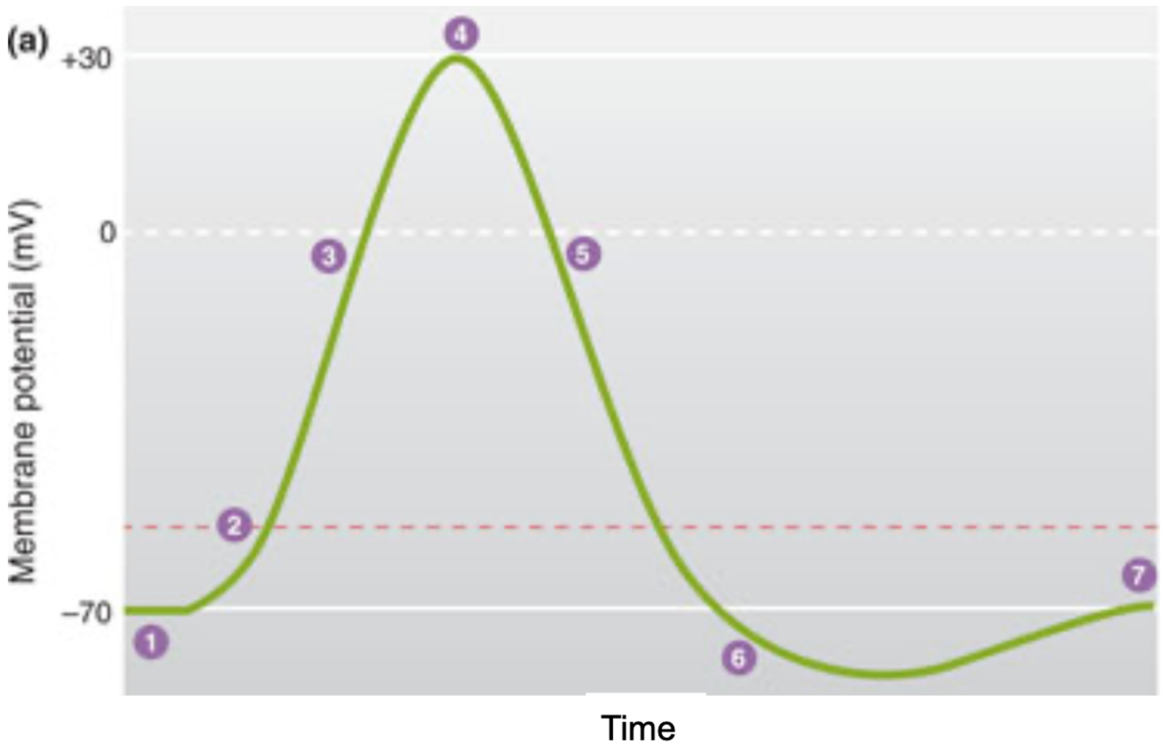
1. [20 points] The Figure (below) shows the membrane potential *vs*. time for an action potential fired on the membrane of an excitable cell; the Table (below) indicates the state (open or closed) of the sodium channel gates and of the potassium channel gate at some of the various labeled time points (1, 2, ... 6, 7) during the action potential. Please fill in (open, closed) the blank entries



Time Point	Na+ channel		K+ channel
	Activation Gate	Inactivation Gate	
1	closed	open	closed
2	open	open	closed
3	**open**	**open**	**closed**
4	open	closed	open
5	**open**	**closed**	**open**
6	**closed**	**open**	**open**
7	closed	open	closed

2. [20 points] With reference to a post-synaptic membrane, explain the mechanism(s) of, and differentiate between, *spatial summation* and *temporal summation*.

