UNIVERSITY OF MORATUWA, SRI LANKA
Faculty of Engineering
Department of Electronic and Telecommunication Engineering
Semester 4 (Intake 2020)

BM2102 Analysis of physiological systems
Assignment 3
Properties of the Hodgkin-Huxley equations

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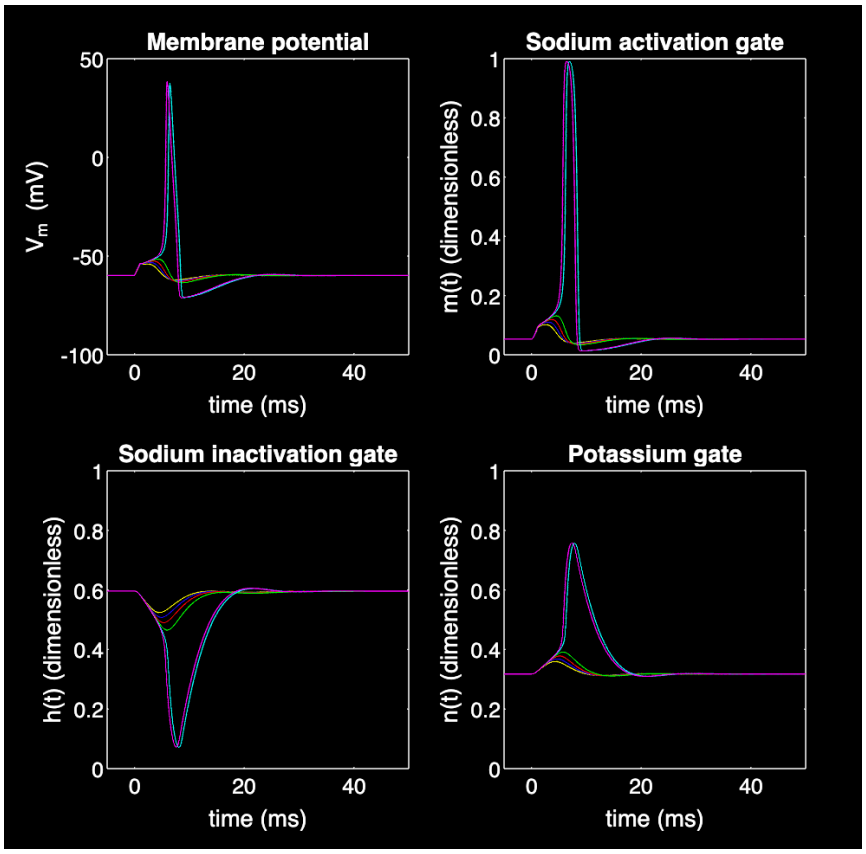
Threshold

Code for bisection of values:

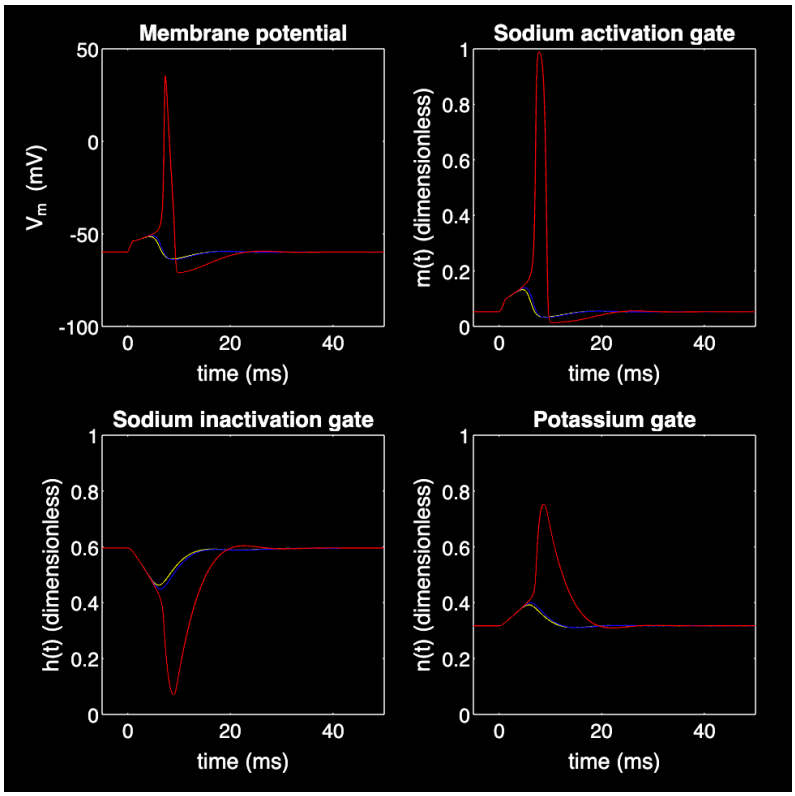
```
width1 = 1;
amp1 = 6;
n = 1;
while true
    amp1 = (amp1 + 7)/2;
    disp(amp1);
    hhmplot(0,50,n-1);
    if n > 5
        break
    end
    n = n + 1;
end
```

Plotted values:

```
6.5000
6.7500
6.8750
6.9375
6.9688
6.9844
```



By observing the plots, it can be seen that action potential is not generated for 6.9375 uAcm^{-2} and is generated for 6.9688 µAcm^{-2}. Therefore, the threshold must be a value in between these 2 values. In order to obtain the threshold for 2 decimal places, plot for 6.94 µAcm^{-2}, 6.95 µAcm^{-2} and 6.96 µAcm^{-2}.



Action potential is not generated for 6.95 µAcm^{-2} and is generated for 6.96 µAcm^{-2} . therefore **6.96 µAcm^{-2}** is an estimate of the threshold stimulating current amplitude.

$$\int_{t_o}^{t_f} J_{ei}\, dt = width1.amp1$$

$$\int_{t_o}^{t_f} \sum_k J_k\, dt = qna + qk + ql$$

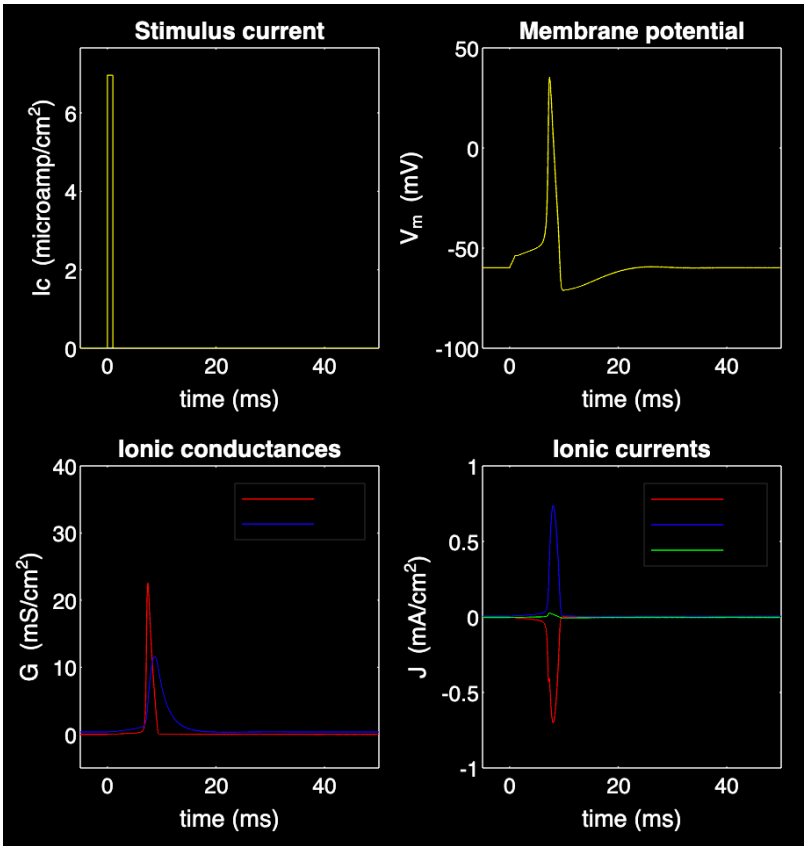
By varying the amp1 (keeping width1 constant), we can obtain different values for J_{ei},

sum_cu...	4.9998	1x1	double
sum_Jei	5	1x1	double
sum_cu...	5.4998	1x1	double
sum_Jei	5.5000	1x1	double
sum_cu...	5.9997	1x1	double
sum_Jei	6	1x1	double
sum_cu...	6.4996	1x1	double
sum_Jei	6.5000	1x1	double
sum_cu...	7.0014	1x1	double
sum_Jei	7	1x1	double

Therefore it can be seen that $\int_{t_o}^{t_f} J_{ei}\, dt$ and $\int_{t_o}^{t_f} \sum_k J_k\, dt$ are nearly equal for all the varied values of J_{ei}.

