NAME: SID:

1. Consider two solutions of $MnBr_2$ at 25 C separated by a semipermeable membrane that is completely permeable to water but only *partially permeable* to Mn++ or Br-, with a reflection coefficient of 0.8 for both ions. Assume the $MnBr_2$ dissolves partially, such that 1 mol $MnBr_2$ yields 0.6 mol dissolved $Mn^{++}$ and 1.2 mol dissolved $Br^-$.

A. If the nominal (analytical) concentrations of the solutions are 250 mM (solution A) and 30 mM (solution B), how much pressure must be delivered to the system to prevent the flow of water from one solution to the other? To which solution must the pressure be applied? (10 pts)

$T = 298K \quad R = 0.0821 \frac{L \cdot atm}{mol \cdot K} \quad \sigma = 0.8$

$MnBr_2 \Rightarrow 3$ particles

$g = 3$

60% dissociation

$C_{A,H} (.60)(250 \text{ mM}) = 150 \text{ mM}$

$C_{B,H} (0.60)(30 \text{ mM}) = 18 \text{ mM}$

$\Pi = g\sigma RT(C_A - C_B)$

$\Pi = (0.8)(298K)(0.0821 \frac{L \cdot atm}{mol \cdot K}) \cdot (150 \text{ mM} - 18 \text{ mM})$

$\Pi = (0.8)(298)(0.0821 \frac{L \cdot atm}{mol})(132 \frac{mmol}{L})(\frac{1 \text{ mol}}{1000 \text{ mmol}})$

$\Pi = 7.75 \text{ atm}$

Pressure must be applied to solution A

B. Consider a different situation in which a water-filled phospholipid vesicle (liposome) of radius 100 nm and membrane thickness 5 nm is immersed in a solution of 100 mM sucrose. Calculate the initial rate of accumulation of sucrose inside the vesicle. Assume that sucrose has a molecular radius of 0.5 nm, a partition coefficient of 0.001, that the temperature is 25C, and that the viscosity of the sucrose solution is 1 cP (=0.001 kg $m^{-1}$ $s^{-1}$). Assume the volume and surface area of the vesicle remain constant. (15 pts)

$r_L = 100 \text{ nm}$

$\Delta x = 5 \text{ nm}$

$r_s = 0.5 \text{ nm}$

$\eta = 0.001 \frac{kg}{m \cdot s}$

$K = 0.001$

$T = 298K$

$k = 1.38 \times 10^{-23} \frac{m^2 kg}{s^2 K}$

$A = 4\pi r_L^2$

$A = 4\pi(1 \times 10^{-5} \text{ cm})^2$

$A = 1.257 \times 10^{-9} \text{ cm}^2$

$D = \frac{kT}{6\pi r_s \eta} = \frac{(1.38 \times 10^{-23} \frac{m^2 \cdot kg}{s^2 \cdot K})(298K)}{6\pi(0.5 \times 10^{-9} m)(0.001 \frac{kg}{m \cdot s})}$

$D = 4.36 \times 10^{-6} \frac{cm^2}{s}$

$J = \frac{KDA}{\Delta x} \cdot \Delta C$

$J = \frac{(0.001)(4.36 \times 10^{-6} \frac{cm^2}{s})(1.257 \times 10^{-9} cm^2)}{5 \times 10^{-7} cm} \cdot \frac{100 \text{ mmol}}{L} \cdot (\frac{1 L}{1000 cm^3})$

$J = 1.097 \times 10^{-12} \frac{mmol}{s}$

NAME: SID:

2. Consider a hypothetical cell suspended in a buffer solution. Suppose the cell membrane is permeable only to monovalent ions A, B, C, and D, and suppose that the intracellular and extracellular concentrations and conductances of these ions are as follows:

| | | Intracellular conc. (mM) | Extracellular conc. (mM) | Conductance (arbitrary units) |
|---|---|---|---|---|
| +1 | A | 1 | 200 | 8 |
| −1 | B | 10 | 40 | 4 |
| +1 | C | 40 | 15 | 2 |
| −1 | D | 500 | 5 | 1 |

A. Calculate the equilibrium potential for each ion, assuming a temperature of 37 C. (10 pts)

$$E = -\frac{RT}{zF} \ln \frac{[C_i]}{[C_o]} = -\frac{(8.31\ J/mol\,K)(310\,K)}{z(96485\ C/mol)} \ln \frac{[C_i]}{[C_o]}$$

60 mV assumption

$$E_A = -\frac{(8.31)(310)}{(1)(96485)} \ln \frac{1}{200} = \boxed{141\ mV}$$ +138 mV

$$E_B = \frac{-(8.31)(310)}{(-1)(96485)} \ln \frac{10}{40} = \boxed{-37.0\ mV}$$ −36.1 mV

$$E_C = -\frac{(8.31)(310)}{(+1)(96485)} \ln \frac{40}{15} = \boxed{-26.2\ mV}$$ −25.6 mV

$$E_D = \frac{-(8.31)(310)}{(-1)(96485)} \ln \frac{500}{5} = \boxed{123\ mV}$$ +120 mV

