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BioE 110 Midterm # 1

1. (10 pts) Consider a single spherical cell with a 10μm diameter. The internal concentration of urea is 0.1mg/μm³ and the external concentration is 1.0 mg/μm³. Assuming that the overall membrane permeability of the urea is 10^{-6} μm/s and the partition coefficient is 10^{-3}, calculate the flux of urea out of the cell assuming simple diffusion?

(2) $J = PA(C_A - C_B)$

(2) $P = 10^{-6}\ \mu m/s$

~~$J = 10^{-6}(314)($~~

(4) $J = 2\times10\,(10^{-6}\ \frac{\mu m}{s})\,314\ \mu m^2\left(0.1\ \frac{mg}{\mu m^3} - 1.0\ \frac{mg}{\mu m^3}\right)$

$= -2.8\times10^{-4}\ \frac{mg}{s}$ (2)

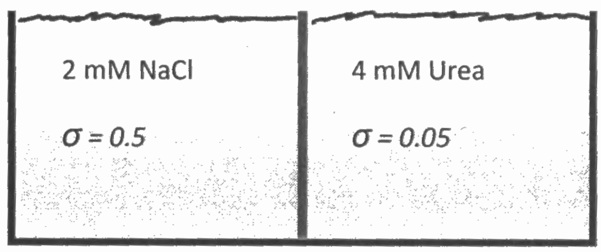
(2) $A = 4\pi r^2 = 4\pi(25\ \mu m^2) = 314\ \mu m^2$

$A = \pi r^2 = 79\ \mu m^2$

$J = -7.1\times10^{-5}\ \frac{mg}{s}$

2. (12 pt) Say we have a container with a membrane in the middle that is only permeable to water.

a. What is the osmolarity of each compartment?



NaCl : osm = g C = 2 × 2 mM = 4 Osm/L

urea : osm = 1 · C = 4 Osm/L

b. What is the ratio of the osmotic pressures, i.e. π_{NaCl}/π_{urea}?

$\pi = gC\sigma RT$

$$\frac{\pi_{NaCl}}{\pi_{urea}} = \frac{2\cdot C\cdot\sigma_{NaCl}RT}{1\cdot C_u\cdot\sigma_{urea}RT} = \frac{\sigma_{NaCl}}{\sigma_{urea}} = 10$$

c. Which way will water flow through the membrane?

water will flow from Urea → NaCl

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3. (10pts) While studying for some annoying midterm exam, you eat a whole bag of very salty potato chips without drinking anything which clearly changes the fluid balances in your body. Explain what happens to the following, i.e. does it go up, down, or stay the same, and why:

a. Total H_2O

no change

b. ECF Osmolality

↑ same amt of H_2O, more NaCl

c. ECF

↑ increased salt ⇒ increased osmotic pressure

so H_2O flow into ECF from ICF

d. ICF

↓ H_2O flows from ICF → ECF because of increased osmotic pressure

4. (15pts) While walking across campus, you stumble across a random giant squid nerve cell and having nothing better to do, you determine the following aspects of it.

Ion	Internal Conc	External Conc	Relative Membrane Permeability
K^+	150 mM	5 mM	1
Na^+	15 mM	150 mM	0.05
Cl^-	10 mM	100 mM	0.5

a. Estimate the resting membrane potential? (use *2.3 RT/F ~ 60 mV*)

$$E_m = \frac{RT}{F} \ln\left(\frac{P_K[K^+]_o + P_{Na}[Na^+]_o + P_{Cl}[Cl^-]_i}{P_K[K^+]_i + P_{Na}[Na^+]_i + P_{Cl}[Cl^-]_o}\right)$$

$$= 60\,mV \ln\left(\frac{5 + 0.05(150) + 0.5(10)}{150 + 0.05(15) + 0.5(100)}\right)$$

$$= 60\,mV \log\left(\frac{17.5}{200.75}\right)$$

$$= -63.6\,mV$$

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b. If Na^+ ion channels suddenly open, what is the electrochemical driving force acting on the sodium in mV?

Driving force = $E_m - E_{Na^+}$

$$E_{Na^+} = -\frac{RT}{z} \ln\left(\frac{[Na^+]_{in}}{[Na^+]_{out}}\right)$$

$$= -60 \log\left(\frac{15}{150}\right)$$

$$= 60\,mV$$

$$E_m - E_{Na} = -63.6 - 60\,mV$$

$$= -123.6\,mV$$

c. What will affect E_m more: blocking all of the Sodium channels or blocking all of the Chloride channels? Show how you determined your answer.

Know $E_m = \frac{RT}{z} \log\left(\frac{P_K[K]_o + P_{Na^+}[Na^+]_o + P_{Cl}[Cl^-]_i}{P_K[K]_i \; P_{Na^+}[Na^+]_i \; P_{Cl}[Cl^-]_o}\right)$ — these are changing

Na^+ closed: $E_m = 60 \log\left(\frac{5 + 0.5(10)}{150 + 0.5(100)}\right) = -78.1\,mV$ ← farther 'away' from E_m (-63.6)

$0.5(100) = 0.1$

Cl^- closed: $E_m = 60 \log\left(\frac{5 + 0.05(150)}{150 + 0.05(15)}\right) = -64.9\,mV$

$= 10$

⇒ Na^+ channels

5. (10pts) Under stress and pipetting frantically in lab, the radii of all the arterioles in Karthik's metabolically active forearm flexor muscles doubles, and his mean systemic arterial pressure also increases by 50%. How much will the blood flow to these muscles increase assuming no change in viscosity of blood?