$$\int_{t_o}^{t_f} J_{ei}\, dt = \int_{t_o}^{t_f} \sum_k J_k\, dt$$

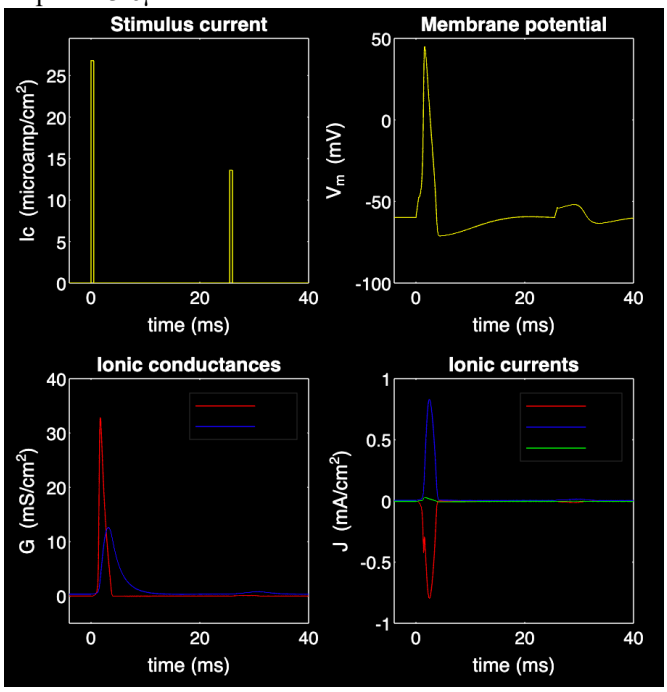
For amp1 = 6.96 μAcm^{-2},



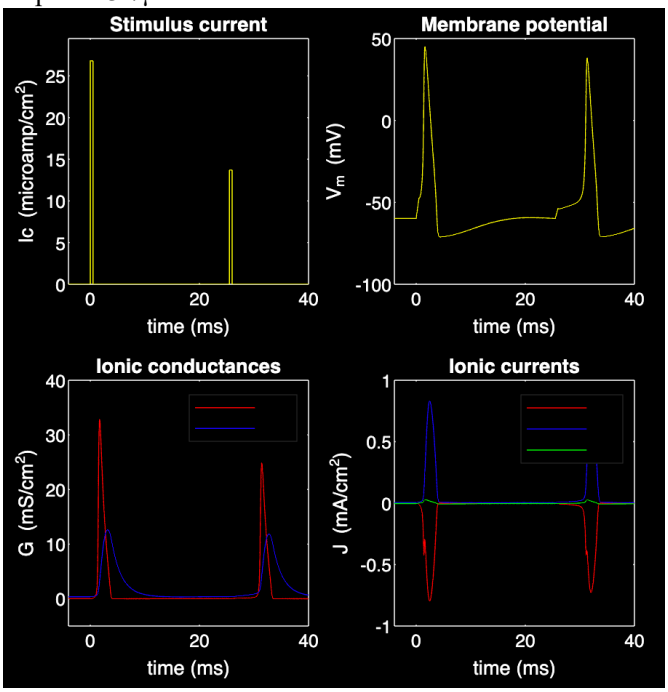
Refractoriness

For delay2 = 25ms, when increasing amp2 by 0.1 μAcm^{-2} from 13.4 μAcm^{-2}, a second action potential just elicit when amp2 is 13.7μAcm^{-2} .

amp2 = 13.6μAcm^{-2}

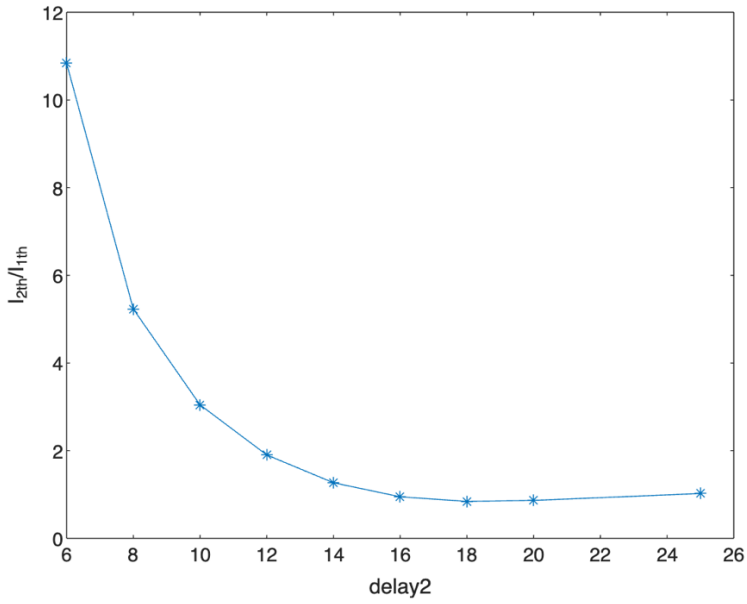


amp2 = 13.7μAcm^{-2}



By continuing this adjustment of amp2 by setting delay2 successively to 20, 18, 16, 14, 12, 10, 8 and 6 ms,

delay2 (ms)	amp2 (μAcm^{-2})
25	13.7
20	11.6
18	11.3
16	12.7
14	17
12	25.5
10	40.8
8	70.1
6	145.2

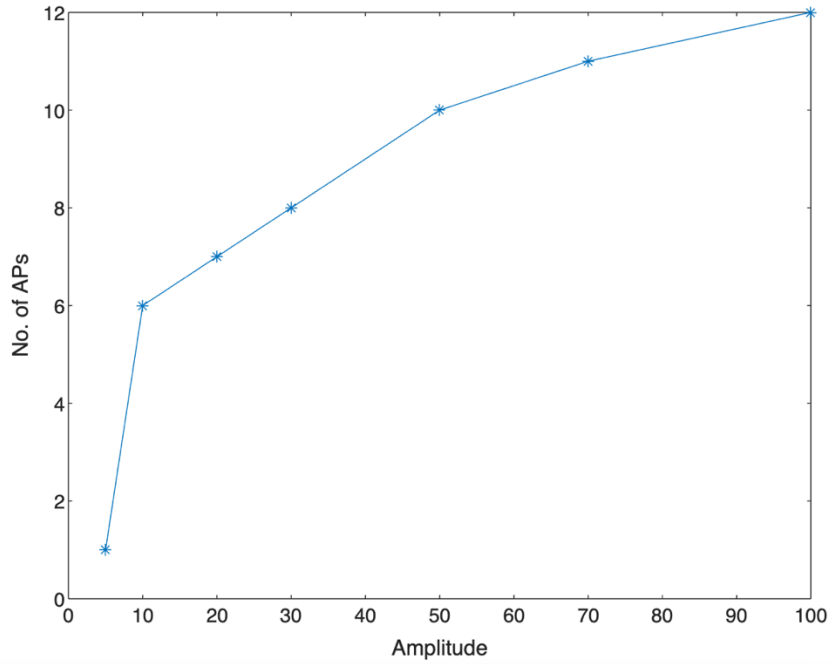


By the graph, I_{2th} (threshold for the second AP) decreases exponentially with increasing time delay. At 6ms time delay, the I_{2th} is more than 10 times I_{1th} which is a significant increase (can be considered as the threshold value in absolute refractory period).
Absolute refractory period : 0 – 6 ms

With increasing time delay, I_{2th} becomes smaller than I_{1th} at 16ms.
Relative refractory period : 6 – 16 ms

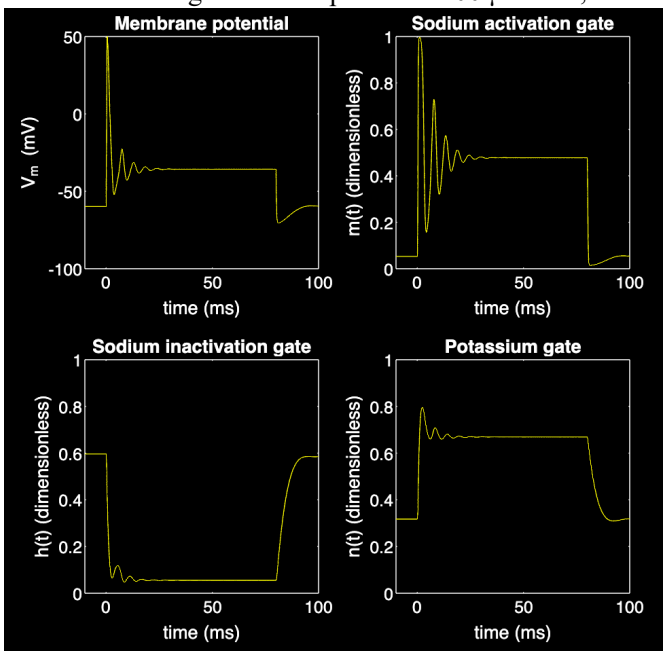
Repetitive Activity

Stimulating current amplitude (μAcm^{-2})	No. of APs
5	1
10	6
20	7
30	8
50	10
70	11
100	12



Observation:
Amplitude of the action potentials decreases as the stimulus intensity amplitude increases.

When stimulating current amplitude is 200 μAcm^{-2} ,



Observation: When the stimulating current amplitude is very high, instead of keep generating APs for a longer period, the amplitudes of APs decreases and the membrane potential is maintained at a constant value (depolarization block).

Explanation: the high stimulating current causes the membrane potential to depolarize more rapidly. This causes the activation of voltage-gated Na channels (m(t)) and a rapid influx of Na^+ ,leading to the initiation of the AP.

However, this increased depolarization also affects sodium inactivation gates (h(t)). As a result, fewer Na channels are available for depolarizing the membrane potential, hence the amplitude of AP decreases.

