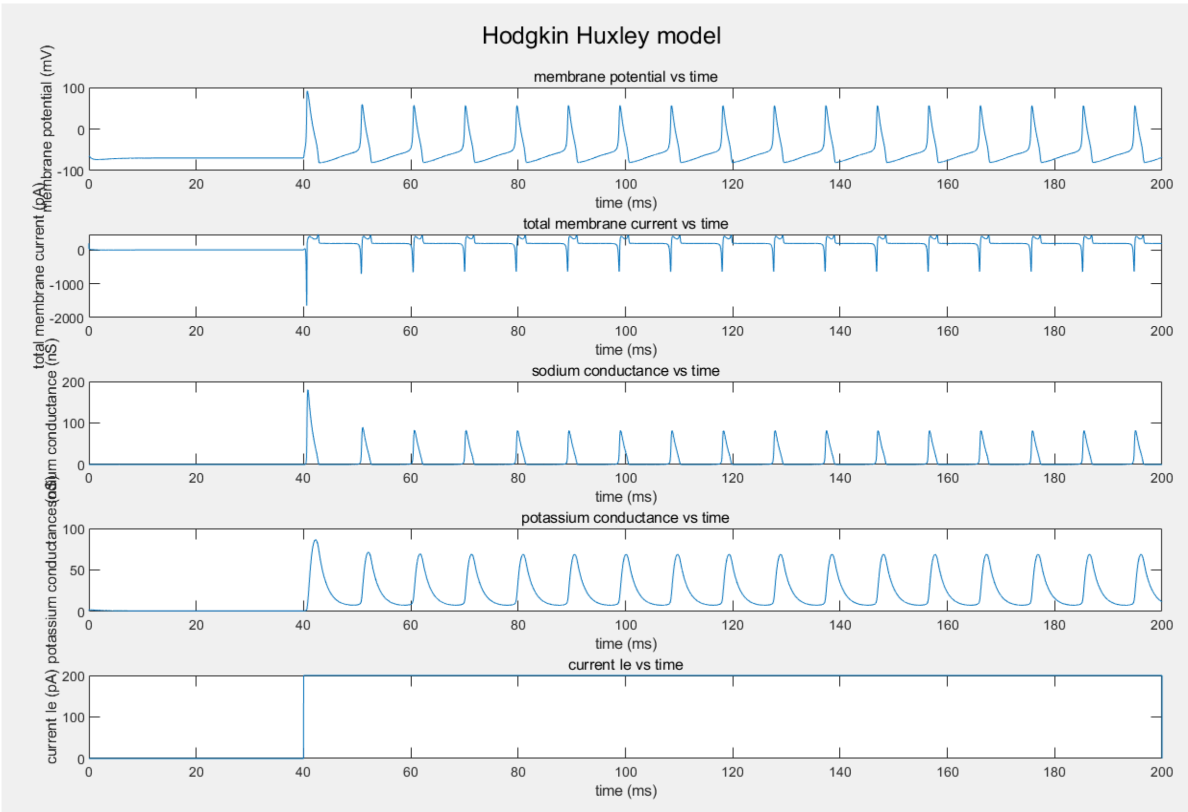
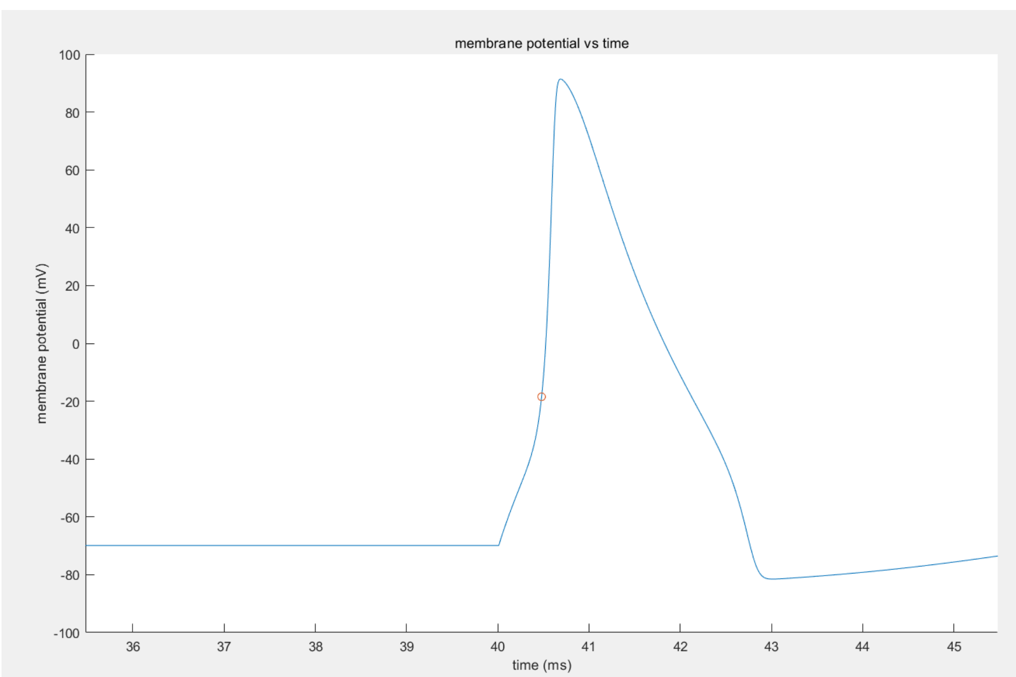
Part A

