1. Suppose you model a cell as a cylinder of diameter 25 μm and length 50 μm, and that the cell membrane has a capacitance of 1 μF/cm².

A. Calculate the total capacitance (in F) of the cell. (5)

B. If the membrane potential is -80 mV, what is the difference in electrical charge (in C) across the plasma membrane? (10)

C. Suppose the intracellular concentration of K^+ is 120 mEq/L. What fraction of total intracellular K+ would need to diffuse out of the cell to create the charge separation calculated in B and therefore account for the membrane potential? (10)

24/25
Good

A. $C_m \times A = C_{tot}$

$A = \pi D h + 2(\pi r^2) =$

$A = \pi(25\times10^{-6}\,m)(50\times10^{-6}\,m) + 2\left(\pi(12.5\times10^{-6}\,m)^2\right)$

$A = 4.9\times10^{-9}\,m^2 \times \frac{[100\,cm]^2}{1\,m^2} =$

$A = 4.9\times10^{-5}\,cm^2$

5

$1\times10^{-6}\,\frac{F}{cm^2} \times 4.9\times10^{-5}\,cm^2 =$

$4.9\times10^{-11}\,F$

B. $V = -8\,mV$

$Q = VC$

10

$Q = (-80\times10^{-3}\,V)(4.9\times10^{-11}\,F)$

$Q = -3.92\times10^{-12}\,C$

$C_i = 120\,mEq/L$

9

$Q = -3.92\times10^{-12}\,C \,/\, 1.6\times10^{-19}\,\frac{C}{charge} = -24{,}500{,}000\,charges$

$-24{,}500{,}000 \times \frac{1\,mol}{6.02\times10^{23}} = -4.06\times10^{-17}\,$ molar equivalents

$= 4.06\times10^{-14}\,mEq$

9

In cell, $\frac{120\,mEq}{L} \times (\pi R^2 \cdot h) \times \frac{1000\,L}{m^3} = 2.9\times10^{-11}\,mEq$

-1 calculation error

$\frac{4.06\times10^{-14}\,mEq}{2.9\times10^{-11}\,mEq} \times 100\% = .137\%$

2. An amphiphilic block copolymer is a synthetic polymer that consists of a hydrophobic component ("block") and a hydrophilic component. It is possible to design these molecules such that they assemble into spherical capsules known as "polymersomes," analogous to how lipids can self assemble into liposomes.

17/20

A. Consider a polymersome of diameter 10 μm. If the polymersome contains a 10 mM KCl solution and is placed in a 37°C bath of 1 mM KCl, how much total force (in N) will the polymersome wall experience? Assume the reflection coefficient is of K^+ and Cl^- are both 0.75. In which net direction will this force act, i.e., will it tend to swell or compress the polymersome? (10)

B. Suppose the polymersome has a wall thickness of 50 nm. What is the wall tension (in N/m^2)? (5)

C. Suppose an agent is added to the bath that reduces the solubility of the KCl solution by a factor of 2 both inside and outside the polymersome. By what factor would the osmotic pressure change? Would it increase or decrease? (5)

A. $P = \frac{F}{A}$ / $1\ A = 760\ mm\ Hg$

$\Pi = gCRT$

$= 2\left(10\times10^{-3} - 1\times10^{-3}\ M\right)(.75)\left(.0821\ \frac{L\,atm}{mol\,K}\right)(310\ K)$

$= 2(.009\ M)(.75)\left(.0821\ \frac{L\,atm}{mol\,K}\right)(310)$

$= .3430885\ atm$

$A = 4\pi(5\times10^{-6}\ m)^2$

The $F = 1.0794\times10^{-10}\ atm\cdot m^2 \times \frac{101.325\ kPa}{atm} = 109.37\ kPa\cdot m^2 = 1.0937\times10^{-5}\ N$

polymerosome will compress as H_2O tries to enter it

B. $P = \frac{2HT}{R}$ $\quad .3435885\ atm = \frac{2(50\times10^{-9}\ m)\,T}{5\times10^{-6}\ m}$ $\quad$ ↳ will swell -2

$T = 17.1794\ atm \times \frac{101.325\ kPa}{atm} = 1740.7\ kPa$

$1\ Pa = N/M^2 = 1.7407\times10^6\ N/m^2$

C. $(10\times10^{-3} - 1\times10^{-3})$ to $(5\times10^{-3} - .5\times10^{-3})$

$.009$ to $.0045$

↳ osmotic pressure would halve, so decrease

27.5/30

3. Imagine that you discover a new strain of yeast that is capable of functioning in environments with ionic compositions very similar to those found in the body but with very different intracellular ion concentrations than are typically found in normal cells. The intracellular and extracellular ion concentrations and their conductances under these conditions are summarized below for your convenience:

	Intracellular conc. (mM)	Extracellular conc. (mM)	Conductance (arbitrary units)
Na+	5	140	7
K+	100	4	15
Cl-	10	105	2
Ca++	0.01	3	1.5