Spatial or temporal summation refer to the summation of multiple EPSPs in order to trigger or not a spike which, depolarizes the post-synaptic membrane to threshold. Spatial summation occurs when the excitatory signals come from *different* presynaptic cells, whereas temporal summation refers to input signals coming from the *same* presynaptic cell at *different* times.
Excitatory postsynaptic potential (EPSP) is a depolarizing graded potential, which has an amplitude decreasing with distance, and smaller than the threshold, necessary to depolarize the neuron's membrane (0.5mv vs. 15mV for the threshold, VSL[15] p161). Thus, an action potential can only be initiated by the combined effect or summation of many EPSPs. **Inhibitory postsynaptic potential** (IPSP) is a hyperpolarizing graded potential, and *IPSPs can also show spatial or temporal summation*. Spatial or temporal summation could be considered as algebraic summation of postsynaptic potential either EPSP or IPSP.

3. [5 points] With reference to the conduction of action potentials and/or sub-threshold changes in membrane potential along the axons or dendrites of neurons, indicate the most correct statement among those given below:
    1. The propagation velocity of action potentials in unmyelinated axons is inversely proportional to axon diameter.
    2. The conduction velocity of action potentials in an unmyelinated axon of diameter 10 µm will be higher than in a myelinated axon of diameter 1 µm.
    3. Saltatory conduction (of an action potential) does not occur in unmyelinated axons.

       This choice is the most correct

    4. In a myelinated axon the cells that wrap around the axon are wrapped most thickly at the Nodes of Ranvier.

4. [20 points] How would the action potential on the cell membrane of an electrically excitable cell change (amplitude and time course) if the ratio of maximal to minimal g_{Na} was 80% of that in a "normal" electrically excitable cell? Assume that the value of the minimum g_{Na} is the same as in a "normal" cell. **NOTE: The statement of the problem is intentionally a bit vague – you will have to make some assumptions. Make sure to explicitly state any assumptions that you make in order to answer this question.**

To limit the number of possible outcomes related to the action potential to consider, we make the assumption that the only changes compared to a “normal” electrically excitable cell are the ratio of maximal to minimal g_{Na} is 80%. We want to identify changes on the action potential with a different range of the sodium conductance.

The time course of the action potential remains unchanged.

We have:

- g_1m and g_1M: the minimum and maximum of the sodium conductance of a “normal” cell
- $[g_2m, g_2M]$: the new range of the sodium conductance for the cell
- $\frac{g_2M}{g_2m} = 0.8 \cdot \frac{g_1M}{g_1m}$ $g_1M \geq 0, g_1m \geq 0, g_2M \geq 0, g_2m \geq 0$
- g1m = g2m

Thus: $g_2M = 0.8\ g_1M$

For most cells, at rest, the membrane cell has a high conductance to potassium, and thus its membrane potential is near the Nersnt potential of the potassium, E_K, but not quite equal to it as given by the chord conductance equation. In particular, if the sodium minimal conductance is non zero, there is some current across the plasma membrane driving the Na^+ ion from outside to inside through voltage-gated sodium channels. As more, Na^+ enter the cell due to a depolarizing stimulus, eventually the membrane potential reaches a critical threshold: Na^+ entry causes more depolarization opening more Na^+ channels, allowing more sodium in and so on until the G_{Na} conductance reaches its peak and at the same time the membrane potential rises to its maximum value close to the Nersnt sodium potential before falling back. This is due to the inactivation gates of the Na+ channels closing and to some extent the slow opening of the K+ channels allowing some ions to leave the cell. With that described, decrease of the maximum value of g_{Na}, will decrease in amplitude the peak of the membrane potential during the overshoot.

5. [5 points] Consider a synapse in which the binding of a neurotransmitter to a receptor on the postsynaptic membrane causes a transient increase in K^+ channel conductance in the region immediately surrounding the receptor. Indicate the most correct statement among those given below.

    A. This will result in an IPSP if the resting membrane potential of the postsynaptic cell was less negative than the potassium Nernst potential for the postsynaptic cell.
    B. This will result in an EPSP if the resting membrane potential of the postsynaptic cell was less negative than the potassium Nernst potential for the postsynaptic cell.

C. The potassium channel inactivation gates would transiently close in response to the binding of the neurotransmitter to its receptor on the postsynaptic cell.
D. Such a change in the local potassium channel conductance of the postsynaptic cell membrane will always trigger an action potential