This high depolarizing level due to the high stimulating current amplitude also causes n(t) to reduce which represents the conductivity of K^+ ions into the neuron (which will reduce the membrane potential). This decrease in n(t) reduces the availability of activated potassium channels and obstructs the repolarizing phase, causing the membrane potential to remain at a constant value (above resting potential).

Temperature Dependence

Action potential duration

The increase of temperature causes the speed of ion channel activation and inactivation process to be increased. This means opening and closing of the ion channels occur more rapidly at higher temperatures resulting in faster repolarization. Hence the action potential duration decreases at higher temperatures.

Action potential amplitude

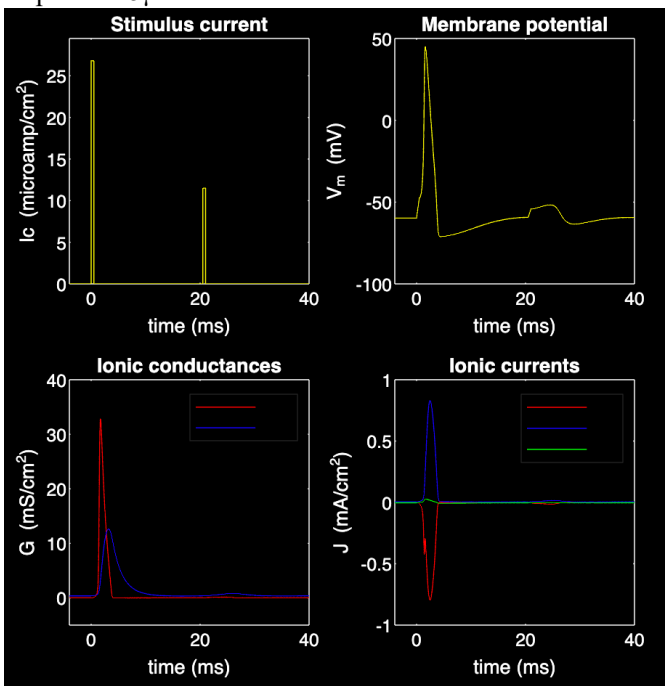
As the ion channels opens up rapidly at higher temperatures, the repolarization by opening of potassium channels occur more rapidly. This reduces the action potential amplitude as the increase of membrane potential by the opening of sodium channels is nullified by opening of potassium channels more quickly. Hence, the amplitude of the action potential decreases at higher temperatures.

