Neuroscience BIO-311
Solutions of exercises for
Unit 2: Action Potentials

1) Explain what a “voltage clamp” is and what a “current clamp” measurement is.

Which electrical quantities are controlled and measured in each type of measurement?

What are the advantages and disadvantages of using each of them?

	control	measure	pros
Voltage clamp	voltage	current	• Eliminates capacitive current • Current proportional to membrane conductance (number of open channels) • Offers control over a key variable (membrane potential Vm) that determines channel gating
Current clamp	current	voltage	• can study action potential • More physiological for cells

2) In this question, the aim is to construct an I-V (current-voltage) relation for Na+ currents, and to understand the difference between the I-V relation of ion currents, and the p_open versus Vm (abbreviated: p_open - V) relation of an ion channel. - Consider the p_open - V relationship for Na+ channels.

- With this information, construct an I-V relation for a simple thought-experiment: Assume you have voltage-clamped a small cell containing N = 10 Na+ channels which have the same open probability as shown below (maximal popen = 0.8). Assume that ... i) N = 10 channels exist in your whole-cell recording, ii) that the maximal open probability is 0.8 (see below) iii) that the single-channel current i_Na = 1 pA at 0mV, iv) that the reversal potential for Na+ channels is (E_rev) is +60 mV Enter the approximate peak whole-cell Na+ current values (I_Na, in units of [pA]) for the indicated membrane potentials (Vm; -60, -40, -20, 0, +20, +40, +60, +80 mV). - In the resulting relationship, which I_Na current do you expect at 0 mV? - Which I_Na current do you expect at +60 mV? - Then enter approximately all other I_Na current values, using the single-channel current amplitudes given in the bottom part of the graph. - Please discuss the differences between the I-V relationship you have just drawn, and the relationship p_open - V.

Assume that ...

$N_{channels}$ = 10 channels

the maximal p_{open}= 0.8

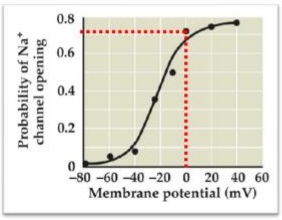
single-channel current i_{Na+} = -1 pA at 0 mV

E_{Na+} = 60 mV

- In the resulting relationship, which I_{Na} current do you expect at 0 mV?

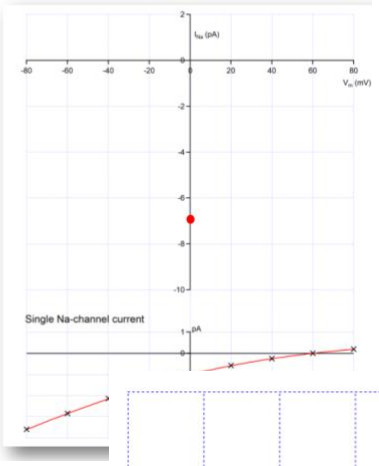
(Note: the single-channel current, bottom graph, was calculated according to the Goldman-Hodgkin-Katz current equation, arbitrarily normalized to 1 pA at 0 mV).

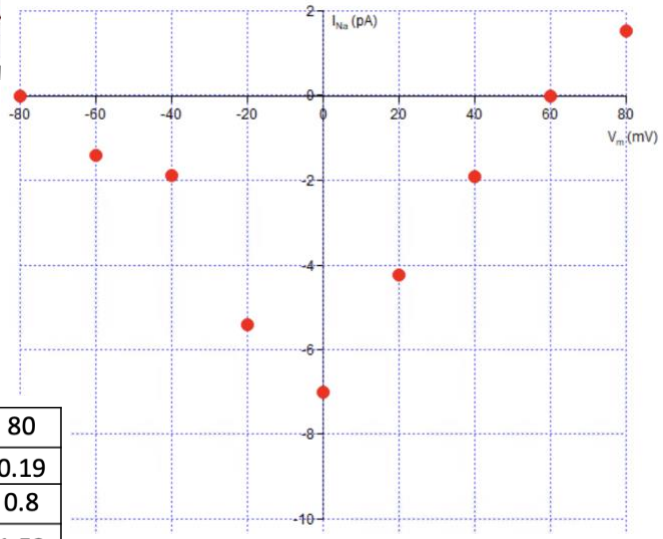
$I_{total} = i_{single\ channel} \times N_{channels} \times p_{open}$



at 0 mV:

I_{Na}= **-1 *10 *0.7 = -7 pA**





Vm	-80	-60	-40	-20	0	20	40	60	80
i_{Na+}	-3.6	-2.8	-2.1	-1.5	-1.00	-0.58	-0.25	0.00	0.19
P_{open}	0	0.05	0.09	0.36	0.70	0.73	0.77	0.8	0.8
I_{Na}	0	-1.4	-1.89	-5.4	-7	-4.234	-1.925	0	1.52

3) Explain what is "saltatory conduction" of an action potential (AP). Why does the myelin sheath increase the speed of AP propagation along the axon?

(i) Saltatory conduction: the action potentials are only generated at the nodes of Ranvier, and then the elicited current flows passively in the myelinated region along the axon until the next node is reached. This cycle is repeated along the axon, which seems that the action potential jumps from one node to another.

(ii) The presence of myelin prevents the local current from leaking across the internodal membrane, so the current can flow farther along the axon and reach several adjacent nodes. Voltage-gated Na+ channels are present only at the nodes of Ranvier, which means that the generation of action potential needs only occur at these regions.

4) Explain how to do a cell-attached, whole-cell and outside-out "patch-clamp" recording.

Cell-attached patch-clamp: The tip of a glass pipette is attached and sealed on a piece of membrane of the target cell.

Whole-cell patch-clamp: After cell-attached patch-clamp, the attached piece of membrane is sucked into the glass pipette by applying negative pressure, so the pipette has direct access to the cytoplasm.

Outside-out patch-clamp: After whole-cell patch-clamp, glass pipette is slowly pulled away from the target cell to break the membrane around the tip of glass pipette from the cell, and then the broken ends of membrane anneal.

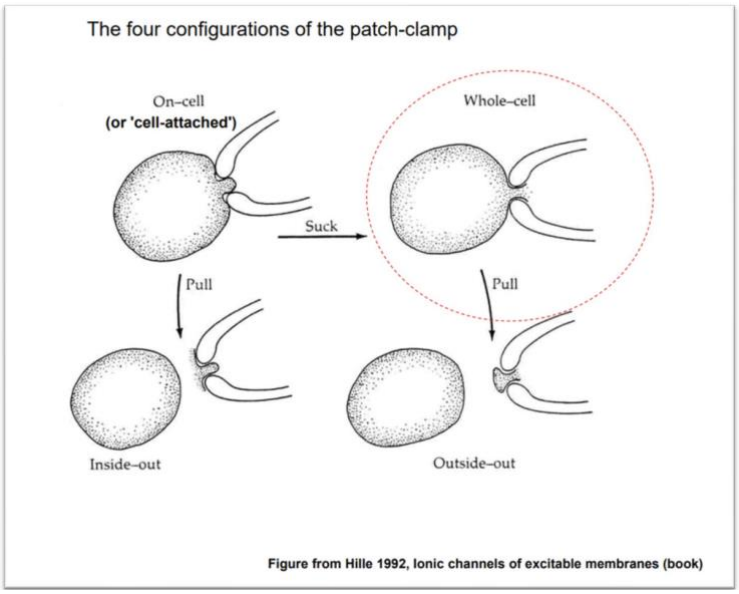


Figure from Hille 1992, Ionic channels of excitable membranes (book)