

Name \_\_\_\_\_  
(write your name on every sheet)

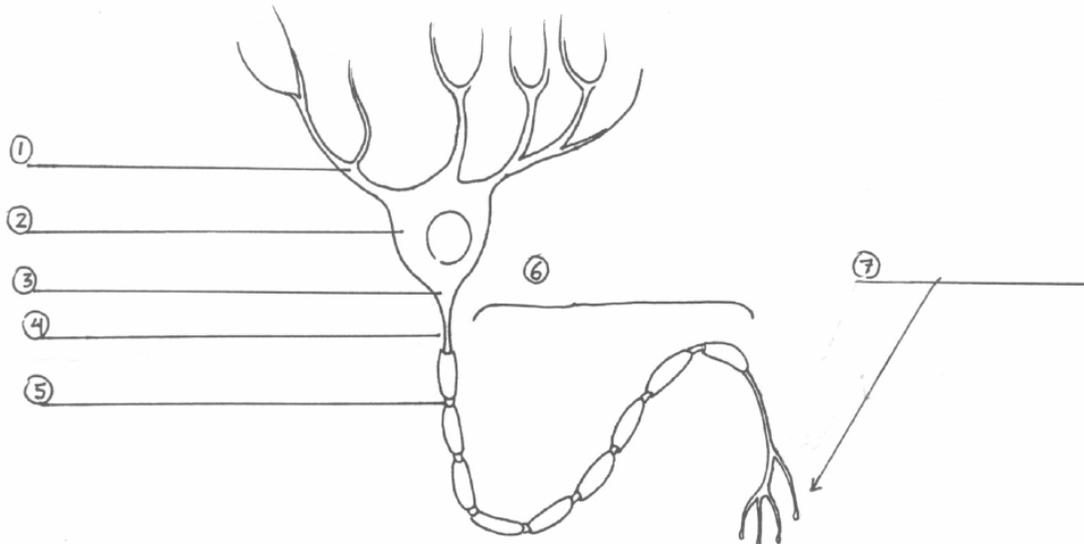
**There are 23 questions.**  
**Point values for each are given.**  
**86 points total.**

1. (5 pts) It is important to have a sense for the relative orders of magnitude of cellular components. Circle the answer which is closest to correct for each physical parameter for a CNS synapse.

vesicle diameter	0.5 nm	5 nm	50 nm	500 nm
synapse width (length of active zone)	5 nm	50 nm	500 nm	5000 nm
Lipid bilayer thickness	.05 nm	.5 nm	5 nm	50 nm
Vesicles released per active zone per action potential	1	10	100	1000
Synaptic delay (pre AP to post AP)	0.1 ms	1 ms	10 ms	100 ms
Synaptic cleft width	0.2 nm	2 nm	20 nm	200 nm
glutamate molecules/ vesicle	50	500	5,000	50,000
resting $[Ca^{2+}]$ in terminal	0.1 $\mu$ M	1 $\mu$ M	10 $\mu$ M	100 $\mu$ M
$[Ca^{2+}]$ near vesicle for release	0.5 $\mu$ M	5 $\mu$ M	50 $\mu$ M	500 $\mu$ M
AMPA receptor protein diameter	1 nm	10 nm	100 nm	1000 nm

2. (2.5 pts) Indicate which of the following are true.
- Microtubules possess great tensile strength that enables axons to withstand mechanical stress.
  - The initial segment and nodes of Ranvier are enormously enriched in delayed rectifier potassium channels.
  - The speed of slow axonal transport is only one order of magnitude faster than simple diffusion.
  - Presynaptic proteins are often synthesized in the axonal terminal, while dendritic proteins are exclusively made in the soma.
  - Dendritic spines are generally thought to constitute the site of long-term, stable memory in CNS neurons.

