K+}/g_{tot})$ $(-E_{Na+}/g_{tot}) / (E_{K+}/g_{tot}) = g_{K+} / g_{Na+}$ $g_{K+} / g_{Na+} = -E_{Na+}/E_{K+}$
1 pt	Plug in values of $E_{Na+} = +65$ mV and $E_{K+} = -95$ mV $g_{K+} / g_{Na+} = -(65)/(-95) = 0.6802.$

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2. Consider the amino acid alanine, which has a molecular radius of around 0.23 nm (2.3 Angstroms).

A. Estimate the diffusion coefficient of alanine in water at 20C, which has a dynamic viscosity of 0.001 Pa-s (1 cP). Express your answer in m^2/s. (10 pts)

3 pts	Write/use equation for diffusion coefficient $D = \frac{kT}{6\pi r \eta}$
4 pts	Correctly plug in and convert: k_B = 1.38 E -23 J/K = 1.38 E -23 kg-m^2/(K-s^2) T: 20C = 293.15 or 293 K r: 2.3 * 10^{-10} m η = 0.001 Pa-s = 0.001 kg/m-s [1 Pa = 1 kg/(m s^2)] -1 for any errors per value (conversion or incorrectly identified)
3 pts	Correct answer D = 9.33 * 10^{-10} m^2/s

B. If two large-volume alanine solutions of concentration 1 mol/L and 0.1 mol/L are separated by a 1 mm-thick membrane for which alanine has a partition coefficient of 1.0, estimate the steady-state rate of diffusion of alanine across the membrane (in mol/s) *[Correction made during the exam: units of the final answer should be in mol/m^2 * s]*. (10 pts)

3 pts	Write/use equation(s) for flux (Fick's Law and permeability or combination) $J = PA\Delta C = \frac{k\,D\,A\,\Delta C}{\Delta x}$ Solve Fick's Law for J/A (to get the units of the final answer) $\frac{J}{A} = \frac{k\,D\,\Delta C}{\Delta x}$
4 pts	Correctly plug in and convert: ΔC: 0.9 mol/L to 900 mol/m^3 Δx: 1 mm to 0.001 m

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	D: $9.33 * 10^{-10}$ m^2/s [value from 2A] P should equal 9.33E-7 m/s -1 for any errors per value (conversion or incorrectly identified)
3 pts	Correct answer J/A = $8.40 * 10^{-4}$ mol/ (m^2 * s)

C. Suppose instead that these two solutions of alanine are separated by a semipermeable membrane for which alanine has a reflection coefficient of 0.5. What is the osmotic pressure (in Pa) across the membrane? For the purposes of this question, assume alanine does not dissociate when dissolved. *[Clarification made during the exam: use the same temperature as in part 2A.]* (10 pts)

3 pts	Write/use equation(s) for osmotic pressure $\pi = gC\sigma RT$
4 pts	Correctly plug in and convert: ΔC: 0.9 mol/L to 900 mol/m^3 g: 1 σ: 0.5 T: 20C = 293.15 or 293 K Use R = 8.31 J K^{-1} mol^{-1} -1 for any errors per value (conversion or incorrectly identified)
3 pts	Correct answer π = $1.10 * 10^6$ Pa (10.82 atm)

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3. Consider blood flowing through an artery with a diameter of 1 cm.

A. If the flow rate of blood through this artery is 500 ml/min, what is the average flow velocity (in cm/s)? (10 pts)

3 pts	Write/use equation(s) for flow velocity $v = Q/A$
3 pts	Correctly plug in and convert: Q: 500 mL/min to 8.33 cm^3/s A: π $(0.5\ cm)^2$ -1 for any errors per value (conversion or incorrectly identified)
4 pts	Correct answer: v = 10.6 cm/s

B. Assuming the same flow rate as in part A, What is the pressure drop (in mmHg) over a 10 cm segment of this artery if the viscosity of blood is 0.003 Pa-s? Note that 760 mmHg = 101,325 Pa. (10 pts)

4 pts	Write/use equation(s) for flow and Poiseuille's $Q = \Delta P/R\ ,\ R = 8\eta l\ /\ (\pi r^4)$
3 pts	Correctly plug in and convert: *Converting to meters is not necessary* (from 3a) Q: 500 mL/min to 8.33 cm^3/s η: 0.003 Pa-s to 2.25 * 10^{-5} mmHg-s r: 0.5 cm l: 10 cm -1 for any errors per value (conversion or incorrectly identified)
3 pts	Correct answer: ΔP = 0.0764 mmHg (10.2 Pa)

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C. If the artery branched into two smaller vessels of 1 mm and 2 mm *[Clarification made during the exam: these measurements are of the smaller arteries' diameters]*, which then immediately coalesced back into a single vessel without loss of fluid, what would the flow rate in the 2 mm vessel be? (10 pts)

3 pts	Write equation for flow with sum of resistors in parallel ΔP is the same $Q_T = Q_1 + Q_2 = \Delta P(1/R_1 + 1/R_2)$
3 pts	Write flow with R_1 in terms of R_2 using Poiseuille's $R_1/R_2 = r_2^4 / r_1^4$
2 pts	Plug in and isolate $\Delta P/R_2$, and get a factor of 16/17 to the original flow
2 pts	Correct answer: Q = 471 ml/min = 7.85 ml/s

calculating ΔP and R_2 solely is incorrect as length is not given

D. Returning to the 1 cm vessel discussed in A-B: If the diameter of the vessel was instead 0.5 cm, and all other values including the flow rate are held constant, what would the pressure drop be (in mmHg)? (5 pts)

2 pts	Write/use equations for flow and Poiseuille's $Q = \Delta P/R, \; R = 8\eta l / (\pi r^4)$
2 pts	Determine factor of R increasing by factor of 16 (and also ΔP from 3b)
1 pts	Correct answer: ΔP = 1.22 mmHg (163 Pa)

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4. Consider a patient in a hospital undergoing a series of tests to evaluate cardiovascular function.

