

PRE-SHEET
ANSWERS
SESSION 1

MEMBRANE POTENTIALS

M.A.S.T.E.R. Learning Program, UC Davis School of Medicine
Revised: Jan 2nd, 2000
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1. Define **osmosis**.
Osmosis is the movement of water driven by chemical potential energy stored in the water concentration gradient.
2. Define **ideal semipermeable membrane**.
A membrane that lets water through and not solute.
3. What are two forces that drive the movement of water?
Osmotic pressure and hydrostatic pressure.
4. What is the working definition of **osmotic pressure**?
It's the pressure required to keep water from moving down its concentration gradient.
5. What creates **osmotic pressure**?
*Particles in solution, regardless of kind! The van't Hoff equation is $p = CRT$. Where: p = pressure, C = concentration of all solutes (Careful! The solute concentration of a 0.10M NaCl solution is NOT 0.10M! There will be 0.10M Na⁺, and 0.10M Cl⁻ making the TOTAL solute concentration 0.20M.)
 RT = Gas constant (0.082 L*atm/mol*K) times Temperature (deg. K) = 25.4 L Atm/mol under standard conditions.*

So, the more particles, the more osmotic pressure. Remember, osmotic pressure sucks! It sucks water. Remember that everything moves down a concentration gradient. In a situation where two compartments have different solute concentrations, the concentration of WATER is lower in the higher solute concentration compartment. Therefore water will flow down its concentration gradient, from where it is high concentration (in the low SOLUTE compartment) to where it is low (the high solute compartment). Physiologists prefer to think of water flowing from a region of high water concentration to low water concentration makes everything more consistent.
6. Define **hydrostatic pressure**.
Pressure exerted by a column of fluid. More practically, the pressure inside a vessel (i.e. blood pressure - the hydrostatic pressure of the blood in an artery).
7. What is the **general equation for flux**?
The general equation for flux is Fick's Law: $J_s = D_s \frac{d[s]}{dx}$ (you can always think back to Cala's basic equation: Flow = Conductance x Force)
8. Write equations for flux of water J_v and flux of non- electrolyte solute J_s .
*Flux of water (J_v) = $L_p A (DP - Dp)$
Flux of non-electrolyte solute (J_s) = $P_s D[S]$, $P_s = D_s b_s / D_x$*
9. Define **chemical potential energy, membrane potential, electrochemical potential energy, equilibrium potential** and **steady state membrane potential**. Write an equation for each

- a) **Chemical potential energy (Dm)** is the potential energy stored in a transmembrane concentration gradient of

$$\text{solute } X: \mathbf{Dm}_X = m_n - m_{out} = RT \ln \left(\frac{[X]_{in}}{[X]_{out}} \right)$$

- b) **Membrane potential (Em)** is the voltage across a membrane due to a separation of charge in the plane of the membrane, or more precisely, it is the electrical potential energy stored across the membrane. Much the same as the chemical potential, except now you have an imbalance of charges (which really are particles themselves when you think about it): $E_m = E_i - E_o$ (mV)

- c) **Electrochemical potential energy ($\Delta\tilde{m}$)** is the sum of the chemical and electrical potential energy (sum of **Dm** and **Em**). This puts it all together. We know that there was a potential energy due to the separation of concentration, and also of separation of charge. These energies are additive:

$$\Delta\tilde{m}(x) = \text{chemical potential energy} + \text{electrical potential energy. Thus } \Delta\tilde{m}(x) = RT \ln \left(\frac{[X]_i}{[X]_o} \right) + zFE_m$$

(J/mol), and dividing by zF , you get:

$$\frac{\Delta\tilde{m}(x)}{zF} = \frac{RT}{zF} \ln \left(\frac{[X]_i}{[X]_o} \right) + E_m = E_m - E_x \text{ (volts)}$$

$$\text{Remember that } E_x = \frac{RT}{zF} \ln \left(\frac{[X]_o}{[X]_i} \right) \text{ and } -E_x = \frac{RT}{zF} \ln \left(\frac{[X]_i}{[X]_o} \right)$$

So the electrochemical potential difference (the force driving the movement of the ion) can be expressed in any of those three ways.