Appendix

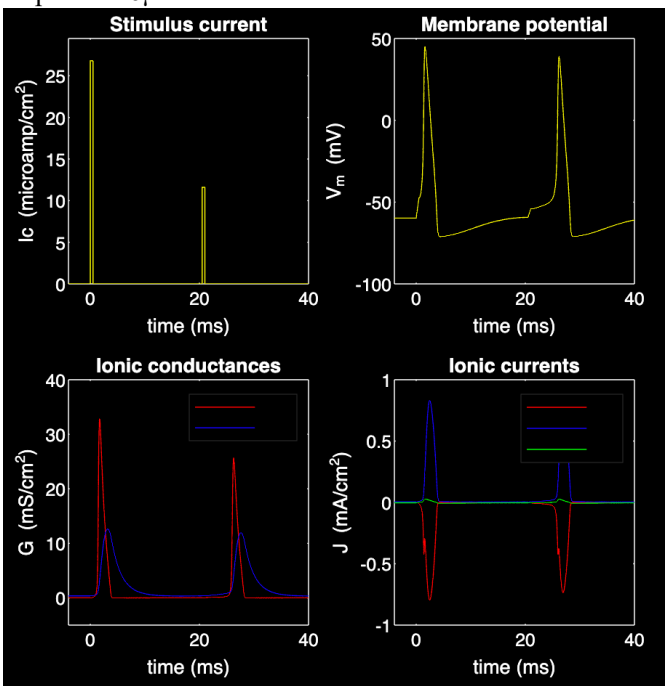
Question 3

delay2 = 20ms

amp2 = 11.5μAcm^{-2}

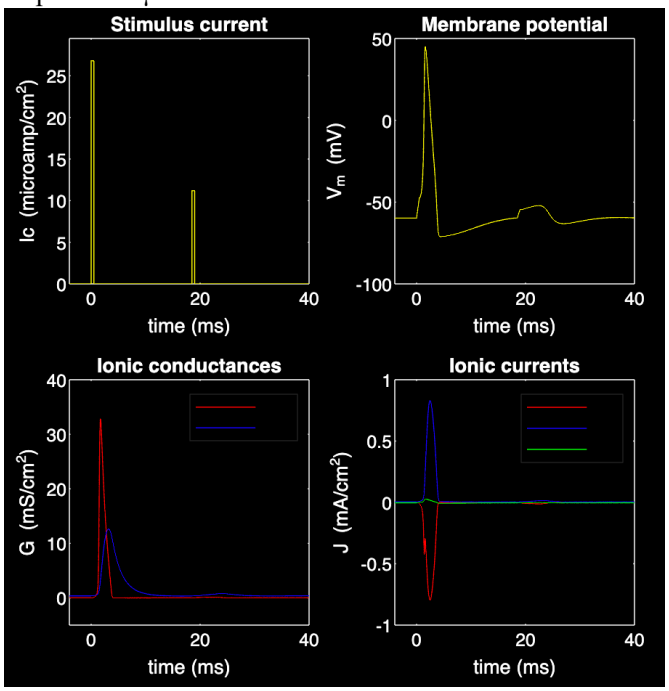


amp2 = 11.6μAcm^{-2}

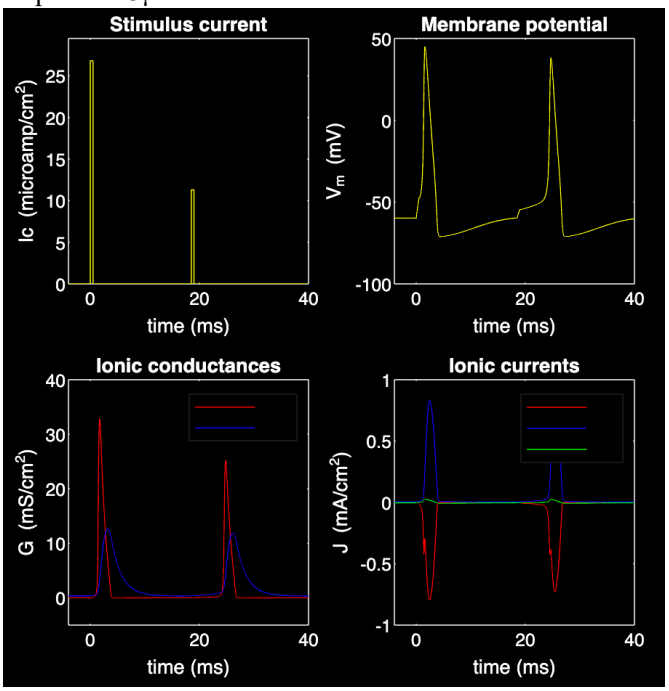


delay2 = 18ms

amp2 = 11.2μAcm^{-2}

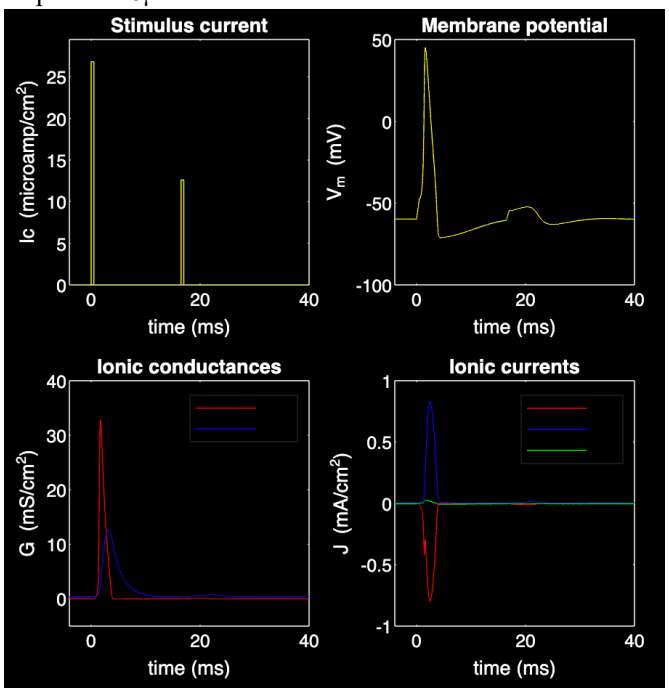


amp2 = 11.3μAcm^{-2}

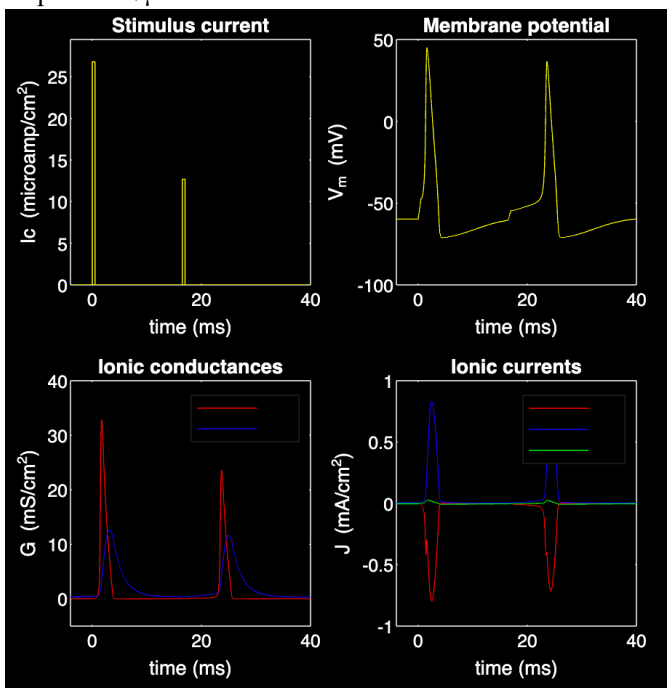


delay2 = 16ms

amp2 = 12.6μAcm^{-2}

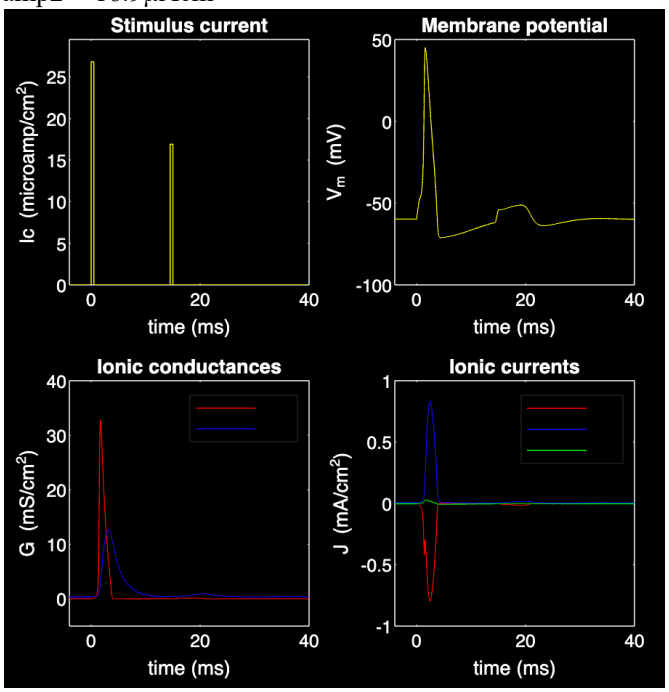


amp2 = 12.7μAcm^{-2}

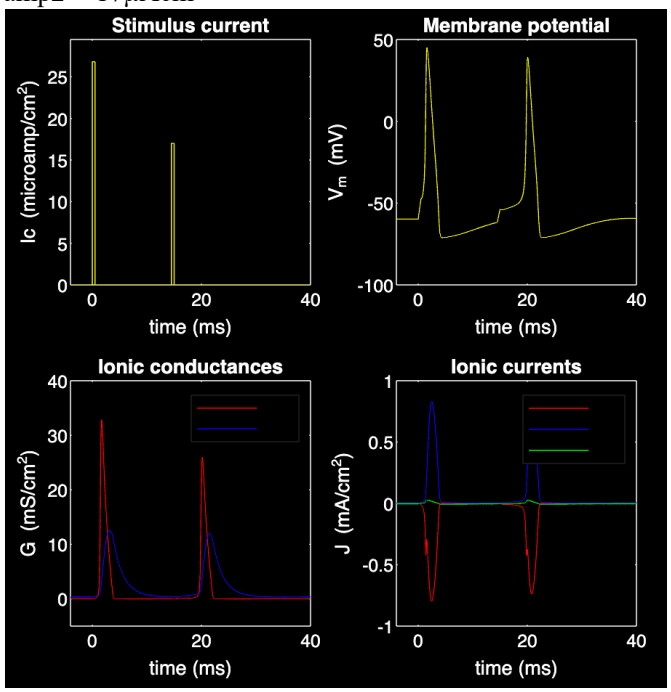