3.a. (3.5 pts) Label the following diagram:



- b. (2.5 pts) Which one of the above structures is *best* known to
- trigger action potentials?
  - contain microtubules that are mostly oriented in the same direction?
  - contain microtubules that are of mixed orientation?
  - contain Nissl substance?
  - be a site of protein synthesis?
4. (3 pts) Myelin... (circle all that apply)
- is made by oligodendrocytes cells in peripheral sensory nerves
  - decreases the effective capacitance of an axon
  - decreases the length constant of an axon
  - decreases the effective resistance of an axonal membrane
  - is lost in the disease myaesthesia gravis
  - increases conduction velocity to 20-100 mm/s
5. (2.5 pts) A typical mammalian CNS synapse differs from the neuromuscular junction (NMJ) in the following ways (circle all that apply):
- A CNS presynaptic terminal typically releases 1 vesicle per action potential while a NMJ terminal releases hundreds.
  - Acetylcholine is hydrolyzed by acetylcholinesterase in the cleft at the NMJ, while glutamate is cleaved by glutamate hydrolase in the cleft in CNS synapses.
  - NMJ synapses have dense-core vesicles while CNS vesicles are usually clear.
  - CNS, but not NMJ presynaptic terminals can be postsynaptic to inhibitory neurons.
  - A muscle cell is innervated by a single motor neuron while a CNS neuron can be postsynaptic to many neurons.

6. (2 pts) Which processes contribute importantly to the resting membrane potential?

- Na-K ATPase pump
- K<sup>+</sup> going through voltage-gated K<sup>+</sup> channels
- K<sup>+</sup> going through inward-rectifying K<sup>+</sup> channels
- Small negatively charged molecules inside the cell

7. (2.5 pts) For channels in the open conformation, we frequently approximate I(V) relationships as Ohmic, but we know that they are not strictly linear. Which of the following contribute to nonlinearities in open-channel I(V) relationships?

- Voltage-dependent gating
- Membrane capacitance
- Voltage-dependent block of pores by intracellular or extracellular ions.
- Differences in the concentration of charge carriers across the membrane.
- Voltage-dependent changes in permeability of the lipid bilayer

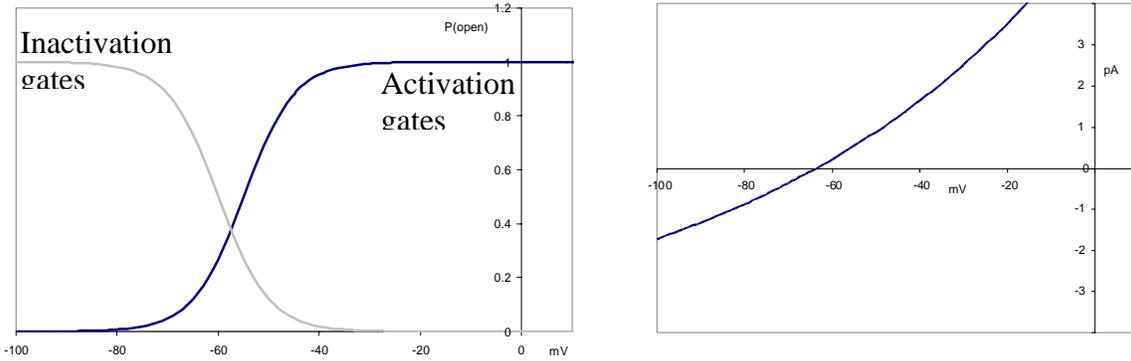
8. (2 pts) The resting conductance of an ordinary neuron is due to a K<sup>+</sup> channel that is always open at the resting potential. If you double the extracellular K<sup>+</sup> concentration, from 5 to 10 mM, what happens to the membrane time constant?

- nearly doubles
- increases slightly
- no effect on time constant
- decreases slightly
- nearly halves

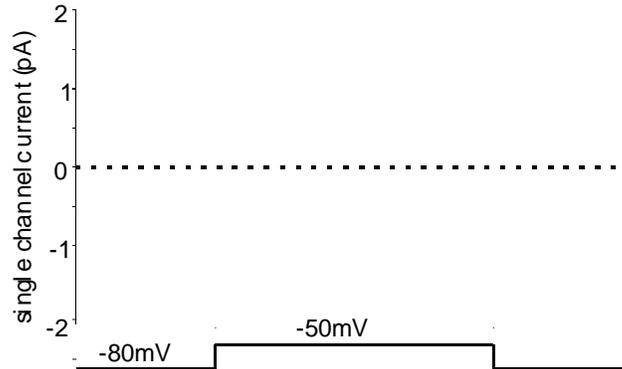
9. (3 pts) In a thermal vent deep in the Pacific, you discover a new bacterium, and decide to characterize its channels. One of them tends to flicker open and closed, so it's easy to measure its reversal potential. Under the following ionic conditions (given in mM), the current reverses at about +29 mV. What ion is the channel permeable to?

