1 (10 pts). A cell has the same internal and external ionic distributions of Na\(^+\), K\(^+\), Cl\(^-\), and Ca\(^{2+}\) as a normal nerve cell. However the cell’s resting permeability is 100 Na\(^+\): 10 K\(^+\): 1 Cl\(^-\): 0 Ca\(^{2+}\). What is this cell’s approximate resting potential (within 10 mV)? Explain your reasoning.

Because \(P_{Na}\) in this cell is much greater than \(P_{K}\), then the resting potential will be much closer to but less than \(E_{Na}\) (+50 mV). An answer of 40 mV +/- 10 mV is therefore acceptable.

2 (10 pts). Donald Trump’s CNS has a nerve cell with an unmyelinated axon. It produces an action potential at the soma that travels down the axon and comes to a branch:

![Diagram of a neuron with two branches]

a. Which branch, if any, does it travel down? Why?

The action potential travels down both branches because each branch is a typical axon with voltage dependent Na\(^+\) and K\(^+\) channels.

b. If branches 1 and 2 are the same length and branch 1 is 1/2 the diameter of branch 2, which terminal does the AP reach first, if any? Why?

The AP will reach terminal 2 first because branch 2 is larger in diameter than branch 1 and the larger the axon diameter, the faster an AP will travel.

c. If a suprathreshold stimulus is applied at terminal 1, what will occur, where will it go, and how far will it travel? (ignore transmitter release; and be serious even if it is Trump’s neuron).

A suprathreshold stimulus, one that is greater than threshold, will trigger an AP that will go 'backwards' up branch 1. When it reaches the junction of branches 1 and 2, the AP will go down branch 2 to terminal 2 and also up the main axon and reach the spike initiation zone.
3 (10 pts). Neuron A makes a chemical inhibitory synapse on Neuron B. The IPSP produced in Neuron B is mediated by a rise in a K⁺ conductance. At the normal resting potential of -70 mV, the amplitude of the IPSP is -20 mV. If Neuron B is hyperpolarized to -90 mV and then Neuron A is stimulated, what will the IPSP look like? Explain your answer briefly.

There will be no observable IPSP at -90 mV because -90 mV is the potassium equilibrium potential (E_K⁺) and thus there will be no net flow of K⁺ ions even if K⁺ channels are open.

4 (10 pts). You are investigating the properties of a passive nerve cell membrane with the following characteristics: E_K⁺ = -90 mV, E_Cl⁻ = -70 mV, E_Na⁺ = +50 mV, V_rest = -70 mV, with an electrogenic Na⁺:K⁺ pump (i.e., 3 Na⁺ out for 2 K⁺ in). What will happen to the resting membrane potential if the following experimental changes were made? (choose one from “depolarize”, “hyperpolarize” or “no effect”). Also please provide a brief explanation for your answer.

A. Chloride permeability is decreased by 2 times

**No effect** because E_Cl⁻ is equal to the resting potential

B. Sodium permeability is halved

**Hyperpolarize** because less Na⁺ is entering cell at rest and K⁺ permeability becomes even more dominant in determining Vm

C. External [K⁺] is increased by 2 times

**Depolarize** because doubling external K⁺ causes the Nernst potential for K⁺ to be more positive (E_K = 58 log ([K⁺]_{out}/[K⁺]_{in}))

D. Doubling extracellular [Ca++]

**No effect** because calcium does not contribute to the resting potential

E. 5 hours after blocking the Na-K pump

**Depolarize** because without the pump the Na⁺ and K⁺ gradients will be destroyed
5 (8 pts). Name four advantages of chemical synaptic transmission over its electrical counterpart.

1. Sub-threshold PSPs that do not generate an action potential
2. Unidirectional transmission
3. Summation of PSPs
4. Inhibitory and excitatory signals
5. Synaptic modulation

6 (10 pts). Match the best answer on the right with the phrase on the left.

