Problem Sets: Questions

These problems are provided to aid in your understanding of basic neurobiological concepts and to guide your focus for in-depth study. These practice questions are optional and answers will not be graded, although they will be discussed during discussion sections. The topics in these problem sets parallel those covered in lecture.

Neurobiological concepts are complex and difficult, and oftentimes are not easily digested at first reading. We suggest that you review the course material several times by reading different texts/papers and talking through your difficulties with us and your fellow classmates. Stick with it because this material can be fully comprehended through persistent and focused effort.

Problems listed below are in order of topics covered in lecture. Problem set numbers do not always correspond to specific lectures or weeks of the term. There are 5 problem sets in this series.
1.1 The equilibrium potential for sodium (\(E_{Na}\)) = +58 mV if the concentration of Na on the outside of the cell is 10 times the concentration of Na on the inside of the cell. What happens to \(E_{Na}\) if the extracellular concentration of sodium ([Na]o) is increased by a factor of 10? factor of 100? decreased by a factor of 10? Explain why \(E_{Na}\) changes in the above examples in terms of the balance between chemical and electrical forces across the cell=s plasma membrane.

1.2 Fill in the blank: the total conductance of a membrane for a particular ion (\(g_{ion}\)) is equal to the number of open channels for that ion x (multiplied by) _______________.

1.3 Write an equation that describes the following statement in mathematical terms: At the contribution to transmembrane potential (\(V_m\)) of each ionic battery is weighted in proportion to the permeability of the membrane for each particular ion. Why is \(V_{rest}\) so much closer to \(E_k\) than it is to \(E_{Na}\)? Why is \(V_m\) at the peak of the action potential so much closer to \(E_{Na}\) than it is to \(E_k\)?

1.4 What are the differences between permeability, conductance, and current? Explain each in terms of its relationship to ions and membrane properties.

1.5 Propose 2 experiments to test the hypothesis that an increase in potassium conductance is responsible for the falling phase of the action potential in a neuron? (Hint: think about voltage clamping, the trough of the action potential, and that cesium and TEA both can be used to block some K currents.)

1.6 Explain why the opening of voltage-gated sodium channels proceeds in a positive feedback fashion during the generation of an action potential. Why isn=t the opening of voltage-gated potassium channels mediated via a similar positive feedback loop?

1.7 Explain the difference between the concepts of equilibrium and homeostasis (steady-state). (Hint: physical molecular forces and active cellular processes).
Problem Set 2 (ION CHANNELS):

2.1 Researchers have identified a gene that, they think, encodes a voltage-dependent potassium channel. How would you go about trying to prove that it does encode such a channel? Hint: frog oocytes can be used to express proteins of interest by injecting them with large amounts of RNA so that the product is of high concentration compared to other proteins in the cell. These cells can then be used for electrophysiology experiments.

2.2 You are performing a patch clamp experiment on a patch of membrane that has precisely 3 voltage-gated sodium channels.
   A) Draw a current trace of all of the possible channel-opening events in response to a single depolarizing stimulus from rest (-70 mV) to above threshold (0 mV) and back to rest in a 1 sec period. (Hint: maximum of 3 events/ voltage step).
   B) Explain why two single-channel events with different mean open times pass the same current and have the same conductance?
   C) Explain why do 2 channels opening at once pass 2x the current of a single channel and have 2x the conductance of a single channel?

2.3 You are in the midst of a patch clamp experiment with a single voltage-activated Na channel. In response to a depolarizing voltage step, the channel current 1) turns on at the onset of depolarization; 2) remains on for a brief period; and 3) turns off (inactivate) before the end of the depolarizing stimulus. Draw the voltage step and the current trace from this experiment. Treat the patch with aconitine, repeat the same experimental protocol using the same voltage steps and draw the resultant current trace, explaining any differences. Rinse away the aconitine and repeat experiment using pronase.

2.4 What properties of ions and their respective transmembrane channels make such channels selective for a specific ion? (Hint: the two main structural parts of channels are the pore and the selectivity filter).