- d) **Equilibrium potential** is the membrane potential that must exist if the transmembrane distribution of a specific solute X is to be at equilibrium (or when the electrochemical potential energy of the solute across the membrane

is zero): $E_x = \frac{RT}{zF} \ln \left(\frac{[X]_o}{[X]_i} \right)$. (Note that the numerator & denominator are flipped!) This is the **Nernst**

Equation, derived by setting $\mathbf{Dm}_x=0$ and solving for E_x . Under standard conditions at body temperature, $RT/zF \ln$ can be rewritten in a simpler form:

$$E_x = \frac{61}{z} \log_{10} \left(\frac{[X]_{out}}{[X]_{in}} \right) \text{ MEMORIZE THIS EQUATION!}$$

Note that the Nernst Equation only describes the membrane potential **at equilibrium**, i.e. when all net currents have **stopped**. That's what's meant by **equilibrium potential**, after all! It cannot be used to predict the membrane voltage when currents are flowing. To calculate membrane potential when currents are flowing, i.e. in the steady state, you have to use the equation below: the **steady state membrane potential**. Make sure you understand the distinction!

- e) **Steady state membrane potential** is the membrane voltage when total membrane current (I_m) equals zero:

$$E_m = \frac{(E_x G_x + E_y G_y)}{(G_x + G_y)} \text{ when membrane is permeable to solute } X \text{ and } Y.$$

Another way to express this is $E_m = \frac{RT}{zF} \ln \left(\frac{P_x [X]_o + P_y [Y]_o}{P_x [X]_i + P_y [Y]_i} \right)$, (called the Goldman Equation, or Chord

Conductance Equation). At standard conditions at body temp, this can be written as:

$$E_m = \frac{61}{z} \log_{10} \left(\frac{P_X [X]_o + P_Y [Y]_o}{P_X [X]_i + P_Y [Y]_i} \right) \text{ MEMORIZE THIS EQUATION!}$$

10. What is the difference between equilibrium potential and steady state membrane potential?

Equilibrium potential is the potential required for a specific ion, at a specific concentration gradient across the membrane, to be at equilibrium. It is concerned with a specific ion, and it gives the membrane potential that must exist for the ion at a given transmembrane distribution to have no net flux across the membrane (i.e. to be at equilibrium). It is used to predict what kind of membrane potential would exist if the given ion were the only ion that we had to worry about. (It can cross the membrane and it carries a charge). Stated another way, given a transmembrane gradient of an ion X, and a membrane that is permeable to X, the ion will move through the membrane from high to low concentration until it creates enough charge separation that the electrical attractive and repulsive forces (whose magnitude is represented by the membrane potential) prevent it from going down its chemical gradient any further, and all diffusion (current) stops. At that point, the membrane potential is called the equilibrium potential.

Steady state membrane potential is a specific membrane potential when the net current sum of all the ions with conductance across the membrane equals zero. It deals with all the ions that have conductance across the membrane. At the steady state membrane potential, the net ion flow of each ion with conductance is not at equilibrium but the sum of the net currents of all the permeable ions is zero.

11. What are the typical equilibrium potentials for Na⁺ and K⁺? Use concentrations given on page 14 of lecture 2.

$$E_K = RT/zF \cdot \ln [K]_o / [K]_i = 26.6 \text{ mV} \cdot \ln (4 \text{ mM} / 150 \text{ mM}) = -96.4 \text{ mV}$$

$$E_{Na} = RT/zF \cdot \ln [Na]_o / [Na]_i = 26.6 \text{ mV} \cdot \ln (150 \text{ mM} / 15 \text{ mM}) = +61.25 \text{ mV}$$

12. Define current, and how is it related to flux?

Current is the net movement of charged particles (ions). Really, current is just another word for the flux of charged particles. And flux is just another word for flow. So current is the flow of charged particles.