ANSWER (use letter)

<table>
<thead>
<tr>
<th>Nodes of Ranvier</th>
<th>G</th>
<th>A. Terminal</th>
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<tbody>
<tr>
<td>Myelin</td>
<td>H</td>
<td>B. Single channel recordings</td>
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<tr>
<td>Voltage-dependent Ca^{2+} channels</td>
<td>A</td>
<td>C. Spontaneous release of transmitter quanta</td>
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<tr>
<td>Connexons</td>
<td>I</td>
<td>D. Flow of charge</td>
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<tr>
<td>Patch clamp</td>
<td>B</td>
<td>E. Undershoot of action potential</td>
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<tr>
<td>Current</td>
<td>D</td>
<td>F. Membrane recycling</td>
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<td>Voltage-dependent K^{+} channels</td>
<td>E</td>
<td>G. Active membrane</td>
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<tr>
<td>Voltage-dependent Na^{+} channels</td>
<td>J</td>
<td>H. Membrane capacitance decrease</td>
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<tr>
<td>Miniature end plate potentials</td>
<td>C</td>
<td>I. Electrical synapses</td>
</tr>
<tr>
<td>Coated vesicles</td>
<td>F</td>
<td>J. Inactivation gate</td>
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</tbody>
</table>
7 (6 pts). Cell A synapses onto Cell B as shown. Large, hyperpolarizing PSPs (10 mV in amplitude) are observed in the dendrites of Cell B when Cell A is stimulated. When Cell A is NOT stimulated, small (0.5 mV in amplitude) hyperpolarizing potentials are occasionally observed. What are these small potentials and how would you test your hypothesis?

These are miniature inhibitory PSPs spontaneously emanating from Cell A. Experimental tests include blocking the post-synaptic receptors or preventing the rise in $[Ca^{2+}]_\text{in}$ by using a Ca$^{2+}$ chelator such as BAPTA or a voltage dependent Ca$^{2+}$ channel blocker to prevent vesicle fusion in the presynaptic terminal.

8 (6 pts). Application of dopamine onto a particular CNS neuron produces an EPSP followed by an action potential, as shown:

Carefully draw what would be recorded in the presence of each of the following combination of drugs (use the same scale of drawing as above):

A) Tetrodotoxin (TTX)  
B) Phencyclidine  
C) TTX and amphetamines

(Dopamine receptor blocker)  
(The latter blocks dopamine uptake and inhibits MAO)
9 (8 pts). A family of patch clamp recordings of 3 channels from a neuron from Ivana Trump looks like this:

![Graph showing patch clamp recordings of 3 channels]

What do you conclude about this channel? Explain your conclusions.

This is a voltage dependent K⁺ channel. The conclusion that the channel is voltage dependent is based on the observation that the channel is open only at more depolarizing voltages (it is closed at -70 mV and -60 mV and open at -30 mV and 0 mV). The conclusion that it is a K⁺ channel is based on the observation that the current amplitude increases at the voltage step increases. This increase in current amplitude occurs when the driving force increases (driving force = Vm - E_{ion}) and the only ion which would have an increase in current flow as the voltage becomes more positive is K⁺.

10 (6 pts). Propose three different experiments to test the hypothesis that an increase in potassium conductance is responsible for the falling phase of the action potential.

1. Make [K⁺]_{out} = [K⁺]_{in} and measure an increase in the action potential duration because of a decrease in the K⁺ driving force
2. Use TEA to block delayed rectifier K⁺ channels
3. Voltage clamp the cell and show that the equilibrium potential for the current underlying the falling phase of the action potential is at E_{K⁺}.
11 (8 pts). The patella knee jerk reflex is diagrammed below. Mark the location of all passive potentials, active potentials (action potentials) and chemical synapses.

12 (8 pts). Most inhibitory PSPs are due to an increase in $g_K$ or $g_{Cl}$. In some instances however occasionally an inhibitory PSP is caused by a decrease in $g_{Na}$. Explain how this is possible.

*In some cells a high resting Na$^+$ conductance is turned off by a transmitter or a sensory stimulus. A decrease in a Na$^+$ conductance leads to a decrease in an inward Na$^+$ current which in turn causes a transient hyperpolarization or IPSP.*