delay2 = 14 ms

amp2 = 16.9μAcm^{-2}

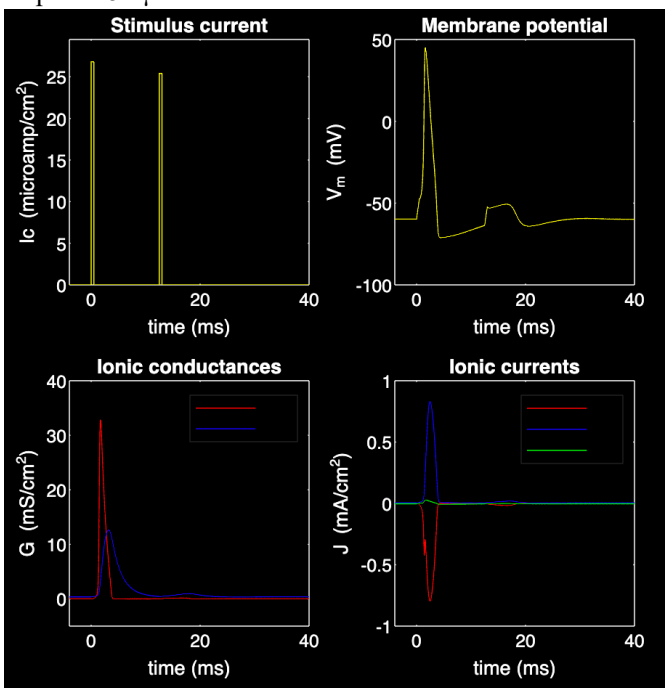


amp2 = 17μAcm^{-2}

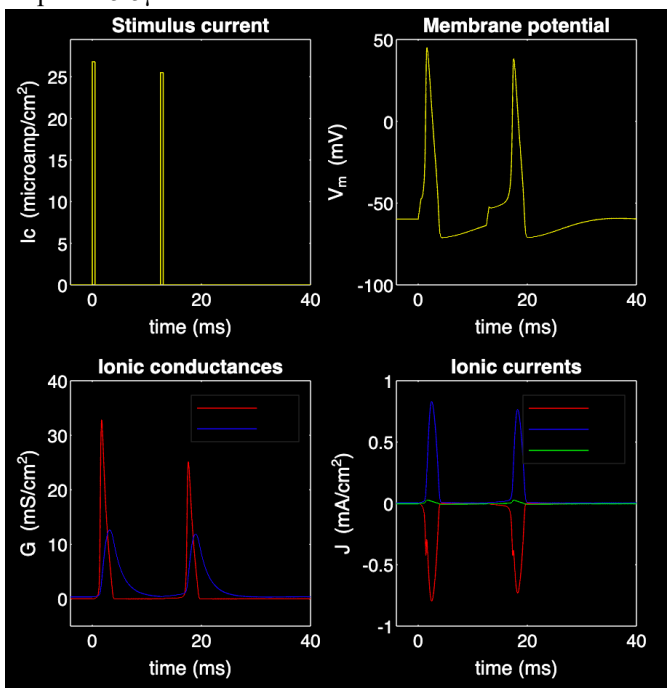


delay2 = 12ms

amp2 = 25.4μAcm^{-2}

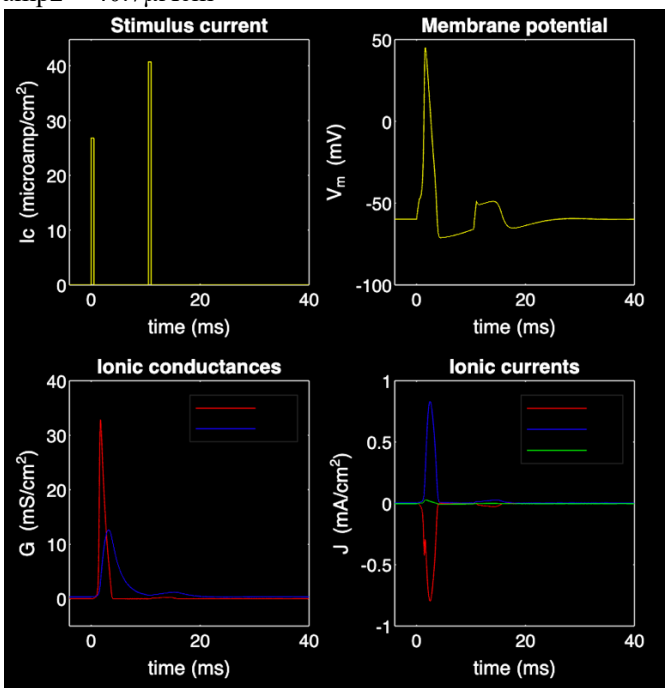


amp2 = 25.5μAcm^{-2}

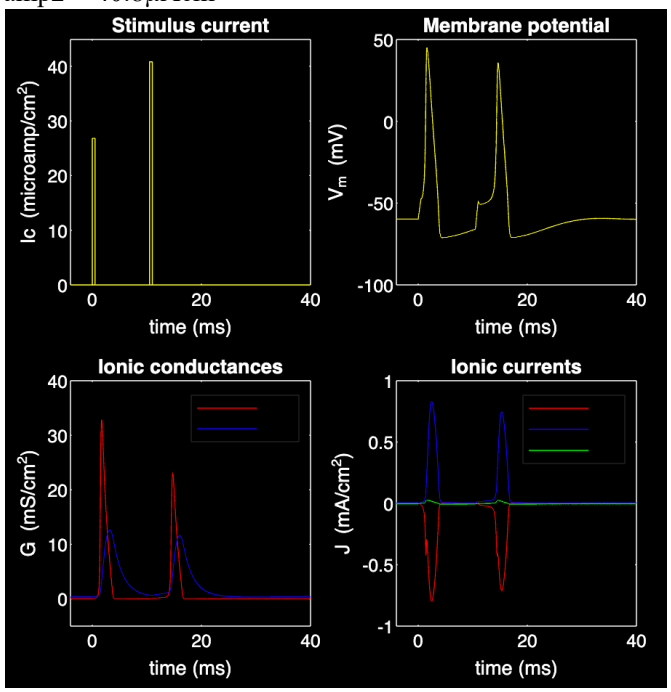


delay2 = 10ms

amp2 = 40.7μAcm^{-2}

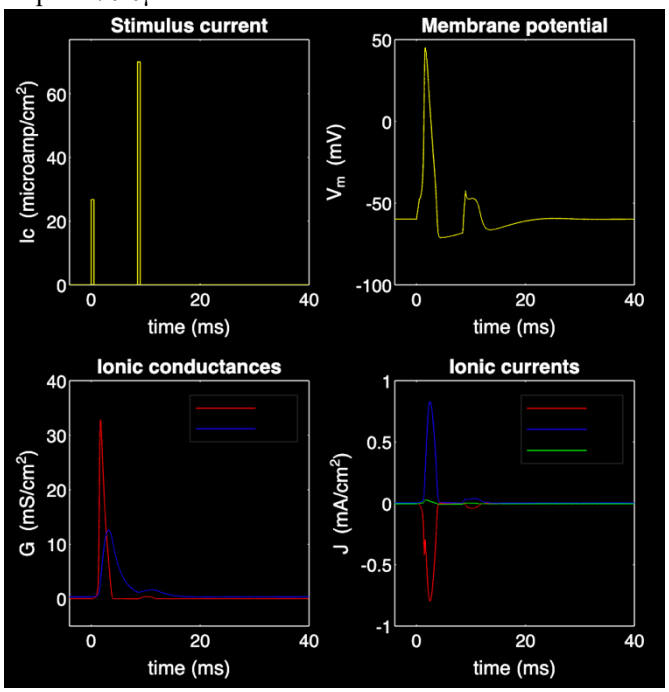


amp2 = 40.8μAcm^{-2}

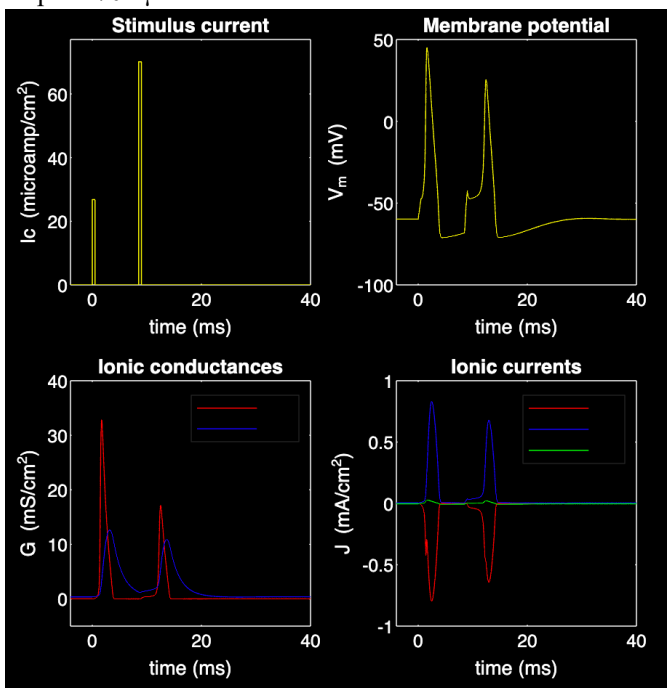


delay2 = 8ms

amp2 = 70.0μAcm^{-2}

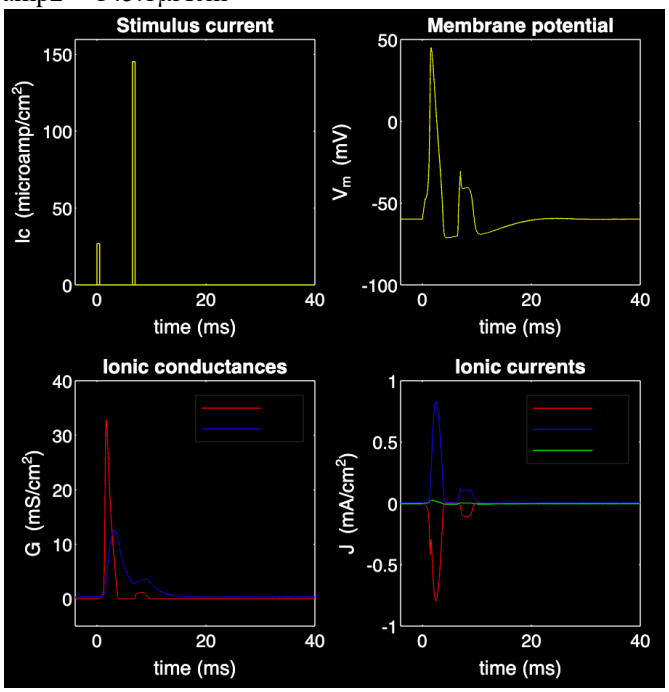