Specifically: Ion Flux (J_s) is expressed in moles/sec $\cdot zF$ which is equal to coulombs/sec = I_s

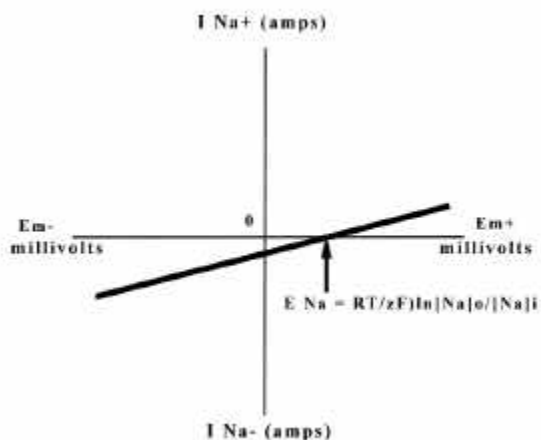
13. Write an expression for the current of ion X across membrane.

Well, since current = flux = flow, we can refer to Cala's favorite equation for flux!

Flux = conductance \times force.... using Ohm's law: $I = V/R$ $1/R =$ conductance G .

$I_x = G_x [E_m - E_x]$. Remember that $E_m - E_x = \Delta u(x) / zF$? This is the electrochemical potential difference expressed in volts, the force (V of Ohm's Law) driving the movement of the ion.

14. Write an equation for the current generated by the movement of Na⁺ across a membrane. Express the equation on a E_m vs. I_{Na^+} graph. What are the significance of the slope of the line and the point at which the line intersects the current-voltage.

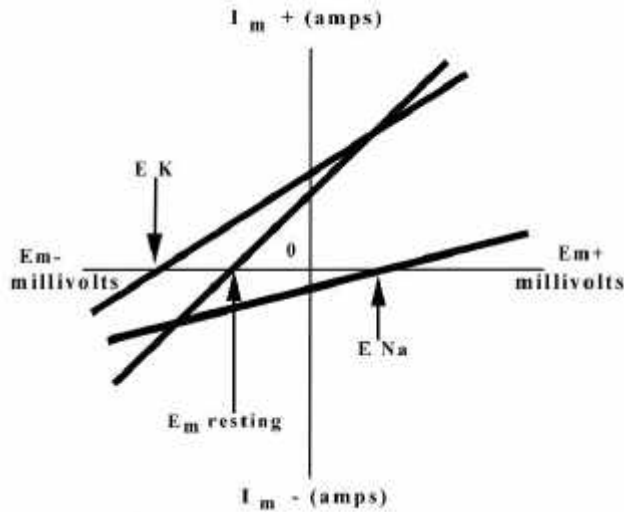


For Na⁺, $I(Na^+) = G(Na^+) [E_m - E_{Na^+}]$ (the electrochemical potential difference in volts).

So the flow of Na⁺ across a membrane is governed by how easily it can get across the membrane (not very well since the membrane is hydrophobic, and Na⁺ is very hydrophilic), and how much electrochemical force is pushing it across.

The slope of the line is I/V or the conductance of Na⁺ (G_{Na^+}) and the point of intersection on E_m axis is E_{Na} .

15. Write an expression for the **total membrane current (I_m)** when the membrane has conductance for both Na^+ and K^+ . Express I_m on a E_m vs. I_m graph. What is the significance of the intersection point of the line on E_m axis?



$$I_m =$$

$$I_{\text{Na}^+} + I_{\text{K}^+} =$$

$$G_{\text{Na}^+}(E_m - E_{\text{Na}^+}) + G_{\text{K}^+}(E_m - E_{\text{K}^+})$$

The intersection point of the line on the E_m axis is the **steady state membrane potential**.