2.5 Draw the current traces obtained from a patch clamp experiment on a single voltage-dependent Na channel exposed to a series of voltage steps (-110mV, -90mV, -65mV (subthreshold), 0mV, 20mV, 50mV, 70 mV) each starting from rest (-70mV) for a 100 msec duration. Repeat with a patch containing a single voltage-dependent K channel. (Hint: V=IR, so I=g(Vm-E, where X= Na or K).
Problem Set 3 (CABLE THEORY):

3.1 Explain why an increase in the surface area of the plasma membrane of a neuron results in an increase of the cell’s time constant. (Hint: think about electrical properties of the cell that are affected by changes in the surface area of the plasma membrane.)

3.2 What is the effect of an increase in input resistance on the length constant of a cell? Explain the reasons for your answer. What is the effect of an increase in axial resistance on the length constant of a cell? Explain. (Hint: consider current leaking across the membrane and current flowing down an axon.)

3.3 What is the effect of increasing the diameter of an axon on the speed of a propagated action potential? Explain the reasons for your answer. (Hint: consider the factors underlying the spread of charge in an axon).

3.4 What is the effect of myelination of an axon on the time and length constants? Explain the reasons for your answers. (Hint: consider the effect of myelination).

3.5 Draw I-V curves for a rectifying and a non-rectifying electrical synapse. (Hint: consider drawing 4 curves total, 2 for each type of synapse: injecting depolarizing and hyperpolarizing current into pre-synaptic cell and measuring voltage in the post-synaptic cell (curve #1), and injecting depolarizing and hyperpolarizing current into post-synaptic cell and measuring voltage in pre-synaptic cell (curve #2)).
Problem Set 4 (SENSORY ADAPTATION, PERCEPTION, RECEPTIVE FIELDS, 2nd MESSENGER CASCADES)

4.1  A) What is adaptation by sensory receptor cells? Describe 3 behavioral examples of adaptation (you have probably experienced dozens of them today unless you are dead).
   B) Describe the different properties of slowly and rapidly adapting neurons. What different functions do they serve? (Hint: consider the different types of information, contained in the physical stimulus).

4.2 Describe, in as much detail as possible, a G-protein-mediated receptor-second messenger cascade that results in a metabotropic response on a neuron’s ion channel. What functions are served by such a pathway?

4.3 What is the difference between an ionotrophic and a metabotropic receptor-mediated response? What is the utility of having metabotropic pathways when ionotrophic pathways are faster and more direct?

4.4 Describe two molecular mechanisms of sensory adaptation in sensory receptor cells. (Hint: consider changes in channel properties).

4.5 What is a receptive field? What type of neurons have receptive fields (be as specific as possible)? What is the effect of inhibition from lower order sensory cells on the receptive fields of higher order relay neurons?

4.6 Describe the labeled line hypothesis of sensory perception. What is a sensory modality? A submodality? Name all human sensory modalities. Name 5 human sensory submodalities.
Problem Set 5 (CENTRAL PATTERN GENERATORS, LEARNING AND MEMORY):

5.1 Explain the concept of a central pattern generator (CPG). Name a human CPG and draw its cellular circuit with its specific neuronal connections (excitatory, inhibitory). What is the input? Output?

5.2 Define the concept of post-inhibitory rebound (PIR) and its underlying molecular mechanisms. (Hint: consider the number of voltage-dependent Na channels that are inactivated at -70mV vs at -90mV). What is the function of PIR in a neuron of a CPG circuit?

5.3 What is meant by LTP between a presynaptic and postsynaptic cell in the hippocampus? How is LTP induced in the hippocampus? What is the role of NMDA receptors in the postsynaptic cell in the induction of LTP? (Hint: the regulation of the NMDA receptor is complex) Postulate how LTP might be involved in learning and memory?

5.4 What is sensitization? Explain how sensitization occurs at the molecular level in a sensory neuron through the input from a facilitating interneuron. (Hint: gill withdrawal reflex in Aplysia.)

5.5 What is habituation to a physical stimulus? Dishabituation? Describe 2 behavioral examples of each and their functional significance to an organism’s survival.

5.6 Describe how second messengers modulate synaptic activity. Include pre- and post-synaptic effects. Give two examples of each.

5.7 What is the difference between declarative and non-declarative memory? Give two examples of each.