<i>Ion</i>	<i>OUT</i>	<i>IN</i>
Mg <sup>2+</sup>	50	5
Sr <sup>2+</sup>	5	50
Cl <sup>-</sup>	260	65
I <sup>-</sup>	5	50
La <sup>3+</sup>	50	5
Dextrose	0	195

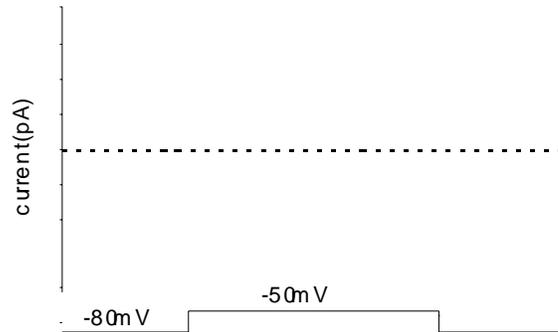
10. One channel type that we did not dwell on is the A-type potassium channel, which activates much like other delayed rectifier channels but which inactivates fairly rapidly. Suppose an A-channel in a particular cell has the following voltage dependencies of activation and inactivation (left) and the following open-channel I(V) curve for a single channel (right). Suppose also that at  $-50\text{mV}$ , the A-current activates with a  $\tau$  of  $0.5\text{ms}$  and inactivates with a  $\tau$  of  $15\text{ms}$ .



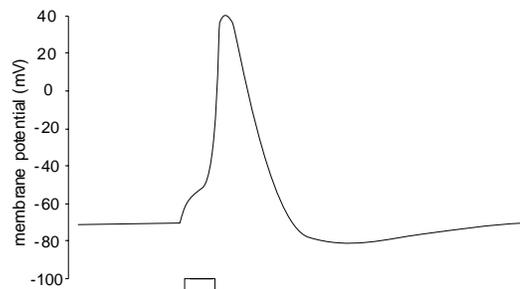
a. (4 pts) With a patch clamp, you record from a SINGLE A-type potassium channel, holding at  $-80\text{mV}$  and stepping to  $-50\text{mV}$  for  $10\text{ms}$ . Draw a typical record for the current through a single channel.



10b. (4 pts) After blocking all other channels, you record from the WHOLE-CELL, holding at  $-80\text{mV}$  and pulsing to  $-50\text{mV}$  for 10ms. Assuming your cell has  $\sim 1000$  A-type  $\text{K}^+$  channels, draw the expected current, indicating an appropriate current scale.



c. (2 pts) To see the effect of the A-type channels on the cell's action potential, you pass current (not in voltage clamp) to stimulate an action potential. If the action potential shown below is in the absence of the A channels, draw what you would expect to happen when they are present.



11. (4 pts) For a standard voltage-gated potassium channel that has inactivation, which part(s) of the protein correspond to each of these functions?

- the voltage sensor
- the selectivity filter
- the activation gate
- fast inactivation

12. You are working with the depicted neuron whose dendritic arborizations are several electrotonic length constants long. You are able to measure  $\text{Ca}^{2+}$  concentrations in the dendrites using calcium-sensitive fluorescent dyes. Your adviser tells you that  $\text{Ca}^{2+}$  entry into dendrites is only mediated by voltage-gated calcium channels.

a. (1 pts) Knowing that voltage-gated calcium channels are closed at  $-80$  mV, you voltage clamp the soma at  $-80$  mV and stimulate input A. To your surprise, you see robust  $\text{Ca}^{2+}$  entry in the distal dendrite! You conclude that the calcium could not have entered through voltage-gated calcium channels, but your adviser disagrees. Why?

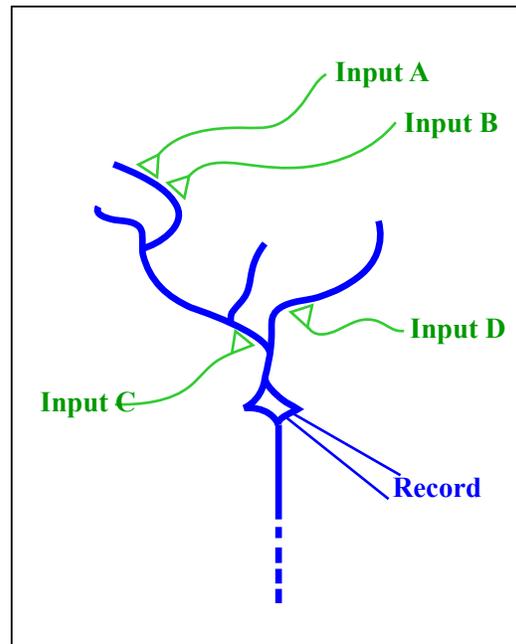


Figure courtesy of MIT OCW.

