Worksheet by
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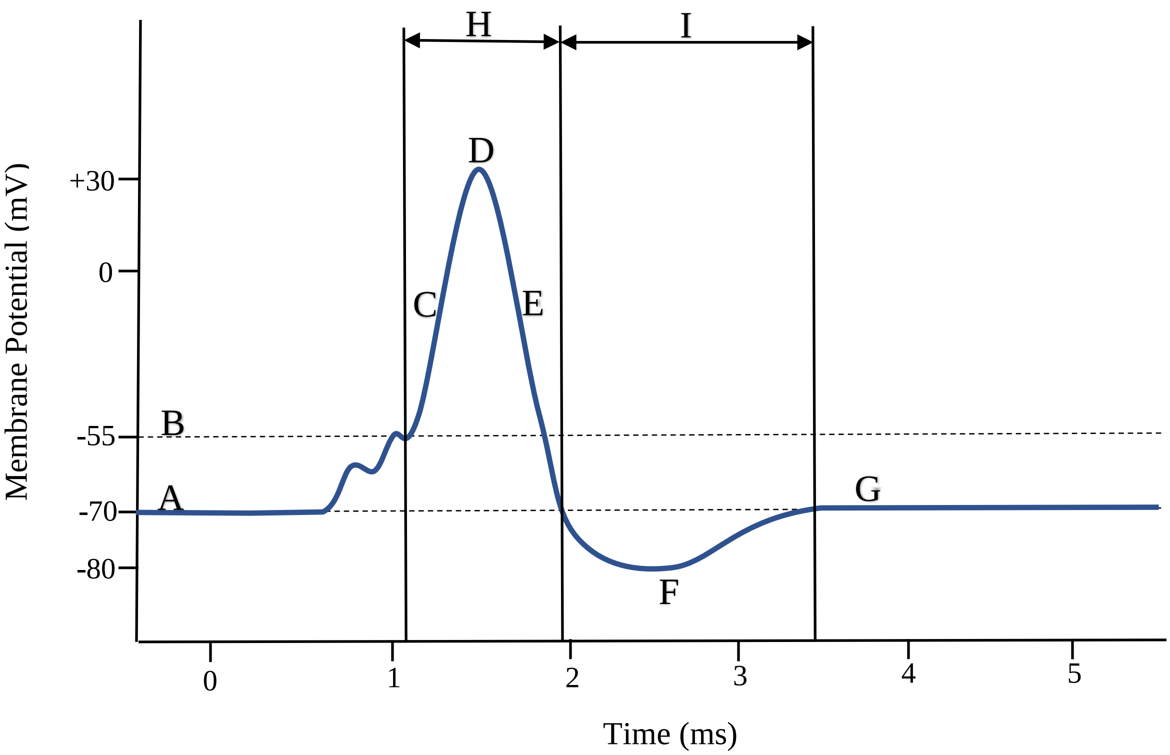
The Action Potential

Label the significant membrane potentials and phases of the action potential in a neuron. Indicate which gates are open/closed as well as the direction of the net movement of sodium and potassium ions across the cell membrane for A-G.



1. What type of summation is shown for the graded potentials in the above graph?

2. What happens when the threshold potential is reached?

3. At approximately +30 mV on the graph, what happens in between the depolarization and repolarization phases?

4. What mechanism is responsible for the occurrence of the hyperpolarization phase?

5. How is the resting membrane potential of the neuron restored?

6. Is it possible to generate a second action potential during either refractory period? If so, which one and how?

Place the following events in chronological order from 1-8:

___________ Na^+ enters the cell, and depolarization occurs to approximately +30 mV.

___________ The voltage across the cell membrane is -70 mV, the resting membrane potential.

___________ Upon reaching the peak of the action potential, the VG Na^+ channels are inactivated by the closing of their inactivation gate and the activation gate of each VG K^+ channel opens.

___________ VG K^+ channels close by the closing of their activation gate, and the resting membrane potential is gradually restored.

___________ An excitatory post-synaptic potential depolarizes the membrane to threshold and the activation gate of VG Na^+ channels open.

___________ Upon returning to the resting membrane potential, VG Na^+ channels are reset by opening of the inactivation gate and the closing of the activation gate.

___________ VG K^+ channels are slow to close, resulting in an excess of K^+ efflux and hyperpolarization.

___________ Depolarization occurs as K^+ flows out of the cell.

Determine whether each statement is true or false. If a statement is false, explain why.

___________ 1. Voltage gated sodium channels are quick to open and slow to close, while voltage gated potassium channels are quick to open and slow to close.

___________ 2. Before a second action potential can be generated, the concentration of sodium and potassium on either side of the cell membrane must be fully restored.