B. Calculate the overall resting membrane potential under these conditions. (10 pts)

$$E_m = \frac{\Sigma g_i E_i}{\Sigma g_i} = \frac{8(141) + 4(-37.0) + 2(-26.2) + (123)}{8+4+2+1}\ mV$$

$$= \boxed{70.0\ mV}$$ (68.6 mV w/ 60mV assumption)

C. If this cell were removed from the buffer and suddenly placed in a bath of distilled water, what would initially happen to the volume of the cell and why? (5 pts)

Increase due to osmotic pressure difference. Cell interior will have higher osmolarity so water will flow into the cell.

NAME: SID:

3. Suppose that blood flow from the aorta is distributed in parallel between the brain, the heart, the kidneys, the GI tract, skeletal muscle, and skin, collected via the venous circulation for each organ system and then pooled into the vena cavae.

A. Suppose that 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: 1: 2: 6: 7: 9. If $R_{brain}$ = 0.02 mmHg min $ml^{-1}$, calculate the total resistance of the system. (10 pts)

$$\frac{1}{R_T} = \frac{1}{R_B} + \frac{1}{R_H} + \frac{1}{R_K} + \frac{1}{R_{GI}} + \frac{1}{R_M} + \frac{1}{R_S}$$

$$\frac{1}{R_T} = \frac{1}{0.02} + \frac{1}{0.02} + \frac{1}{0.04} + \frac{1}{0.12} + \frac{1}{0.14} + \frac{1}{0.18}$$

$$\frac{1}{R_T} = 146.03 \frac{mL}{mmHg/min} \Rightarrow R_{Tot} = 6.85 \times 10^{-3} \text{ mmHg min ml}^{-1}$$

B. If the velocity of blood in this patient's aorta is 1800 cm/min, and the aorta has a diameter of 25 mm, what is the cardiac ouput? Model the aorta to be a cylinder. (10 pts)

$$CO = V \cdot A =$$

$$A = \pi\left(\frac{D}{2}\right)^2$$

$$A = \pi\left(\frac{2.5\ cm}{2}\right)^2$$

$$A = 4.91\ cm^2$$

$$CO = \left(1800 \frac{cm}{min}\right)\left(4.91\ cm^2\right)$$

$$CO = 8835.73 \frac{cm^3}{min}$$

C. If the mean aortic pressure is 110 mmHg, using your answers in A and B, estimate the mean pressure in the vena cavae just prior to their arrival at the right atrium. (5 pts)

$$\Delta P = Q \cdot R$$

$$\Delta P = CO \cdot R = \left(8835.73 \frac{cm^3}{min}\right)\left(6.85 \times 10^{-3} \frac{mmHg \cdot min}{mL}\right) \cdot \left(\frac{1\ mL}{1\ cm^3}\right)$$

$$\Delta P = 60.52\ mmHg$$

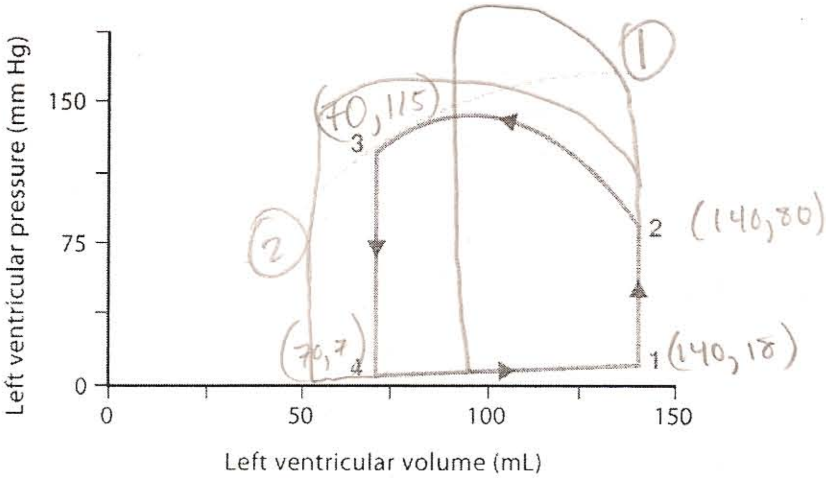
$$\Delta P = MAP - P_{VC}$$

$$60.52\ mmHg = 110\ mmHg - P_{VC}$$

$$P_{VC} = 49.5\ mmHg$$

NAME: SID:

0 4. Consider the following left ventricular pressure-volume loop:




Assume the coordinates on the loop are as follows:

Point 1: (V,P) = (140 mL, 18 mmHg)
Point 2: (V,P) = (140 mL, 80 mmHg)
Point 3: (V,P) = (70 mL, 115 mmHg)
Point 4: (V,P) = (70 mL, 7 mmHg)

A. Calculate the stroke volume, ejection fraction, and cardiac output. Assume a heart rate of 75 beats/min. (10 pts)

$SV = V_1 - V_4 = 140 - 70 = 70 \text{ mL} = SV$

$EF = \frac{SV}{V_1} = \frac{70}{140} = 0.5 = EF$

$CO = SV \cdot HR = (70 \text{ mL})(75 \frac{\text{Beats}}{\text{min}})$

$CO = 5250 \frac{\text{mL}}{\text{min}}$

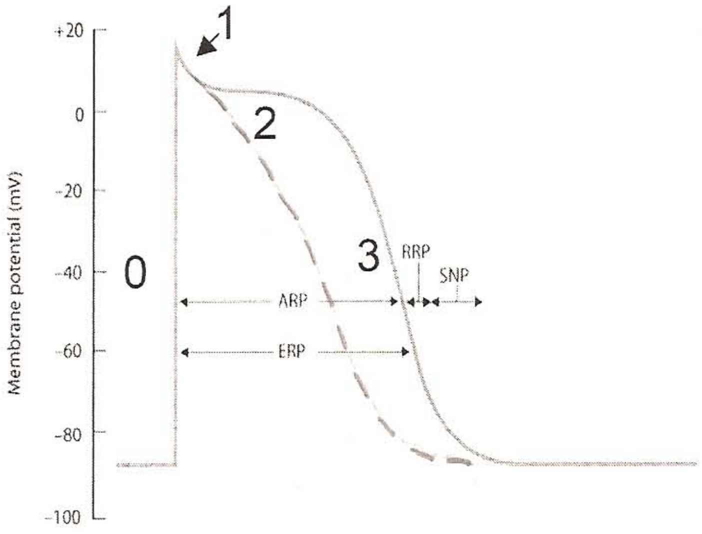
B. Give the term used to describe the process that occurs in the segment between points 3 and 4, and describe briefly what is happening to the myocardium at that time. (5 pts)

Isovolumetric relaxation – Muscle relaxes
$\Delta V = \emptyset$, valves closed.

C. On the graph above, draw how the loop would change if the patient were given a drug that increased aortic pressure and label this "1". Draw how the loop would change if the patient were instead given a positive inotropic agent and label this "2." (10 pts)

NAME: SID:

5. Consider the following ventricular action potential:




A. Identify the cation(s) whose currents are primarily responsible for driving changes in membrane potential observed in each of segments 1-4. Note that there is one cation associated with segments 0, 1, and 3, and two cations associated with segment 2. (10 pts)

| Segment | Key cation(s) |
| --- | --- |
| 0 | $Na^+$ |
| 1 | $K^+$ |
| 2 | $Ca^{2+}$ $K^+$ |
| 3 | $K^+$ |

B. During which segment of the action potential does the ventricular myocyte begin to contract, and why? (5 pts)

2 due to $Ca^{2+}$ influx

C. If this patient were treated with a drug that blocked L-type Ca++ channels (e.g., nifedipine), draw on the graph above how you would expect the action potential to change, and briefly explain why below. (10 pts)

Plateau phase is associated w/ inward $Ca^{2+}$ current. Thus, AP shifts toward repolarization earlier.

NAME: SID:

6. Consider a capillary in the brain of a patient with hydraulic conductance of 1 ml $min^{-1}$ $mmHg^{-1}$, from which fluid is leaking at a rate of 7 ml/min. Suppose the hydrostatic pressure in the capillary is 27 mmHg, the interstitial hydrostatic pressure is 2 mmHg, and the interstitial oncotic pressure is 5 mmHg.

A. Calculate the oncotic pressure in this capillary. (10 pts)

$$J_v = K_f[(P_c - P_i) - (\pi_c - \pi_i)]$$

$$+7 \frac{mL}{min} = 1 \frac{mL}{min\ mmHg}[(27 - 2\ mmHg) - (\pi_c - 5\ mmHg)]$$

$$\pi_c = \boxed{+23\ mmHg}$$

B. Estimate the protein concentration in this capillary, assuming a temperature of 37 C. (10 pts)

$$\pi_c = g C \sigma R T$$

Blood brain barrier to proteins $\Rightarrow \sigma = 1$

$$23\ mmHg \times \frac{1\ atm}{760\ mmHg} = (1) C (1)(.0821 \frac{L\ atm}{mol\ K})(310\ K)$$

$$C = \boxed{1.19 \frac{mmol}{L}}$$

C. Suppose you gave this patient an agent that suddenly reduced venous compliance. How you expect the rate of filtration through this capillary to change and why? (5 pts)

$\downarrow$ Venous compliance $\Rightarrow \uparrow P_c \Rightarrow \uparrow J_v$