b. (1 pts) You insist, however, that voltage-gated  $\text{Ca}^{2+}$  channels are not the only possible explanation for increased cytosolic  $\text{Ca}^{2+}$ . How else might a glutamatergic synaptic input increase intracellular calcium?

c. (3.5 pts) You now switch to voltage recording (current clamp). You see that a single stimulus at input A or at input B produces a very small EPSP in the soma. However, when you stimulate them simultaneously, you see an EPSP which is greater than the sum of the two. Which of the following are likely to explain this phenomenon? (choose all that apply)

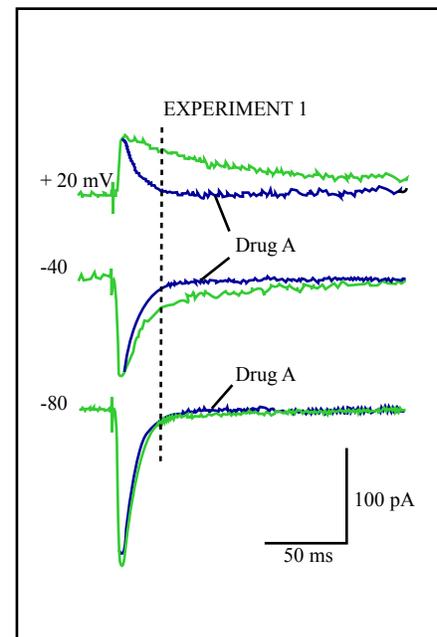
- activation of voltage-gated  $\text{Ca}^{2+}$  channels in the distal dendrites
- activation of  $\text{GABA}_A$  channels in the distal dendrites
- facilitation
- an increase in the electrochemical driving force for  $\text{Ca}^{2+}$
- presence of NMDA receptors
- metabotropic mGluRs opening dendritic  $\text{K}^+$  channels
- activation of a postsynaptic  $\text{Ca}^{2+}$  ATPase

12.d. (3 pts) Assume all inputs have ionotropic glutamate receptors except for input C, which is a GABAergic synapse dominated by GABA<sub>A</sub> receptors. You study the effect of input C on inputs B and D. Although input D is electrotonically closer to input C, you find that input C has a greater inhibitory effect on input B. Why?

13. You voltage clamp a hippocampal pyramidal cell at various holding potentials, stimulate its glutamatergic input fibers and observe the following EPSCs in response (drawn in black.) You are surprised that the time course is quite different at positive and negative holding potentials. When you add Drug A, the time course becomes much more consistent (drawn in gray).

a. (2 pts) What is the likely target of Drug A?

b. (2 pts) Why does Drug A have little or no effect at a holding potential of  $-80$  mV?



c. (1 pts) You decide to do the experiment one more time (just to be sure), but realize right before that you have run out of external solution for your experiment. You hurriedly make up a new batch. This time, however, you're surprised to see that at  $-80$  mV the EPSC now has a long, slow time course similar to that seen at  $+20$  mV. Furthermore, addition of Drug A makes the EPSC at  $-80$  mV quick again, as in Experiment 1. What ion did you forget to add to your solution?

14. (2.5 pts) Which of the following is true about transmission of EPSPs along dendrites.
- EPSPs become smaller in amplitude and shorter in duration as they move along passive dendrites
  - Potentials travel more readily away from the soma than towards it
  - Inhibitory inputs shunt EPSPs more readily when they are near the cell body than when they are in distal dendrites
  - At dendritic branch points the length constant can either increase, decrease or stay the same
  - EPSPs from distal dendrites are often larger than expected from passive propagation both because synapses are stronger at distal locations and because they can stimulate action potentials in the dendrites
15. (2.5 pts) Which of the following are true about the propagation of the action potential down an axon (circle all that apply):
- increasing axon diameter speeds up propagation
  - increase the number of  $K^+$  leak channels speeds up propagation
  - increasing the number of voltage-gated  $Na^+$  channels speeds up propagation
  - the myelin sheath primarily increases propagation velocity by decreasing  $R_m$
  - because conduction between nodes is saltatory, eliminating a single node of Ranvier would abolish propagation along the axon
16. (2 pts) There is potassium channel made of KCNQ2 and KCNQ3 subunits, which is partly open at rest, and slowly opens more when depolarized. This channel is closed by acetylcholine or muscarine, and so current through this channel is called the M-current. Which are likely to be true about the M-current?
- acetylcholine probably acts on the current through a second messenger
  - application of acetylcholine to dendrites containing KCNQ2/3 will increase the length constant of the dendrite
  - cells with KCNQ2/3 will have a harder time firing a burst of action potentials than a single action potential
  - application of acetylcholine to a presynaptic terminal containing KCNQ2/3 will decrease vesicle release

