Quantitative Physiology: Cells and Tissues
2.791J/2.794J/6.021J/6.521J/BE.370J/BE.470J/HST.541J
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I appreciate the effort, but next time remember
we work on the *squid giant* axon,
not the *giant squid* axon.

Problem 4.12. A propagated action potential is recorded at one position along an axon. Five points in time during this action potential are identified in Figure 1.

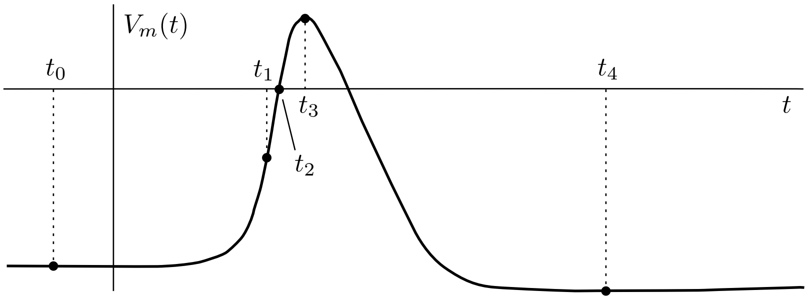

Figure 1. Propagated action potential.

- At t_0 the membrane is in its resting state, i.e. $V_m(t_0) = V_m^o$.
- At t_1 the membrane potential has a point of inflection, i.e. $[\partial^2 V_m/\partial t^2]_{t_1} = 0$.
- At t_2 the membrane potential is zero, i.e. $V_m(t_2) = 0$.
- At t_3 the membrane potential has its maximum value.
- At t_4 the membrane potential has its minimum value.

	t_0	t_1	t_2	t_3	t_4
a					
b					
c					
d					
e					
f					
g					
h					
i					
j					
k					
None					

Table 1. Organization for answers to Problem 4.12.

For each of the times t_0, t_1, t_2, t_3, and t_4 determine which, if any, of the following statements apply in a *precise manner.* If none applies precisely then indicate *none*. Indicate your answers with a check mark in the appropriate places in a table such as Table 2.

a) The sodium conductance equals the potassium conductance.
b) The membrane current is zero and changes from inward to outward.
c) The membrane current is zero and changes from outward to inward.
d) The capacitance current is zero.
e) The total ionic current is zero.
f) The sodium conductance has a maximum value.
g) The potassium conductance has a maximum value.
h) The sodium conductance has a minimum value.
i) The potassium conductance has a minimum value.
j) The magnitude of the potential difference between the membrane potential and the sodium equilibrium potential is a minimum.
k) The magnitude of the potential difference between the membrane potential and the potassium equilibrium potential is a minimum.

Problem 4.28. Each of the panels in Figure 2 shows action potentials computed from the Hodgkin-Huxley model of a space-clamped axon in response to a current pulse of duration 0.5 ms and of amplitude 20 μA/cm^2. In each panel the dashed curve shows the response for the standard parameters of the Hodgkin-Huxley model. Each of the solid curves was obtained by computing the response of the Hodgkin-Huxley model with identical parameters as the dashed curve except that one parameter of the model was changed. For each of the waveforms a)-d), determine which one of the following statements is consistent with the computation.