16. Define **Resting Membrane Potential**

The voltage (or electrical potential energy) which exists across a membrane at rest, i.e. when no action potentials are being generated or conducted. RMP is determined by

Ions present in solution

The permeability (ease of ions passing thru membrane) or conductance (flow of charged ions thru channels)

Membrane properties (i.e. resistance and capacitance)

17. What is a **generator potential**?

Generator potentials represent electrotonic potentials that arise as a result of stimulus-induced changes in the ionic conductance of the sensory cell membrane. The application of a stimulus of the appropriate type and intensity produces a change in receptor membrane conductance leading to current flow and a change in the membrane potential.

18. Define **adaptation**.

Adaptation is defined as a decreased response to stimuli over time.

19. True or False: An increase in Na^+ conductance or a decrease in K^+ conductance will lead to a decrease in the membrane potential (the membrane potential will move closer to zero).

True. This occurs because the membrane potential depends on the relative permeabilities of Na^+ and K^+ , and permeability is related to conductance across the cell's plasma membrane. Normally K^+ is approximately 100x more permeable than Na^+ , therefore if you increase Na^+ conductance you bring the membrane potential closer to the Nernst potential of Na^+ or more +. Additionally, if you decrease the conductance of K^+ you diminish the contribution of K^+ 's Nernst potential to the overall membrane potential thereby also bringing the membrane potential closer to 0

Look at the Goldman equation another way, play around with the permeability of the ions and notice how it may or may not change the E_m .

$$E_m = 61 \log \frac{[K]_o + (P_{\text{Na}}/P_{\text{K}}) [Na]_o}{[K]_i + (P_{\text{Na}}/P_{\text{K}}) [Na]_i}$$

20. What is the difference between **absolute** and **relative refractory periods**?

*The **Absolute Refractory Period** is the period in time when the cell is unable to fire an action potential regardless of the intensity of the stimulus. ARP is associated with the inactivation of the fast Na⁺ channels responsible for the action potential. The **Relative Refractory Period** is the period in time when the cell can elicit an action potential, but only if the stimulus is sufficiently large. The RRP is associated with the increase in K⁺ conductance produced during the action potential.*

21. Outline the sequence of events in chemical synaptic transmission.

1) Action potential in presynaptic cell

2) Depolarization of the plasma membrane of the presynaptic axon terminal.

a. Entry of Ca⁺⁺ into presynaptic terminal

b. Release of Synaptic Vesicle from docking and fusion with presynaptic membrane

c. Release of the transmitter by the presynaptic terminal

d. Chemical combination of the transmitter with specific receptors on the plasma membrane of the postsynaptic cell

e. Transient change in the conductance of the postsynaptic plasma membrane to specific ions

f. Current flow caused by the Electrotonic potential reaches the area of the cell with fast Na channels and if the resulting voltage is large enough and action potential is generated.

22. What are **excitatory postsynaptic potentials (EPSP)** and **inhibitory postsynaptic potentials (IPSP)**?

Neurotransmission at a central synapse may elicit either a depolarization or a hyperpolarization of the postsynaptic cell membrane. EPSP is a transient depolarization of the postsynaptic neuron as the result of an action potential in a presynaptic cell. An IPSP is the transient hyperpolarization caused by an action potential in an inhibitory input, this will drive the Em farther away from threshold.

23. Discuss **Neuronal Integration** and **Summation**

*Neurons receive multiple synaptic inputs, both excitatory and inhibitory. These inputs are additive and are therefore summed. Summation occurs in both a temporal and spatial manner. **Temporal summation** refers to the addition of two synaptic inputs occurring at different times. For example, if you have 2 excitatory signals coming in rapid succession such that the 1st depolarization does not return to resting potential **before** the 2nd depolarization occurs the two are additive and together (or with additional signals) may be sufficient to reach threshold. **Spatial summation** refers to the addition of two synaptic inputs occurring at different locations on the neuron (e.g. on different dendrites). The overall sum of all synaptic inputs determines the response of the neuron (i.e. if the sum of the signals is sufficient to reach threshold the neuron will fire an action potential)*