17. (3 pts) How do tetanus toxin and botulinum toxin interfere with synaptic transmission (explain in molecular detail)? How does one produce a rigid paralysis, while the other causes flaccid paralysis?

18. (2.5 pts) To impress your parents and show them that their tuition loan was worth it all, you begin to tell them all you learned about the sites of action of cannabinoids in the brain. Your recollection is a little foggy, however, as you still have a buzz from that very fine stuff you smoked last night. What are some of the things you are trying to recall? (circle all that apply)

- a. tetrahydrocannabinol (also the active ingredient in marijuana) is normally synthesized by medium spiny neurons of the striatum
- b. anandamide is a membrane-permeant cannabinoid which can diffuse from a postsynaptic neuron to a presynaptic terminal as a form of retrograde transmission
- c. binding of anandamide to CB1 receptors potentiates voltage-gated  $\text{Ca}^{2+}$  channels, leading to more neurotransmitter release
- d. cannabinoids inhibit GABA release by neurons of the nucleus accumbens, stimulating dopaminergic neurons of the ventral tegmental area
- e. morphine inhibits GABA release by neurons of the nucleus accumbens, stimulating dopaminergic neurons of the ventral tegmental area

19. (2.5 pts) Long term potentiation in the hippocampus, at CA3 to CA1 synapses, has the following characteristics (circle all that apply)

- a. it lasts minutes to hours
- b. it requires the influx of  $\text{Ca}^{2+}$  primarily through AMPA receptors
- c. it requires insertion of new AMPA receptors in the postsynaptic membrane
- d. it can be a mechanism for associating signals from two neurons, as depolarization evoked by one neuron can potentiate the synapse from another neuron
- e. it differs from LTP at mossy fiber synapses (dentate gyrus to CA3), which is primarily presynaptic

20. (2 pts) You have spent years to identify the gene for a rare, dominantly inherited paralytic disease. The disease is characterized by a temporary inability to generate action potentials in the muscle after heavy exercise. The gene you finally identify encodes an inwardly rectifying potassium channel, and the disease is correlated with a single amino acid change in its selectivity filter. Experiments on mutant channels expressed in cultured cells indicate that the channel becomes less selective for  $K^+$  when lactic acid builds up and the residue is protonated. What is the single most likely etiology for the disease?

- $Na^+$  influx depolarizes the muscle to a region where voltage-gated  $Na^+$  channels are largely inactivated.
- Because the channel is less  $K^+$ -selective,  $K^+$  leaks into the muscle, shifting the  $K^+$  Nernst potential more negative and hyperpolarizing the cell
- $Ca^{2+}$  influx stimulates continuous neurotransmitter release, and desensitization of nACh receptors
- $K^+$  accumulation in the T-tubules depolarizes the muscle cells

21. (6 pts) Execution by lethal injection involves administration of the following drugs, in order: sodium thiopental (a barbiturate), tubocurarine chloride (a.k.a. curare), and potassium chloride. For each, indicate the important molecular target, and the effect on the inmate.

sodium thiopental

target:

effect:

tubocurarine chloride

target:

effect:

potassium chloride

target:

effect:

22. (3 pts) What are three widely used treatments for epilepsy?

Name \_\_\_\_\_

(write your name on every sheet)

HST 131/Neuro 200  
Exam I, Sept 29, 2004

23. (4 pts) Bipolar disorder is often treated with drugs such as Prozac, Celexa, Zoloft, and imipramine. While they apparently target synapses, an unusual feature of them is that they don't have much effect for the first 2-3 weeks.

a. What synaptic process or molecule is thought to be their target?

b. What new hypothesis for their action would explain the delay in efficacy?