A. Calculate the equilibrium potential (in mV) for <u>each ion</u> at 37 C. (10)

B. Calculate the <u>overall</u> resting membrane potential (in mV). (10)

C. Suppose you use an electrophysiological pipette to clamp the membrane potential to the equilibrium potential for Ca^{++} calculated in A. Sketch membrane potential as a function of time. (5)

D. Suppose you use an electrophysiological pipette to clamp the membrane potential at 0.5 V. Calculate the ratio of the the Na+ current to the K+ current (I_{Na+}/I_{K+}), assuming the conductance of each ion is independent of membrane potential. (5)

A) $T_K = 310K$ so $E = \frac{-60mV}{z} \log_{10}\left[\frac{C_i}{C_o}\right]$

Na^+ $E = \frac{-60mV}{1} \log_{10}\left[\frac{5}{140}\right] = 86.29mV$

K^+ $E = \frac{-60mV}{1} \log_{10}\left[\frac{100}{4}\right] = -83.876mV$

Cl^- $E = \frac{-60mV}{-1} \log_{10}\left[\frac{10}{105}\right] = -61.27\ mV$

Ca^{++} $E = \frac{-60mV}{2} \log_{10}\left[\frac{.01}{3}\right] = 74.31\ mV$

B) $E_m = \frac{\sum_{ion} E_{ion} g_{ion}}{g_{tot}}$ — chord conductace

$E_m = \frac{7 \cdot 86.29mV + 15 \cdot -83.876mV + 2 \cdot -61.27mV + 1.5 \cdot 74.31mV}{25.5}$

$E_m = \frac{604.03 + -1258.14 - 61.27 + 111.465}{-23.68\ mV}$

4. Consider an artery that branches into 4 equal arterioles, each of which branches into 10 capillaries. Suppose all vessels have circular cross sections and that the cross-sectional area of the artery is 25 cm^2, the cross-sectional area of each arteriole is 10 cm^2, and the cross-sectional area of each capillary is 1 cm^2. Assume that blood has a viscosity of 10 cP (0.01 Pa-s) and a density of 1.0 kg/m^3.

A. If the velocity of blood flow through the artery is 0.5 cm/sec, calculate the velocity (cm/sec) in each arteriole and capillary. (10)

B. Calculate the pressure drop per unit length (in Pa/cm) in the artery. (5)

C. Would you expect flow in an arteriole to be laminar or turbulent? Justify your answer with a calculation. (5)

D. Now suppose some event causes one arteriole to increase its cross-sectional area by a factor of 4. What will be the ratio of volumetric flow rate in that arteriole to the volumetric flow rate in any of the other three arterioles? (5)

A) $V_1 A_1 = V_2 A_2$ $\quad A_2 = \sum A_{\text{arterioles}} = 40\,cm^2$

$.5\,cm/sec \cdot (25\,cm^2) = V_2 (40\,cm^2)$

$V_2 = 1.25\,cm/sec$ ← Arteriole

$.5\,cm/sec\,(25\,cm^2) = V_2 (40\,cm^2)$

$V_2 = 12.5\,cm/s$ ← Capillary

$\frac{12.5\,cm^3}{sec} \times \frac{m^3}{[100\,cm]^3}$

B) $\Delta P = QR$ $\quad R = \frac{8\eta L}{\pi r^4}$

$\frac{\Delta P}{L} = Q\left(\frac{8\eta}{\pi r^4}\right) = \frac{1.25 \times 10^{-5}\,m^3}{sec}\left(\frac{8(.01\,Pa\cdot s)}{\pi (.0282m)^4}\right)$ $\quad \sqrt{\frac{25}{\pi}} = r = 2.82\,cm$

$= .5033\,\frac{Pa}{m} \times \frac{m}{100cm} = .005033\,\frac{Pa}{cm}$

C) Reynold's #

$N = \frac{\rho d V}{\eta} = \frac{1\,\frac{kg}{m^3} \times (.0564m)\left(.005\frac{m}{s}\right)}{.01\,Pa\cdot s}$

$= .0282$

Very low reynold's number, so most likely laminar

D) $Q = vA$ if A increases by 4 w/o velocity changing, then Q will decrease to 1/4 of it's original value (the value of the other arterioles)

$\frac{Q_S}{Q_S} = \frac{P_S/R_S}{P_S/R_S} = \frac{R_S}{R_S}$ since $R = \frac{8\eta L}{\pi r^4}$, $R_S = \frac{1}{16} R_S$, so $\frac{Q_S}{Q_S} = 16$

5. Consider a contractile cardiomyocyte maintained in culture.

A. Suppose this cardiomyocyte is induced to undergo a single action potential. Plot membrane potential as a function of time. (10)

B. Suppose you take the same cardiomyocyte and place it in a medium (liquid) identical to that used in (A) except that the extracellular Ca^{++} concentration is now only 10% as great as in (A). On the same set of axes, sketch the new action potential. Justify your answer. (10)

C. Now consider conduction in the whole heart. Sketch the relationship between left ventricular end-systolic pressure vs. left ventricular end-diastolic volume in the presence and absence of an Na+/K+ ATPase inhibitor. (5)

