NAME ______________________________________

BI 360 Final Exam
Fall 2018
N. Tublitz

This is an open book, open notes exam. Choose any 7 questions (out of 10) to answer. Each question is worth 15 points. Typed answers are encouraged but are not necessary if your handwriting is legible.

Only the first 7 questions answered will be graded. No extra credit will be given. Please mark the questions you are NOT answering with a large X to avoid confusion.

You may make use of any reference material but may not discuss the exam with anyone.

You may take up to 23 hours to complete this test.

PLEASE PUT YOUR NAME ON ALL SHEETS.

The test must be returned to the Biology Department office (77 Klamath) by

1030 am Friday November 30th

(PLEASE NOTE THAT EXAMS TURNED IN AFTER THE DEADLINE WILL NOT BE GRADED AND WILL RECEIVE A FAILING GRADE)

This test will be graded only if the following statement is signed:

"On my honor, I did not collaborate with any other person, including a fellow student, during this exam. I also state I did not plagiarize from any source."

Signature____________________________________

Under no circumstances should your answers exceed the space given.
1. Many bats use echolocation to identify and localize objects in their environment. They accomplish this by sending out a high frequency signal and measuring the time it takes a reflection of that signal to return to them. Some bats use their echolocation abilities to distinguish between an object that is 49 cm away and one that is 50 cm away. They accomplish this in spite of the fact that the difference between a reflected echo from a 49 cm target and one from a 50 cm target is less than 10 microseconds ($10^{-5}$ sec). How can the nervous system determine this timing difference considering it is two orders of magnitude less than the duration of a single action potential ($10^{-3}$ sec)? Propose a neural mechanism that might be able to accomplish this feat.

If a bat’s CNS is capable of distinguishing between two echoes whose difference is smaller than the fastest possible electrical signal generated by a single neuron, then the bat CNS must be using a network of neurons to detect this minute difference. One possibility is that the bat uses a detection system similar to that employed for audition, namely individual or networks of cells uniquely “tuned” to respond to specific high frequencies. This mechanism would be able to measure timing differences as small as 10 microseconds.
2. You are recording from a squid giant neuron whose resting potential is -60 mV. You inject square pulses of hyperpolarizing current (1 nA = 10^{-9} A) into the cell for 20, 40 and 100 ms in duration, respectively. These current injections generate the voltage and current records presented below (left arrow denotes the beginning of the current injection). For all questions, show your calculations.

A) What is the cell’s time constant (\(\tau\); answer should be in msec (5pts)?

20 ms or \(2 \times 10^{-2}\) sec (time taken for the signal to drop 63%).

This value was calculated because in this example the total voltage change in response to a 1 nA hyperpolarizing pulse is -100 mV (from -60 mV to -160 mV). 63% of that change is -63 mV. Hence the time constant is the time it takes for the voltage to drop 63 mV from -60 mV or to -123 mV which is approximately 20 ms. The left arrow is the start of the voltage change; the right arrow marks the point where the \(V_m\) has dropped by 63%.

B) What is the cell’s membrane resistance (\(R_m\); answer should be in ohms) (5 pts)?

\(1 \times 10^8\) Ohms or 100 megohms (calculated by solving \(V = IR\), where \(V = -100\) mV or \(1 \times 10^{-1}\) V and \(I = -1\) nA or \(1 \times 10^{-9}\) A)

C) What is the cell’s membrane capacitance (\(C_m\); answer should be in farads) (5 pts)?

\(C_m = 2 \times 10^{-10}\) farads (obtained by solving \(\tau = R_m C_m\) where \(\tau = 20\) ms or \(2 \times 10^{-2}\) sec and \(R_m = 1 \times 10^8\) ohms)
3. Define the concept of a receptive field as it applies to sensory systems (5 pts). How does this concept apply to olfaction (2.5 pts)? To gustation (2.5 pts)? Describe the receptive fields of an olfactory and a gustatory sensory cell (5 pts).

