Physiological Foundations Spring 2004: Midterm Examination

March 10, 2004

Name: _____

SSN: _____

I certify that all of the work in this exam is entirely my own. I have not referred to any notes or to any other individual while taking this exam.

Signature: _____

1. a)_____/11	6. _____/14
b)_____/11	7. _____/14
c)_____/6	8. _____/8
d)_____/11	9. _____/14
e)_____/9	10._____/8
2. _____/15	11._____/8
3. a)_____/11	12._____/8
b)_____/11	
c)_____/15	TOTAL_____/200
4. _____/18	**EXTRA CREDIT _____/2**
5. _____/8	

Question 1

        Part a) (11 points) Tell which ion (or ions) typically produces each of the following potentials by increasing its conductance (or by being the largest conductance in the membrane).

        Resting potential _____

        Positive peak of the action potential _____

        EPSP _____

        IPSP _____

        Hyperpolarization after an action potential _____

        Part b) (11 points) Draw an electrical circuit diagram that incorporates all the elements needed to produce the potentials discussed in part a). Label each part of the circuit with the potential from a) that it produces.

        Part c) (6 points) Write an equation that expresses the *equilibrium potential for calcium ions*. Explain, in one sentence, what it expresses.

        Part d) (11 points) Write an equation that expresses the steady (D.C.) membrane potential V for the circuit that you drew in part b), i.e. in the situation where the ion conductances have been steady for some time.

        Part e) (9 points) A cell has a metabotropic receptor for GABA that decreases the open probability of the gating of a certain potassium channel. Tell what effect release of GABA would have on this cell.

Question 2 (15 points)

In order to add an H channel to the HH model you studied in the homework, you need to add two functions to the Matlab program. The first computes $h_\infty(V)$ and the second computes $t_h(V)$. Write Matlab functions to compute these two variables from the membrane potential V using the following functional forms.

$$h_\infty(V) = 0.5\left[1 - \tanh\left(\frac{V+70}{10}\right)\right] \quad \text{and} \quad \tau_h(V) = \frac{10}{\cosh\left(\dfrac{V+70}{20}\right)}$$

Question 3

In order to determine which ion(s) pass through a synaptic receptor channel, it is usual to determine the *reversal potential* of the channel. This means voltage clamping the membrane to a range of potentials, activating the synapse during the voltage clamp, and then looking for some magic condition that reveals the reversal potential.

Part a) (11 points) What is the magic condition? Part of your answer should be an equation, based on the circuit you produced in Question 1b, that explains how the voltage clamp is used to determine the reversal potential.

BECAUSE YOU MAY WISH TO USE CABLE THEORY TO SOLVE ONE OR MORE OF THE FOLLOWING PROBLEMS, ASSUME THAT THE RESTING MEMBRANE POTENTIAL IS 0 mV FOR THE FOLLOWING PROBLEMS.

Part b) (11 points) The plot at right shows the current through a synaptic channel at various values of V_{clamp} (i.e. at various voltage clamp potentials). The clamp potentials are given by the numbers on the curves (40, 30, etc.). What is the reversal potential of this synapse?
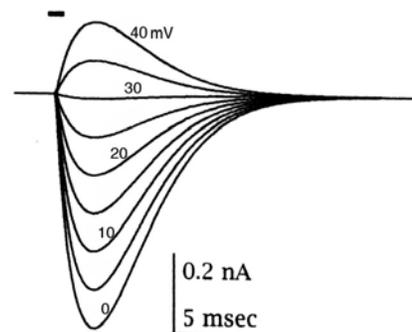
Part c) (15 points) Suppose the synapse is 300 μm away from the point of voltage-clamp (and current recording) along a dendrite, as in the drawing below. Assume the dendritic tree of the neuron is very long (i.e. for all practical purposes, infinitely long). What is the reversal potential of the synapse in this situation, given the same data at the recording site as in the figure above? It may help to know that for this membrane, $R_m=10^4$ Ω·cm² and $R_i=200$ Ω·cm.

Voltage-clamp system — synapse — 300 μm — 10 μm
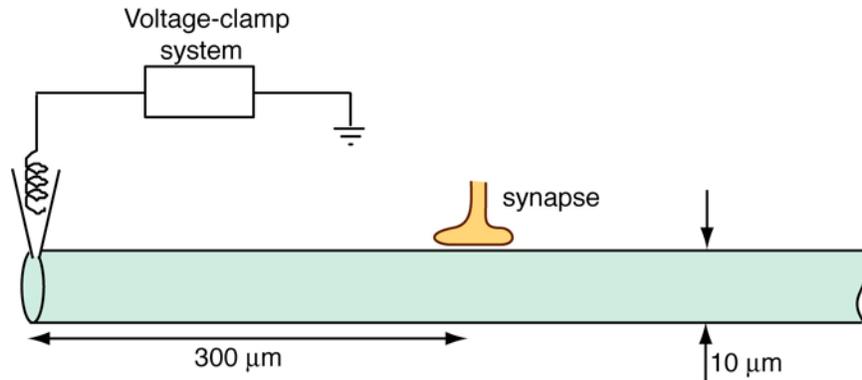
Question 4 (18 points)

It was found that an aqueous extract of the common morning glory caused significant motor weakness when injected into rats. Direct electrical stimulation of muscle showed no change, and recordings from nerve were normal, suggesting that synaptic transmission was reduced by morning glory tea. Intracellular voltage recordings from muscle fibers showed that exposure to morning glory tea reduced the amplitude of postsynaptic potentials so that they often failed to initiate a muscle action potential. One laboratory has proposed that morning glory tea blocks presynaptic calcium channels. Another laboratory has proffered the alternative hypothesis that morning glory tea blocks postsynaptic acetylcholine (ACh) receptors. Explain how you would use spontaneous transmitter release and quantal analysis to distinguish between these two hypotheses.