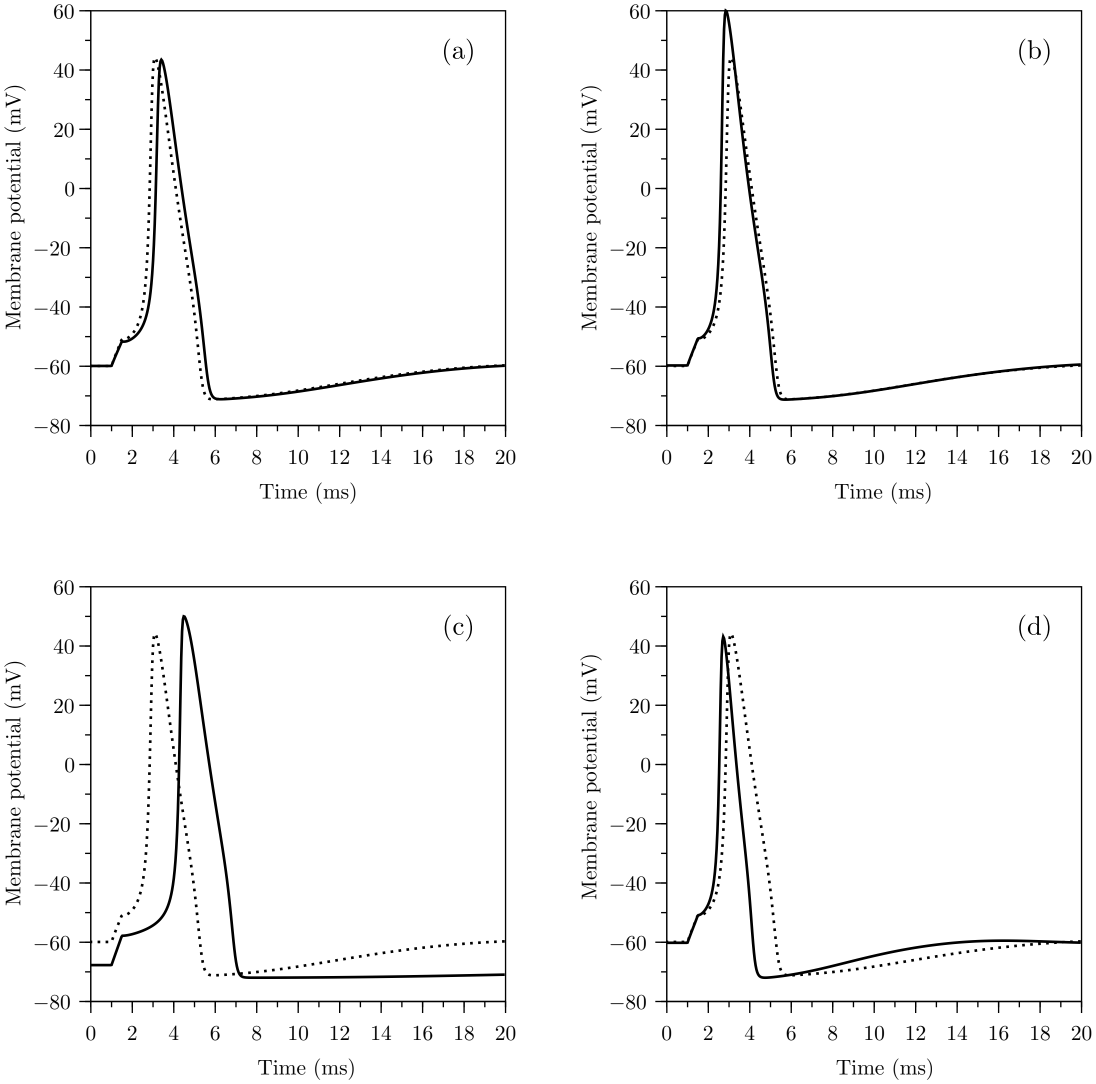

Figure 2. Waveforms of action potentials computed from the Hodgkin-Huxley model.

(1) The leakage conductance was reduced from $G_L = 0.3$ to 0.01 mS/cm^2.

(2) The temperature was increased from 6.3 to $10°$C.

(3) The membrane capacitance was increased from $C_m = 1$ to 1.1 μF/cm^2.

(4) The intracellular sodium concentration was reduced from 50 to 25 mmol/L.

	t_0	t_1	t_2	t_3	t_4
a					
b					
c		√			
d	√			√	√
e	√				
f					
g					
h					
i					
j				√	
k					√
None			√		

Table 2. Properties at different points in a propagated action potential (Problem 4.12).

Solutions

Problem 4.12. From the core conductor model

$$J_m(z,t) = \frac{1}{2\pi a(r_i + r_o)} \frac{\partial^2 V_m(z,t)}{\partial z^2}.$$

Since the action potential is propagating at constant velocity ν,

$$J_m(z,t) = \frac{1}{2\pi a(r_i + r_o)\nu^2} \frac{\partial^2 V_m(z,t)}{\partial t^2}.$$

Therefore, $J_m(z,t) = 0$ when $\partial^2 V_m(z,t)/\partial t^2 = 0$. Also the capacitance current is

$$J_C(z,t) = C_m \frac{\partial V_m(z,t)}{\partial t}.$$

Therefore, $J_C(z,t) = 0$ when $\partial V_m(z,t)/\partial t = 0$. Taking these results into account leads to the answers shown in Table 2.

Problem 4.28.

a. **Ans. is (3)**. The action potential shows a slower depolarization at the onset and a slower repolarization. This is consistent with an increase in the membrane capacitance.

b. **Ans. is (4)**. The peak action potential goes to a higher potential which is consistent with an increase in the Nernst equilibrium potential for sodium.

c. **Ans. is (1)**. The resting potential is decreased and the undershoot of the action potential has been reduced implying that the resting potential is closer to the potassium equilibrium potential. This is consistent with a reduction in the leakage conductance.

d. **Ans. is (2)**. The action potential shows a more rapid depolarization at the onset and a faster repolarization. This is consistent with an increase in the temperature.