amp2 = 70.1μAcm^{-2}

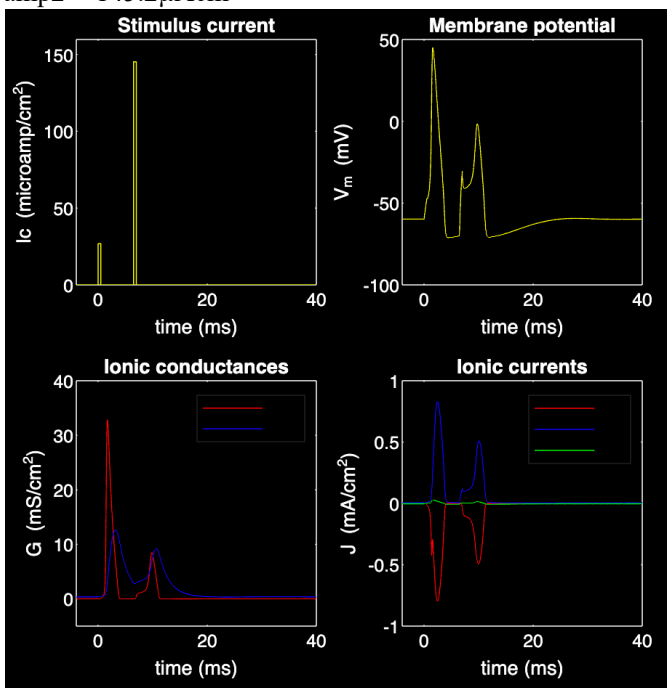


delay2 = 6ms

amp2 = 145.1μAcm^{-2}

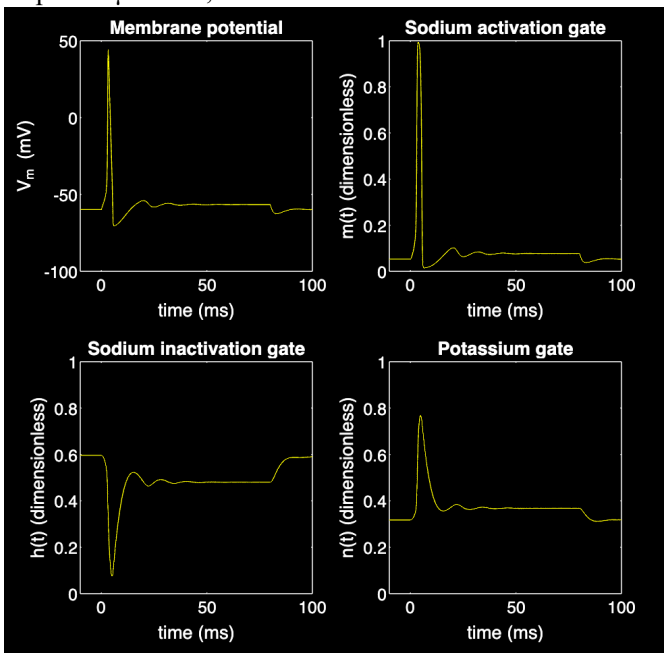


amp2 = 145.2μAcm^{-2}

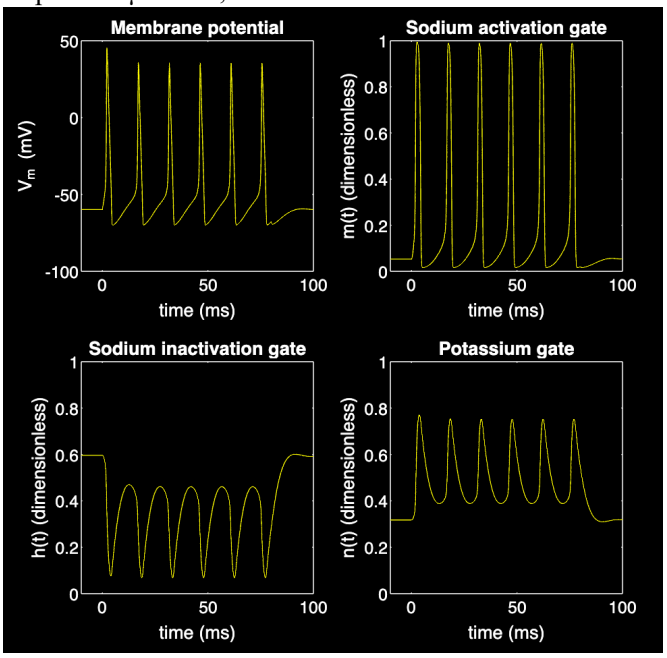


Question 5

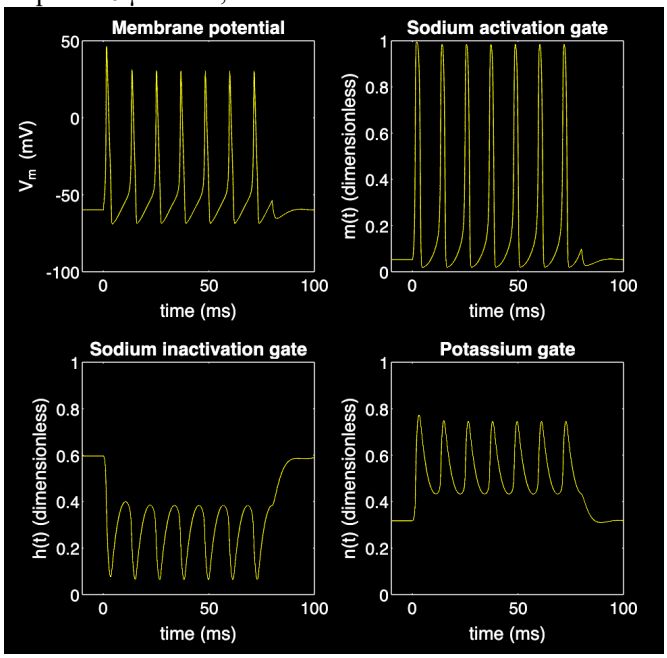
amp1 = 5 μAcm^{-2},



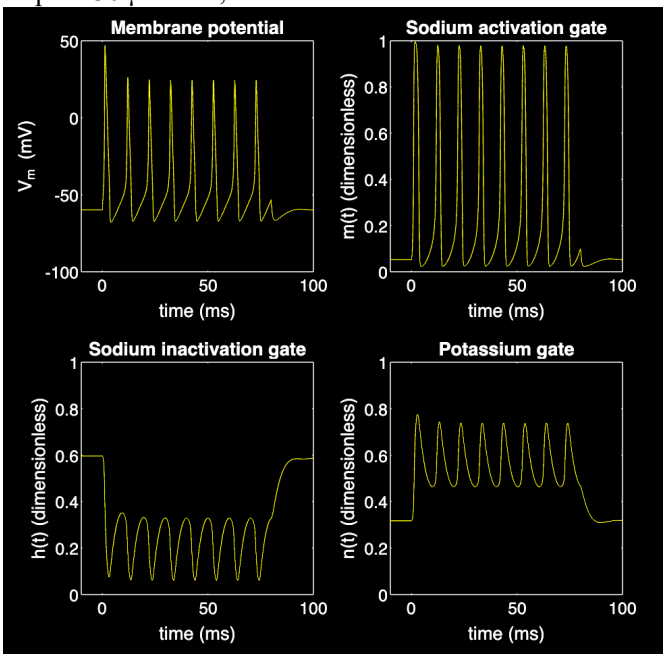
amp1 = 10 μAcm^{-2},



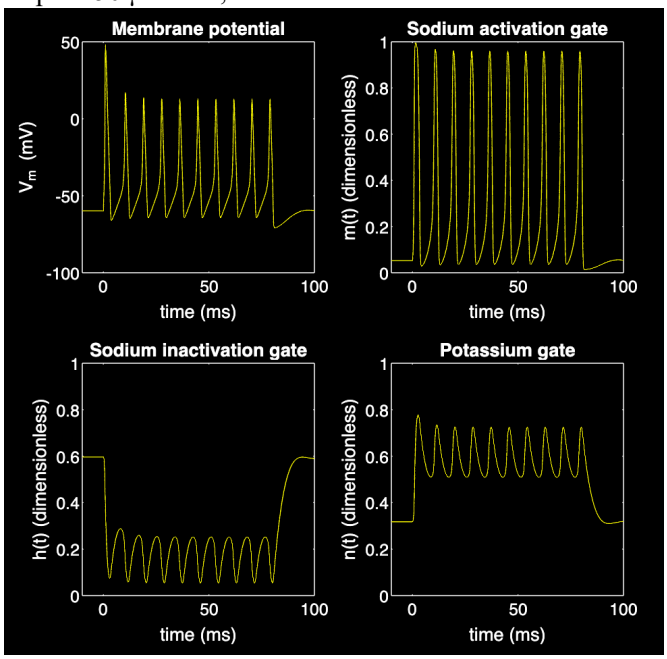
amp1 = 20 μAcm^{-2},



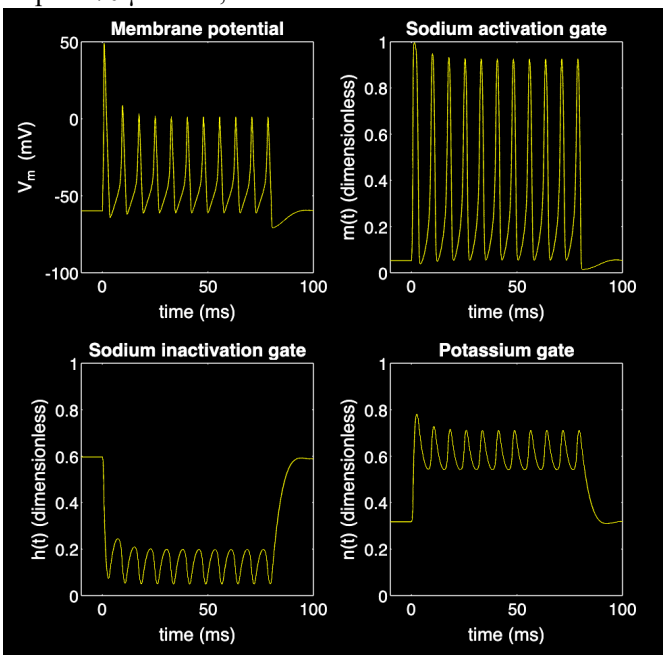
amp1 = 30 μAcm^{-2},