The receptive field of a sensory neuron is defined as that part of sensory space which, when stimulated, activates the cell. For a visual photoreceptor (e.g., rods and cones), its receptive field is that part of visual space that activates the cell. For olfaction and gustation, individual sensory receptors are responsive to specific chemical stimuli. Their receptive fields are those stimuli which stimulates the cell to fire. In the gustatory system, individual taste receptors are each tuned to a specific class of chemical stimulus; i.e., salt, bitter, sugar, sour or umami (the latter activated by monosodium glutamate). Similarly, olfactory receptors are tuned to specific odorant classes. In this respect, the receptive field concept applies to the olfactory and gustatory systems as well as to the visual, auditory, and somatosensory systems.
4. You are recording from a mammalian nerve cell that has never been recorded before. Using patch clamp techniques, you voltage clamp a small patch of membrane that has one or a few of a particular type of channel. The recordings you obtain look like this:

A) Is this channel voltage gated? Why or why not (5 pts)?

The channel is not voltage gated because it is open at all voltages.

B) The experimental solutions used to obtain these recordings were:
   Extracellular: 150 mM KGluconate (gluconate is an impermeant anion) & 10 mM NaCl
   Intracellular: 150 mM KCl & 1mM MgCl2
   What ion(s) carries (carry) the current observed in the figure? Explain your answer (5 pts).

K⁺, because \( E_K = 0 \, \text{mV} \) and the reversal potential of the current is at \(~0 \, \text{mV} \). Na⁺ cannot be the current carrier because it is only present extracellularly (i.e., in the pipette) and thus \( E_{Na} \) will be positive.

C) Draw the I-V curve for this channel (5 pts).

Straight line with points \((X,Y)\) at \((20 \, \text{mV}, 1.6 \, \text{pA})\); \((0 \, \text{mV}, 0 \, \text{pA})\); \((-30 \, \text{mV}, -1.8 \, \text{pA})\); \((-50 \, \text{mV}, -3\, \text{pA})\).
5. Barnacle photoreceptor cells have a typical neuronal morphology as shown below.

These cells are unusual, however, in that light produces a generator potential in their dendrites which travels all the way to the terminal and activates transmitter release without producing an action potential. Explain how this is possible using your knowledge of passive properties of neurons.

Barnacle photoreceptors are able to transmit the generator potential all the way down their axons to their terminals without the necessity for action potentials because the length constant ($\lambda$) of their membrane is greater (i.e., very long) that is seen in a typical neuron. Using the equation $\lambda = \sqrt{(Rm/Ri)}$, there are only two variables that can change $\lambda$, $Rm$ or $Ri$. Either one is acceptable for this answer. However, in reality, the barnacle photoreceptor has these unusual properties because of a substantial increase in $Rm$. 

NAME ________________________________

5. Barnacle photoreceptor cells have a typical neuronal morphology as shown below.

DENDRITES  SOMA  AXON  TERMINAL

These cells are unusual, however, in that light produces a generator potential in their dendrites which travels all the way to the terminal and activates transmitter release without producing an action potential. Explain how this is possible using your knowledge of passive properties of neurons.

Barnacle photoreceptors are able to transmit the generator potential all the way down their axons to their terminals without the necessity for action potentials because the length constant ($\lambda$) of their membrane is greater (i.e., very long) that is seen in a typical neuron. Using the equation $\lambda = \sqrt{(Rm/Ri)}$, there are only two variables that can change $\lambda$, $Rm$ or $Ri$. Either one is acceptable for this answer. However, in reality, the barnacle photoreceptor has these unusual properties because of a substantial increase in $Rm$. 

NAME ________________________________
6. A) Describe Hebb’s rule of learning for both strengthening and weakening synapses (5 pts).

The rule comes from Donald Hebb who in 1949 stated that “when neuron A repeatedly participates in firing neuron B, the strength of the action of A onto B increases”. In other words, repeated activation of A leads to a stronger synaptic signal being received by B. The implication of Hebb’s rule is that a reduction in the activation of A leads to a weaker synaptic signal in B.

B) Discuss Hebb’s rule in terms of possible molecular mechanisms in pre- and post-synaptic cells (5 pts).