Question 5 (8 points)

Perceptrons are the simplest feedforward networks that are trained by supervised learning. The following statements about perceptrons are true except for one. Circle the one that is false.

(A) Perceptron learning rule can be derived by gradient descent on an error function, and this method can be generalized to multi-layer perceptrons.
(B) A perceptron can sometimes learn to classify complex patterns after only a single trial of training.
(C) The XOR problem cannot be learned by a feedforward network regardless of the amount of training.
(D) Even if a perceptron has learned to classify the patterns used in training, the classification may not generalize to new patterns.

Question 6 (14 points)

Consider a simple perceptron with n input lines and n weights, and the threshold parameter is fixed to zero. This perceptron can learn to classify an input pattern into one of two classes, depending on whether the output is positive or negative. After training, suppose two

input patterns $\mathbf{a} = (a_1, a_2, \cdots, a_n)$ and $\mathbf{b} = (b_1, b_2, \cdots, b_n)$ are classified into the same class. Explain how this perceptron would classify the new pattern given by $\mathbf{a} + \mathbf{b} = (a_1 + b_1, a_2 + b_2, \cdots, a_n + b_n)$.

Question 7 (14 points)

In a Hopfield network, the weight W_{ij} for the synaptic connection from neuron j to neuron i depends on all the memory patterns stored in the network. Show that no matter how many memory patterns are stored, the symmetry $W_{ij} = W_{ji}$ always holds; that is, every pair of neurons in a Hopfield network must always be reciprocally connected with equal strength.

Question 8 (8 points)

The Hopfield network is a recurrent network with interesting collective dynamic properties. The following statements about a standard Hopfield network are true except for one. Circle the one that is false.

(A) Different memory patterns can be stored without interference if these patterns are statistically independent of one another.
(B) Starting from any initial state, a Hopfield network always settles into a stationary state as guaranteed by the existence of a Liapunov function.
(C) After many synaptic connections are cut off, the network can still retrieve a stored memory pattern without a single error even if the reciprocal connections are no longer symmetric.
(D) Sometimes a Hopfield network can settle into a stationary state that is different from any of the stored memory patterns.
(E) A Hopfield network can store multiple memory patterns as long as all the weights are specified at once. If a new memory pattern is added later, the previously stored memory patterns are destroyed.

Question 9 (14 points)

NDMA channels are important for one form of synaptic long-term potentiation. What conditions are needed to open an NMDA channel? Why this is related to Hebb's learning rule?
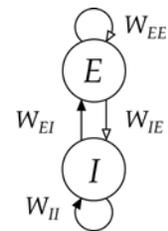
Question 10 (8 points)

Which of the diagrams shown here best describes the timing dependence of LTP and LTD in excitatory synapses as explained in the lectures. The vertical axis represents the change of EPSP, and the horizontal axis represents $T_{pre} - T_{post}$ with T_{pre} and T_{post} being the times of pre- and postsynaptic activations, respectively.
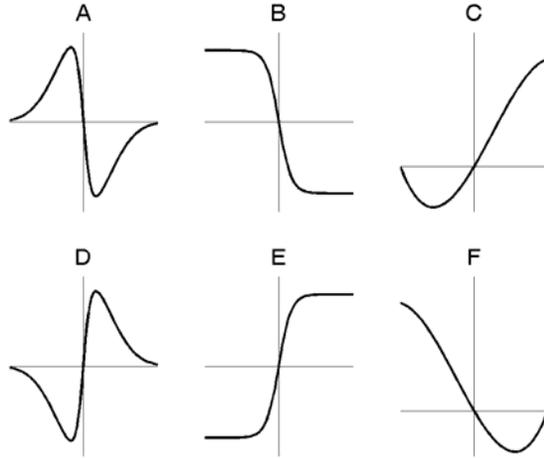
Question 11 (8 points)

Dr. X suspected that the neural oscillations that he observed were due to the interaction of excitatory (E) and inhibitory (I) neuronal populations. He found that the oscillatory behavior could be modeled well by an excitatory-inhibitory network as shown with the following parameters: $W_{EE} = 4$, $W_{II} = -1$, $W_{EI} = -2$, $W_{IE} = 2$. To further test the model, he applied a Wonder Drug that can selectively reduce the neurotransmitter release of inhibitory synapses by about a half. Among the sets of parameters listed below, which one is most suitable for modeling the network behavior after the drug application?

(A) $W_{EE} = 2$, $W_{II} = -1/2$, $W_{EI} = -1$, $W_{IE} = 1$
(B) $W_{EE} = 4$, $W_{II} = -1/2$, $W_{EI} = -2$, $W_{IE} = 1$
(C) $W_{EE} = 4$, $W_{II} = -1/2$, $W_{EI} = -1$, $W_{IE} = 2$
(D) $W_{EE} = 4$, $W_{II} = -1$, $W_{EI} = -1$, $W_{IE} = 1$
(E) $W_{EE} = 2$, $W_{II} = -1$, $W_{EI} = -2$, $W_{IE} = 1$

Question 12 (8 points)

Recurrent networks have a rich repertoire of dynamic behaviors. The following statements are true except for one. Circle the one that is false.

(A) Adding lateral connections in a feedforward network can make a neuron become sensitive to the behaviors of its neighbors.
(B) When synaptic connections in a network are asymmetric, a traveling wave of activation can occur.
(C) A recurrent network can have point attractors in its state space.
(D) The existence of a limit cycle in the state space of a network does not necessarily mean that the network allows periodic oscillations.
(E) A recurrent network can implement winner-take-all, a highly nonlinear operation.