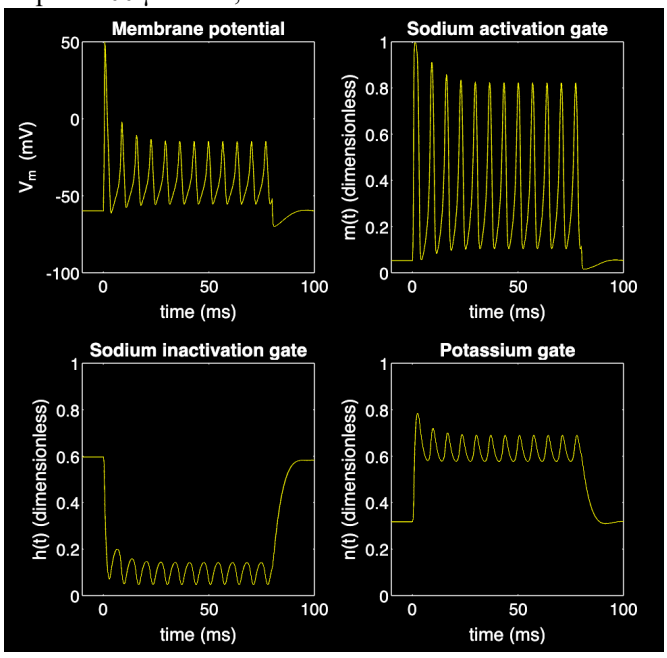
amp1 = 50 μAcm^{-2} ,



amp1 = 70 μAcm^{-2} ,

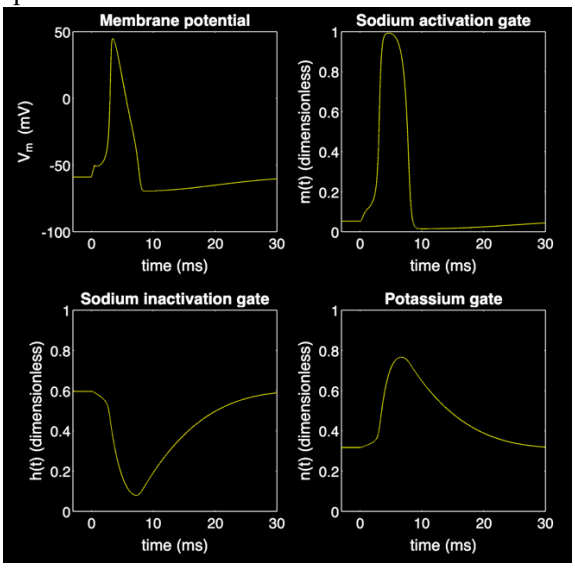


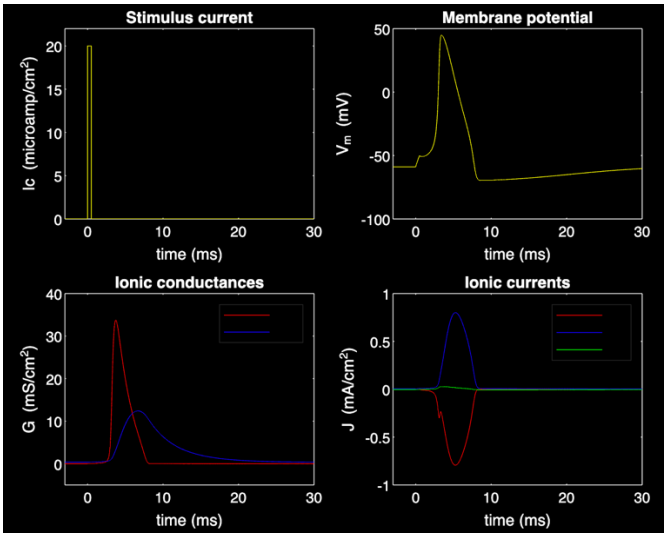
amp1 = 100 μAcm^{-2} ,



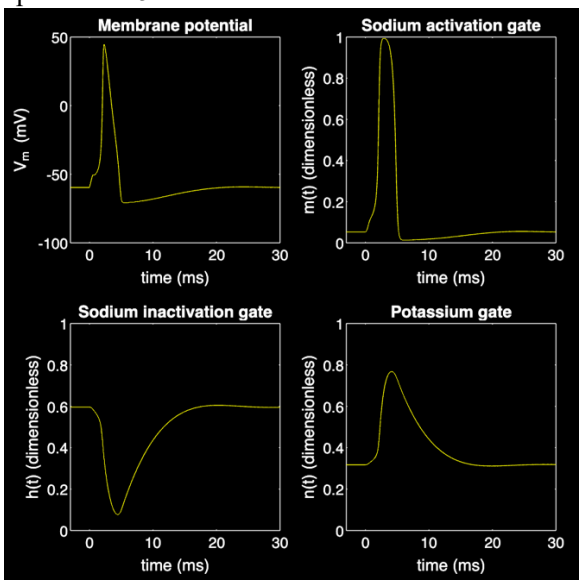
Question 7

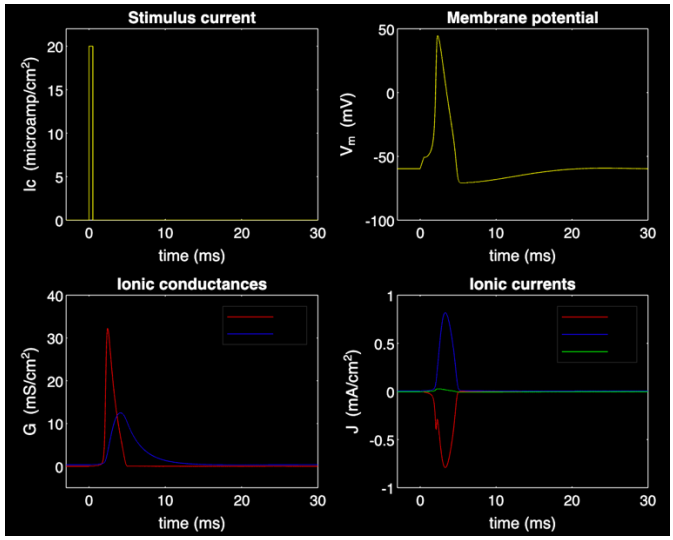
Temperature = 0 ^{0}C



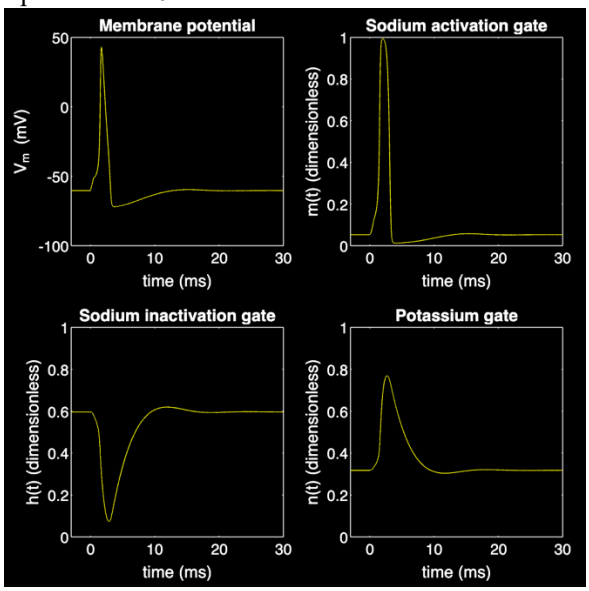


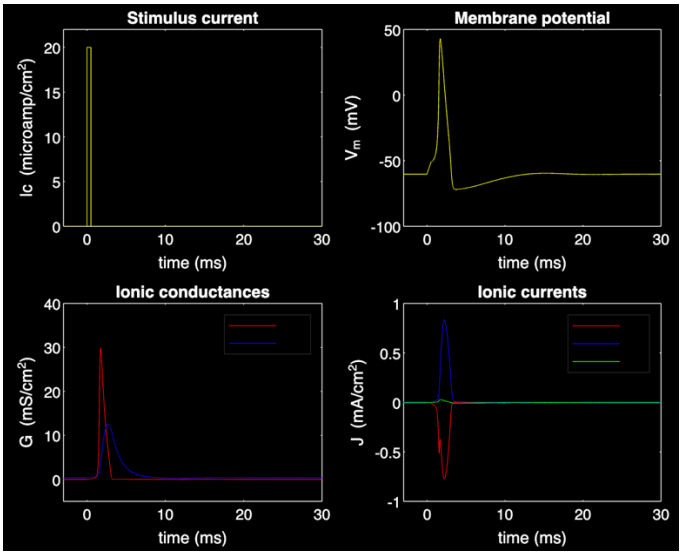
Temperature = 5 ^{0}C



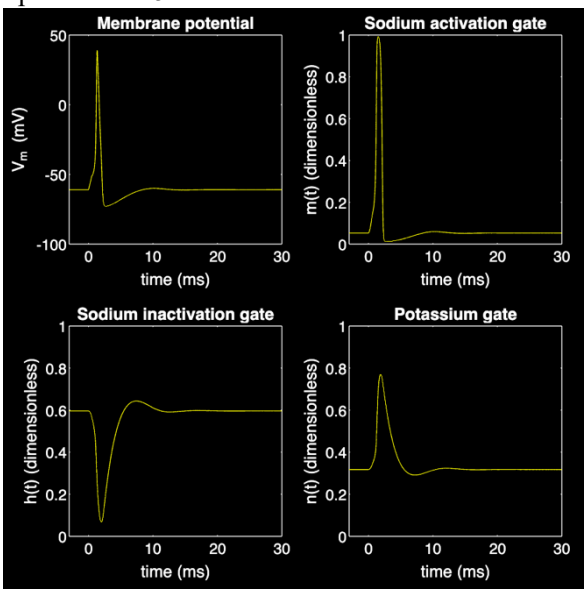


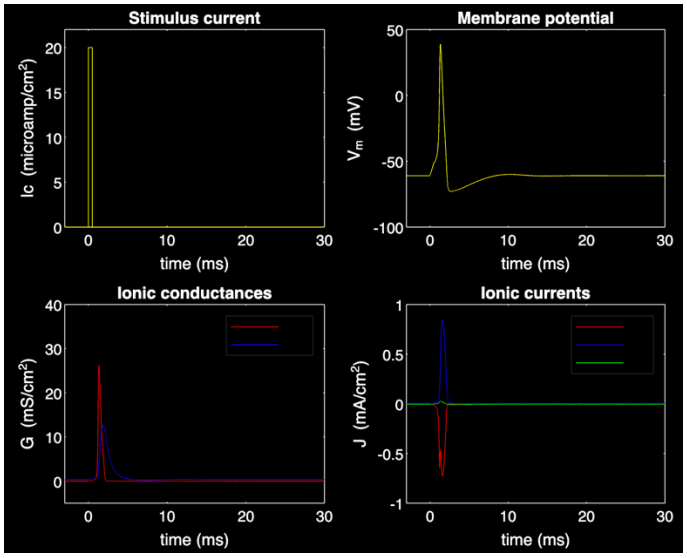
Temperature = 10 ^{0}C