1.



Hodgkin Huxley model
membrane potential vs time
membrane potential (mV)
time (ms)
total membrane current vs time
total membrane current (pA)
sodium conductance vs time
sodium conductance (nS)
potassium conductance vs time
potassium conductance (nS)
current Ie vs time
current Ie (pA)

2.



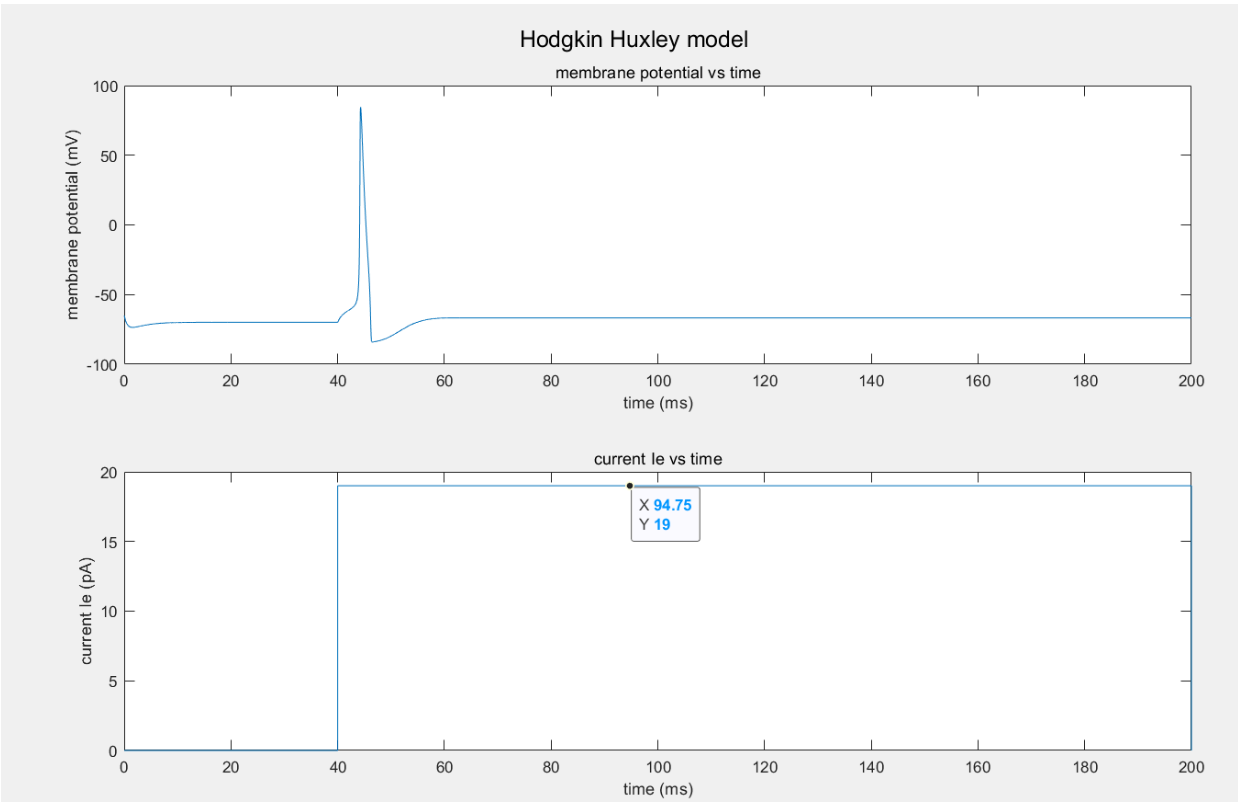
membrane potential vs time
membrane potential (mV)
time (ms)

the number of total spikes in a given time: n_spk = 17;