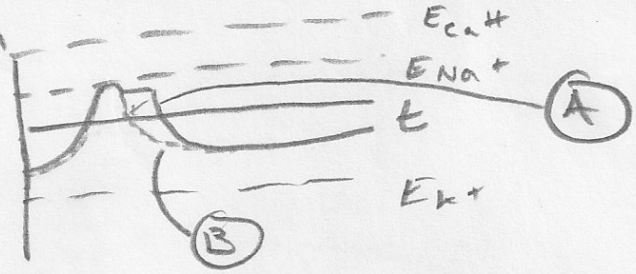
D. Sketch the relationship between left ventricular pressure vs. left ventricular volume for a single cardiac cycle (i.e. PV loops) in the presence and absence of systemic hypertension. (5)

E. Consider a patient who suffers a myocardial infarction (heart attack) that specifically targets the sinaotrial node but leaves all other regions of the heart unaffected. What would you expect to happen to this patient's resting heart rate and why? (5)

F. Suppose instead the patient has a lesion that causes delayed conduction through the atrioventricular node. Which one of the following EKG abnormalities would you expect, and why: (1) ST segment elevation; (2) lengthened PR interval ; (3) shortened QT interval; (4) increased QRS complex amplitude. (5)

35/40

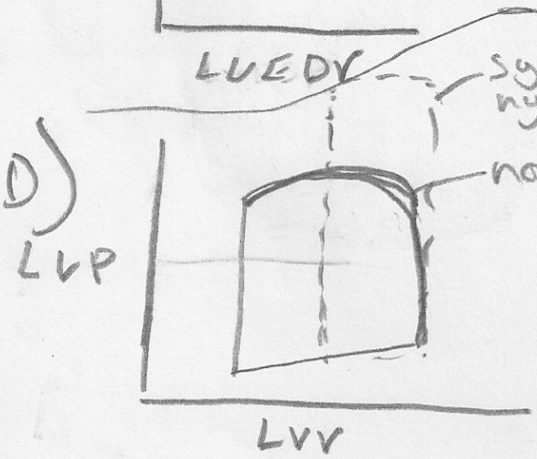
10/10 A)



10/10 B) Ca^{++} much lower, most likely reduces plateau as the plateau is a balance of $E_{Ca^{++}}$ and E_{K^+} This is the dotted line

3/5 C)

ATPase inhibitor of Na^+/K^+ increases contractility as it is a cardiac glycoside rxn, so, less volume pumped out despite higher preload



5/5 D)

hypertension = increased afterload

9 8/10

6. If fluid is being secreted from a capillary at a rate of 5 mL/min, the oncotic pressure in the capillary is 25 mmHg, and the oncotic pressure outside the capillary is 5 mmHg, what is the difference in hydrostatic pressure (in Pa) across the capillary wall? Assume the hydraulic conductance is 0.5 mL/(mmHg·min) and be clear on whether the pressure is higher inside or outside the capillary. (10)

$J = 5$ mL/min $\pi_c = 25$ mmHg $\pi_i = 5$ mmHg

$K = .5$ mL/(mmHg·min)

$J = K_f((P_c - P_i) - (\pi_c - \pi_i))$

$= K_f((\Delta P) - (25 - 5)_{mmHg})$

$\frac{5 mL}{min} = \frac{.5 mL}{(mmHg)(min)} \Delta P - \frac{10 mL}{min}$

$\frac{15 mL}{min} = \frac{.5 mL}{mmHg\ min} \Delta P$

$30 \text{ mmHg} = \Delta P$

$P_c - P_i = 30$

must express in Pa -1

so capillary pressure is 30 mmHg higher inside the capillary

7. Provide 1-2 sentence responses to the following questions (5 each):

A. Which myocardial process requires more energy: isovolumetric contraction or systolic ejection?
B. What is the difference between the relative and absolute refractory period of the axonal action potential?
C. What is the Fick principle and how can it be used to calculate cardiac output?
D. How does arteriosclerosis directly contribute to increased blood pressure?

via muscle contractions

A. Isovolumetric contraction is isometric tension; it requires O_2 and much more energy as it is building the pressure, systolic ejection does not build any pressure, it simply relaxes by opening the valve and relying on the pressure differential to fill the ventricle

B. absolute is the time reset the realistic time it takes to create concentrating that can be utilized by a new AP. relative is the correct concentrations.

Rel - hyperpolarization
Abs - Na^+ channels inactivate

-5

C. Fick principle states that the rate of oxygen consumption should equal the difference in oxygen concentrations between the pulmonary arteries and veins

$$CO = \frac{\text{total } O_2 \text{ consumption } [\text{vol}/\text{min}]}{[O_2]_{\text{pulmonary vein}} - [O_2]_{\text{pulmonary artery}}}$$

$\frac{\text{vol } O_2}{\text{vol blood}}$

D) Arteriosclerosis lowers artery compliance, raising blood pressure so that the same volume of blood can be pumped around the body

$(\downarrow C) = V/(P\uparrow)$

compliance