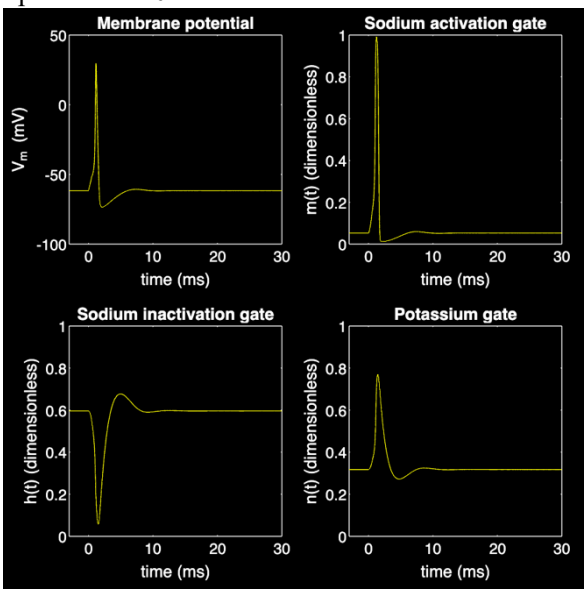


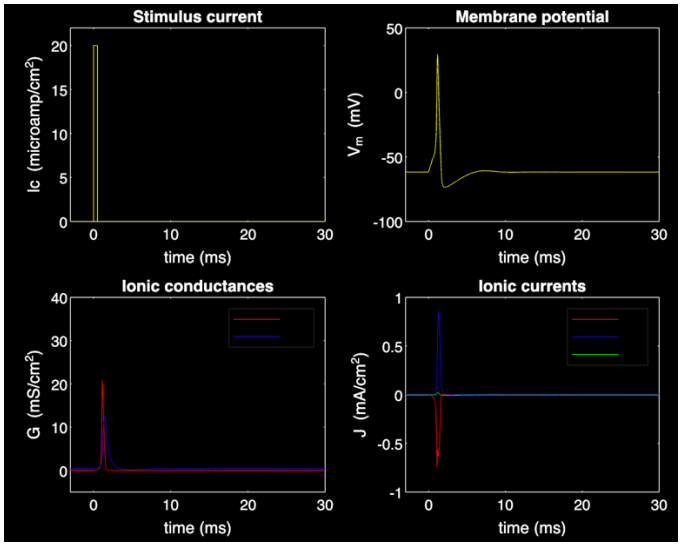
Temperature = 15 ^{0}C



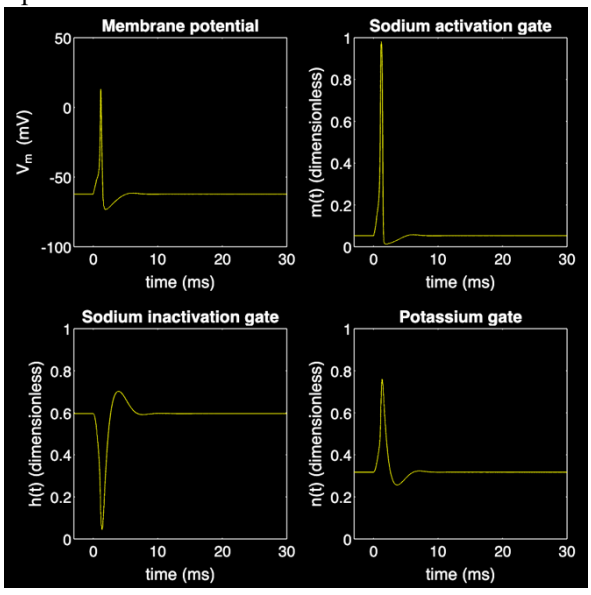


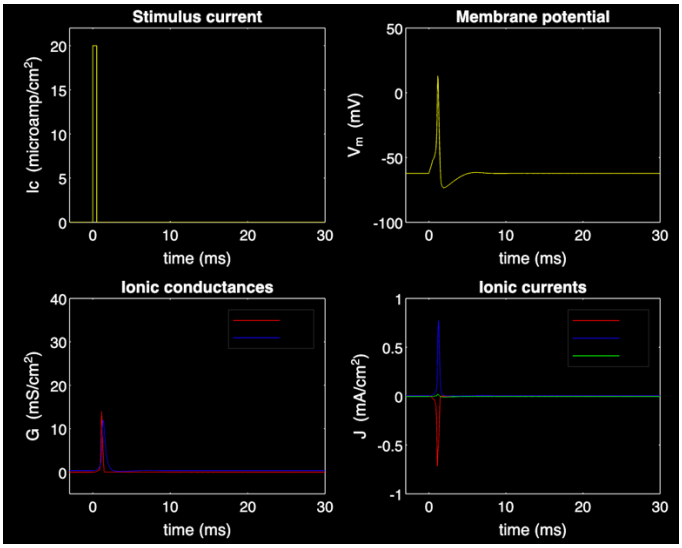
Temperature = 20 ^{0}C



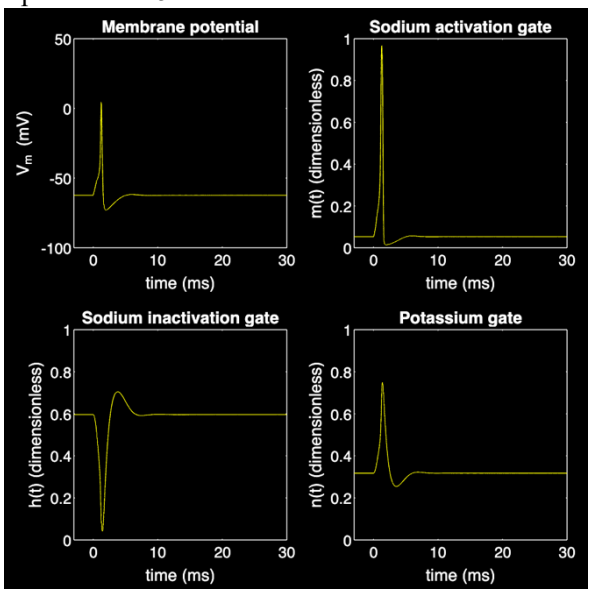


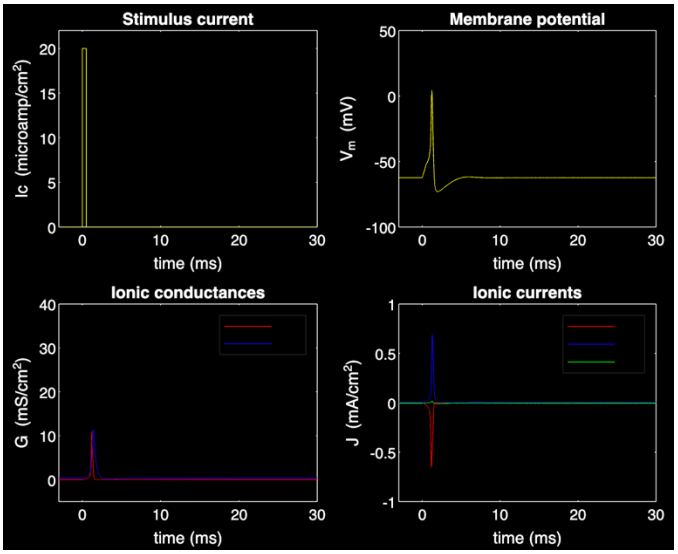
Temperature = 24 ^{0}C



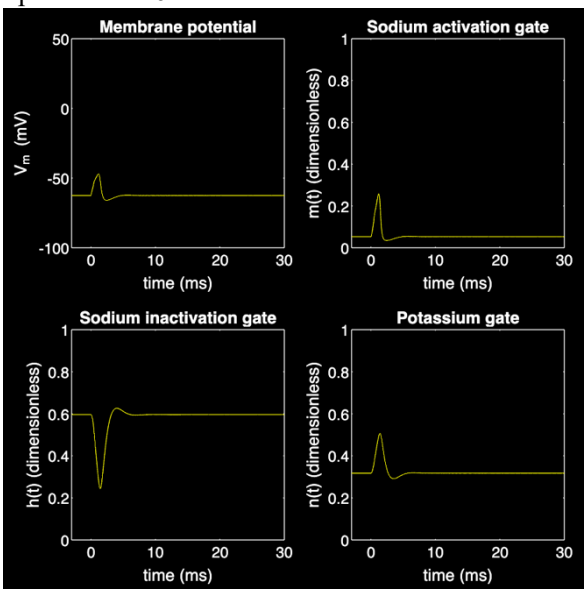


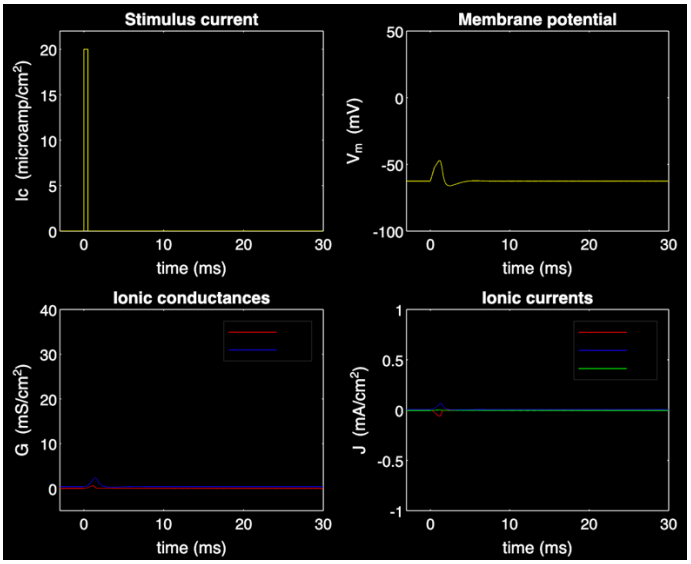
Temperature = 25 ^{0}C





Temperature = 26 ^{0}C





Temperature = 30 ^{0}C