A. Over the course of the patient's hospitalization, both arterial and venous blood gases are drawn. In the most recent such blood draws, arterial oxygen content is found to be 0.25 mL O_2 per mL blood, and venous oxygen content is found to be 0.18 mL O_2 per mL blood. Assuming a standard oxygen consumption value of 250 mL O_2/min, estimate the cardiac output (mL/min). (10 pts)

3 pts	Write/use equation for Fick Principle $CO = O_2\ consumption / ([O_2]_{arterial} - [O_2]_{venous})$
3 pts	Correctly plug in and convert: *No conversions necessary* -1 for any errors per value (conversion or incorrectly identified)
4 pts	Correct answer: CO = 3571 mL/min

B. Echocardiography reveals a left ventricular end-diastolic volume of 135 ml. If the heart rate is 65 beats per minute, estimate the left ventricular end-systolic volume (mL) and ejection fraction (%). (10 pts)

2 pts	Write/use equation for Cardiac Output $CO = HR * SV$, SV = 54.94 mL
2 pts	Write/use equation for Stroke Volume $SV = EDV - ESV$
2 pts	Write/use equation for Ejection Fraction $EF = SV / EDV$
2 pts	Correct answer for LV ESV = 80.1 mL
2 pts	Correct answer for EF = 40.7%

C. Assume the density of blood is 1.02 g/ml. At steady-state, what is the rate (mL/min) at which blood flows into the right atrium? (5 pts)

3 pts	Write/use steady state $CO = Venous\ return$
2 pts	Correct answer: 3571 mL/min

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PART II: MULTIPLE CHOICE (10 questions, 5 pts each)

<u>Clearly</u> circle or write your answer.

1. Which of the following is an example of primary active transport?

   A. Reabsorption of glucose from the gut with a luminal Na^+/glucose symporter

   B. Acidification of the proximal tubule with an Na^+/H^+ antiporter

   C. Acidification of the stomach with an H^+/K^+ ATPase

   D. Conduction of Ca++ in SA node cardiomyocytes by L-type calcium channels

2. Blood flow in capillaries is slower than in arteries despite the fact that an individual capillary has a much smaller cross-sectional area than an individual artery. Why?

   A. The capillary wall is much more permissive to diffusion than the arterial wall

   B. The capillary wall is much more compliant than the arterial wall

   C. Capillaries far outnumber arteries and thus have a much larger total cross-sectional area

   D. The premise is incorrect; blood flow in capillaries is actually much faster than anywhere else in the bloodstream

3. The resting membrane potential of a newly discovered cell type is found to be around +50 mV. Assuming normal intra- and extracellular ionic concentrations, which ion would you expect this membrane to be most permeable to at rest?

   A. Na^+

   B. K^+

   C. Cl^-

   D. Ca^{++}

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4. Suppose a patient develops an arrhythmia that produces unusually *fast* conduction of an electrical signal through the AV node. Which of the following predictions about stroke volume (SV) is most correct?

A. SV should increase, because faster AV node conduction produces more forceful ventricular contraction

B. SV should increase, because faster AV node conduction reduces the compliance of the ventricular wall

C. SV should decrease, because faster AV node conduction leaves less time for ventricular filling

D. SV should stay the same, because AV node conduction speed is irrelevant to stroke volume

5. A 16-year-old male receives an EKG as part of a sports physical, which reveals an unusually long QT interval. A patient history reveals a history of occasional syncope (fainting), which together with the family history, supports a diagnosis of long QT syndrome. Which of the following conduction defects is most directly associated with the EKG finding?

A. Slow atrial depolarization

B. Fast atrial repolarization

C. Slow ventricular depolarization

D. Slow ventricular repolarization

6. Digoxin (digitalis) and other cardiac glycosides have historically been used to treat congestive heart failure. What is the mechanism of action through which this modality is conventionally though to work?

A. Increases affinity of association between actin and myosin

B. Increases elasticity of tensin

C. Inhibition of Ca^{++} induced Ca^{++} release from the sarcoplasmic reticulum

D. Reduces expulsion of Ca^{++} from the cytosol of the cardiomyocyte

7. Which of the following complications is the most *direct* effect of aortic valve stenosis (narrowing)?

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A. **Left ventricular hypertrophy**
B. Right ventricular hypertrophy
C. Carotid artery narrowing
D. Reduced venous return

8. When you started this exam, your heart rate might have gone up, in which case you might have also felt your heart beating harder. Why?

A. **Increasing heart rate leaves less time to sequester intracellular calcium at the end of each contraction**
B. Renin-angiotensin-aldosterone axis activation due to sweat loss
C. The effect is entirely psychological; the force/tension of the heartbeat does not actually increase with heart rate
D. Changes in heart rate influence plasma membrane fluidity

9. Which phase of the cardiac cycle requires the most myocardial oxygen consumption?

A. **Isovolumetric contraction**
B. Ventricular ejection
C. Isovolumetric relaxation
D. Ventricular filling

10. Where would you expect to find the bulk of the voltage-gated Na^+ and K^+ channels in a myelinated axon?

A. Distributed evenly along the axon
B. **Clustered within the Nodes of Ranvier**
C. Clustered in the regions of myelination (internodes)
D. Concentrated within the cell body