A direct interpretation of Hebb’s rule is that any change in the strength of a synaptic connection is a function of the activities of both pre- and post-synaptic cells. At the level of the pre-synaptic cell, these changes can occur by increasing or decreasing the amount of transmitter being released. At the level of the post-synaptic cell, changes in synaptic efficacy can be the result of increasing or decreasing the sensitivity of the transmitter receptor detection system.

C) Explain how the molecular mechanisms responsible for long term potentiation (LTP) are consistent with Hebb’s rule (5 pts).

In LTP, a brief train of action potentials in the pre-synaptic cell in the hippocampus (e.g., CA3 cell) causes an enhanced response in the post-synaptic cell (e.g., CA1 cell). This increased post-synaptic responsiveness is mediated by a number of molecular mechanisms, including activation of NMDA receptors, increased responsiveness by existing AMPA receptors and the addition of new AMPA receptors. The post-synaptic cell also generates a retrograde messenger that acts on the pre-synaptic terminal to increase transmitter release. All these mechanisms lead to a strengthening of synaptic transmission at this hippocampal synapse and support Hebb’s rule.
7. One of the classic methods to depolarize a cell is to increase the extracellular concentration of K+ ions.

A Explain exactly why this works (5 pts).

The resting potential is primarily due to a resting K⁺ conductance. The Goldman-Hodgkin-Katz equation unequivocally shows that a change in external concentration of K⁺ will increase the resting membrane potential of the cell.

B Increasing extracellular Na⁺ concentrations does not have this effect. What effect is seen and why (5 pts)?

The permeability of the membrane of a neuron at rest to Na⁺ is much lower in comparison to its K⁺ permeability. Increasing extracellular Na⁺ will cause a minor depolarization however that effect will be slight if at all.

C Increasing extracellular K⁺ levels in the presence of TEA will lead to what effect on the resting potential of the neuron? Why?

TEA blocks voltage-dependent K⁺ channels, not the resting K⁺ conductance. Hence TEA will not impact the depolarizing effect of increased extracellular K⁺ on the resting membrane potential.
8. What insights into neuroscience have you gained from reading *The Man Who Mistook His Wife For A Hat* and viewing the Nova video? Include at least one specific example each from the book and the video in your answer.

A correct answer to this question focuses on several general issues raised by the book and the movie (e.g., neural deficits; plasticity; behavioral abnormalities) using at least one example each from the book and the video to support your answer.
9. Vertebrate dorsal root sensory cells have a Na$^+$-dependent action potential. Voltage clamp experiments reveal that the inward Na$^+$ current is reduced but not eliminated in the presence of TTX. What do you conclude from this results? Describe two experiments to test your conclusion.

If TTX does not entirely block the inward Na$^+$ current, then there must be a second, voltage dependent Na$^+$ current that is TTX insensitive. Blocking the TTX sensitive current reveals a TTX insensitive current. Two experiments to test this conclusion are to show that changing extracellular concentrations of K$^+$ or Cl$^-$ ions has no effect on the two Na$^+$ currents. A second experiment would be to voltage clamp the cell and demonstrate that both currents have a reversal potential at the Na$^+$ equilibrium potential. Another possibility is that calcium ion flow underlies the TTX-insensitive current. In that scenario, changing the levels of [Ca$^{2+}$]$_{out}$ would affect the magnitude of the current, and clamping at the Na$^+$ equilibrium potential would have no effect on the current (Note: this possibility does not exist in nature however such an answer will receive full credit).
10. You undoubtedly studied one aspect of nervous system function you regarded as important but was not covered on this exam. So that all that studying was not a total waste, pose a question that covers a topic from any part of this course not addressed by other questions on this exam, and then answer your own question. You’ll be graded both on the quality of the question (7.5 points) and on the quality of the answer (7.5 points). Your question should not be too trivial (e.g., name two kinds of cells in the nervous system), it should not be a twist on one of the questions already on the exam and ought to reflect your judgment of what a fair yet relatively difficult exam question should be.

Many correct answers are possible. Points were awarded on the basis of the originality and quality of the experiment and answer.