___________ 3. The strength of an action potential is represented by the amplitude of the wave. A stronger stimulus will generate an action potential with a higher peak than a weaker stimulus.

___________ 4. Action potentials travel in a non-decremental manner down the axon, with the voltage constantly being regenerated along the way, unlike graded potentials which quickly diminish over short distances.

___________ 5. Contiguous conduction is faster than saltatory conduction.

___________ 6. Action potentials originate in the axon hillock and travel down the axon to the terminal boutons (pre-synaptic axon terminals).

Answer Key

Graph Labels and Channel States

A. Resting membrane potential. VG Na^+ channels are in the "closed but capable of opening" state. VG K^+ channels are closed.

B. Threshold potential (typically 50-55 mV). VG Na^+ channels open, VG K^+ channels remain closed.

C. Depolarization. VG Na^+ channels are open, net flow of Na^+ from ECF to ICF (into the cell). VG K^+ channels remain closed.

D. Peak. VG Na^+ channels are closed and inactivated. VG K^+ channels open.

E. Repolarization. VG Na^+ channels are closed. VG K^+ channels are open, net flow of K^+ from ICF to EFC (out of the cell).

F. Hyperpolarization. VG Na^+ channels have been reset to the "closed but capable of opening" state. VG K^+ channels are delayed in closing.

G. Resting membrane potential. VG Na^+ and VG K^+ channels remain closed. The combined actions of the Na^+/K^+ ATPase pump, Na^+ leak channels and K^+ leak channels have restored the membrane potential to -70 mV.

H. Absolute refractory period.

I. Relative refractory period.

Graph Question Solutions

1. Temporal summation. One can see two distinct excitatory post-synaptic potentials occurring in rapid succession, rather than one large excitatory post-synaptic potential (which would be spatial) generated by two different pre-synaptic neurons firing at the same time.

2. When the threshold potential is reached at approximately -55 to -50 mV, the activation gate of each voltage gated sodium channel opens and allows a net flow of sodium ions down their electrochemical gradient into the neuron until the membrane potential is approximately +30 mV.

3. At the peak between the depolarization and repolarization phases, the inactivation gate of each voltage gated sodium channel closes, preventing further inflows of sodium ions. However, the activation gate of each voltage gated potassium channel opens. This makes possible the depolarization phase in which potassium ions flow out of the cell down their electrochemical gradient.

4. Although the voltage gated potassium channels begin to close once depolarization to the resting membrane potential has occurred, there is a delay caused by the slow closing of these channels which allows more potassium ions to leave than is necessary. Due to the excess of potassium ions flowing out of the cell before the voltage gated potassium channels have closed, hyperpolarization beyond -70 mV occurs.

5. The resting membrane potential and electrochemical gradients are restored by the sodium-potassium pump, potassium leak channels and sodium leak channels. The sodium-potassium pump actively pumps three sodium ions out and two potassium ions in, while potassium and sodium leak channels allow the free movement of each of their respective ions down their electrochemical gradients (potassium leak channels are more numerous than sodium leak channels). All combined action of these channels results in a stable resting membrane potential of -70 mV.

6. It is impossible to generate a second action potential in the same neuron during the absolute refractory period because all voltage gated sodium channels rapidly open at the threshold potential, and any additional excitatory post-synaptic potential beyond -55 mV will not make any difference (all-or-none principle). After the peak of the action potential during the absolute refractory period, the generation of a second action potential is prevented by the inactivation of the VG sodium channels (due to the closing of the inactivation gate), placing them in the "closed and not capable of opening" state. However, once the VG sodium channels are reset (inactivation gate opens and activation gate closes), which marks the beginning of the relative refractory period, a second action potential may be initiated by a suprathreshold stimulus (a larger than typical excitatory post-synaptic potential) large enough in magnitude to overcome the hyperpolarization and bring the membrane potential to the threshold.

Chronological Order Sequence: 3, 1, 4, 8, 2, 6, 7, 5

True or False Question Solutions

1. True

2. False. Only a relatively small amount of sodium and potassium ions move down their electrochemical gradient per any given action potential. This makes it possible for multiple action potentials in a row to be generated without the need for the sodium-potassium pump to keep up. However, without the sodium-potassium pump, the electrochemical gradients which make action potentials possible would disappear and no further action potentials would be possible.

3. False. Upon reaching the threshold, an action potential will run its course irrespective of the strength of the initial stimulus so long as the stimulus is sufficient. There is no such thing as a "stronger" or "weaker" action potential. It is the frequency of the action potentials which gives one the perception of strong or weak sensations.

4. True.

5. False. Myelination of the axon by Schwann cells in the PNS or oligodendrocytes in the CNS allows for much quicker saltatory conduction, with electrically insulated segments being bypassed and the movement of ions occurring from node of Ranvier to node of Ranvier.

6. True.