Know $Q = \frac{\Delta P}{R}$ ← Resistance $\qquad R \approx \frac{\mu L}{r^4}$

Flow when stressed: $Q_s = \frac{\Delta P_s}{R_s} = \frac{1.5 \Delta P_o \, r_s^4}{\mu L}$ $\qquad r_s = 2r_o$

$$\frac{Q_s}{Q_o} = \frac{\Delta P_s}{\Delta P_o}\frac{R_o}{R_s} = \frac{1.5\Delta P_o}{\Delta P_o}\left(\frac{\mu L}{r_o^4}\frac{r_s^4}{\mu L}\right)$$

$$= 1.5\left(\frac{(2r_o)^4}{r_o^4}\right)$$

$$= 1.5 \cdot 2^4$$

$$= 1.5 \cdot 16 = 24$$

$$\boxed{Q_s = 24 Q_o}$$

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6. (10 pts) During exercise, a healthy 30-year-old male with no evidence of cardiac shunts consumes 2 liters of oxygen per minute. His brachial artery O2 content is 200 ml/L and the oxygen concentration of mixed venous blood obtained from the pulmonary artery is 100 ml/L. What is his cardiac output?

$$CO = \frac{O_2 \text{ consumption}}{[O_2]_{pa} - [O_2]_{pv}} = \frac{2\,l/min \;\checkmark O_2}{\frac{200\,ml\,O_2}{1\,l\,Blood} - \frac{100\,ml\,O_2}{1\,l\,Blood}}$$

$$= \frac{2000\,ml\,O_2/min}{\frac{200\,ml\,O_2}{1\,l\,Blood} - \frac{100\,ml\,O_2}{1\,l\,Blood}}$$

$$= \frac{20\,l\,Blood}{min}$$

7. (10 pts) A person's electrocardiogram (ECG) has no P wave, but has a normal QRS complex and a normal T wave. Therefore, his pacemaker is located in which of the following? State your reasoning.

(A) sinoatrial (SA) node
(B) atrioventricular (AV) node ← no P wave ⇒ no SA depolarization
(C) bundle of His
(D) Purkinje system
(E) ventricular muscle

8. (23 pts) The radius of the aorta in a test subject determined by MRI is 1.2 cm. At rest, her end diastolic volume is 140 mL and her end systolic volume is 55 mL. Her diastolic pressure is 70 mmHg and his systolic pressure is 115 mmHg. If we start the cardiac cycle at the opening of the mitral valve, the aortic valve in this person opens at 0.55 s and closes at 0.9 s. The entire cycle lasts 1.1 s in this person. Assume that the density of blood is 1.0 g/mL and its viscosity is 0.03 g/cm/s. Using this information, answer the following questions:

a. What is the stroke volume?

$SV = DV - Sys\ Volum$
$= 140\,ml - 55\,ml$
$= 85\,ml$

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b. What is the heart rate?

Cardiac cycle takes 1.1 s $\Rightarrow$ $HR = \frac{1}{1.1\,s} = 0.91\ \frac{beat}{sec}$

$= 0.91 \cdot 60 = 54.5\ bpm$

c. What is the cardiac output?

$CO = SV \cdot HR$

$= (85\,ml)(0.91\ \frac{beats}{s}) = 77\ ml/s$

$= (85\,ml)(54.5\ bpm) = 4.6\ l/min$

d. What is the period of ejection?

Aortic valve opens at 0.55 s, closes at 0.9 s $\Rightarrow$ period of ejection = 0.35 s

e. What is the average velocity of blood in the aorta?

(Spatial) average velocity $= \frac{85\,cm^3}{\pi r^2 \cdot PE} = \frac{85\,cm^3}{\pi (1.2\,cm)^2\, 0.35\,s}$

$\bar{v} = 53.7\ cm/s$

if you averaged over a heart beat $\Rightarrow$ $\Delta t = 1.1\,s$ so $\bar{v} = 17.1\ cm/s$

f. What is the Reynolds number for blood during ejection?

$Re = \frac{\rho \bar{v} r}{\mu}$ or $\frac{\rho \bar{u} D}{\mu}$ $\quad Re = \frac{(1.0\,g/cm^3)(53.7\,cm/s)(2.4)\,cm}{0.03\ g/cm \cdot s} = 4{,}300$

or

using radius $\rightarrow$ 2,148

g. What is the kinetic energy of the ejected blood?

$KE = \frac{1}{2} m v^2 \qquad m = (SV\ \frac{cm^3}{s})(\rho\ \frac{g}{cm^3})$

$KE = \frac{1}{2}(85\ \frac{cm^3}{s})(1\ \frac{g}{cm^3})(53.7\ \frac{cm}{s})^2$

$KE = 122{,}600\ \frac{g\,cm^2}{s^2} = 0.0123\ J$

(ergs or dyne-cm)

h. What pressure-volume work is done during ejection?

work $= \int P\,dV$ for ejection $= MAP \times SV$

MAP: mean arterial pressure $\sim DP + \frac{1}{3}(SP - DP)$ (DP: diastolic pressure; SP: systolic pressure)

$SV = 85\ ml$

$MAP = 70 + \frac{1}{3}(115 - 70)\ mmHg$

$= 85\ mmHg$

work $= (85\ mmHg)(85\ cm^3)$

$= 7{,}225\ mmHg\text{-}cm^3 = 9.6 \times 10^{-2}\ J$