3.

Answer

I_1 : 19

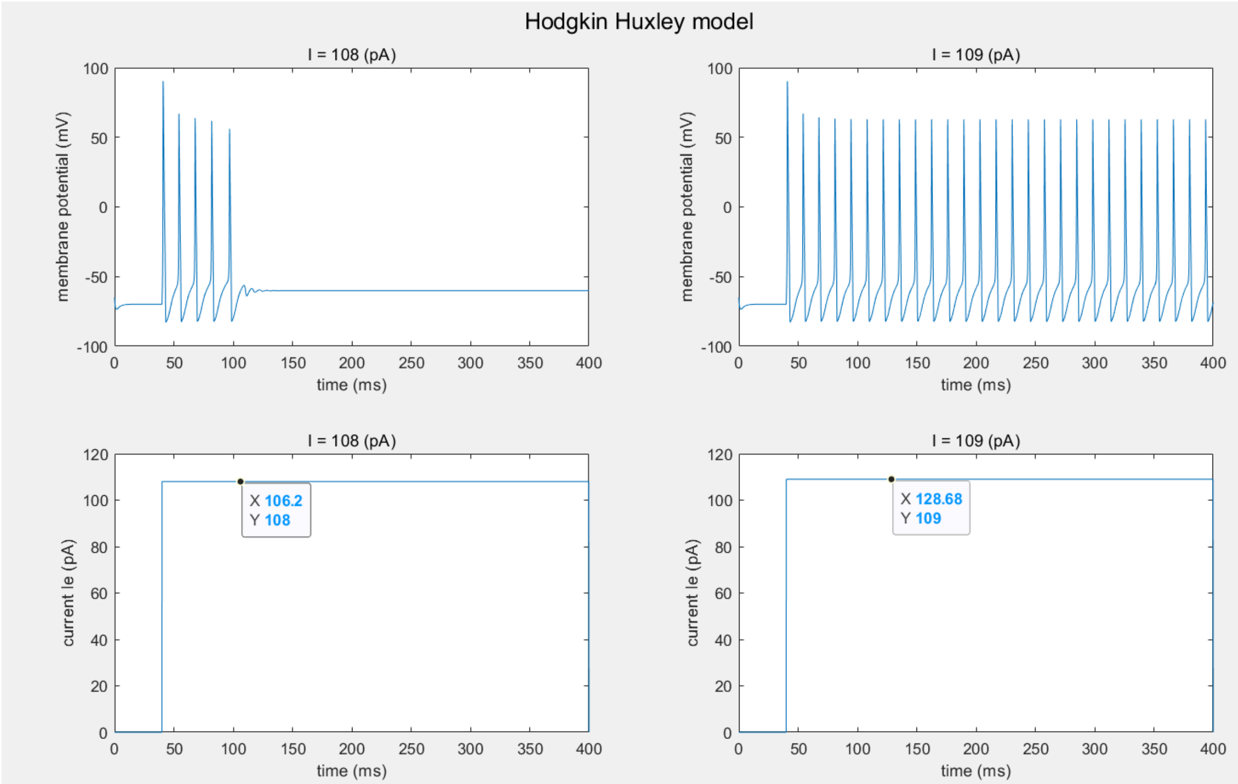


4.

```
% I got I_rh = 109 when the total time is 200
% Finally, I confirmed the I_rh by increasing the total time 200=>400.
% However, the value of I_rh is the same.
% Thus I_rh = 109    /    c_spk(109)=27   when the totaltime:400   / c_spk(108)=5
```

Answer

I_rh = 109



5.

```
% fr_m1 and fr_m2 contain firing rates for each input current
% which is from 80 to 130
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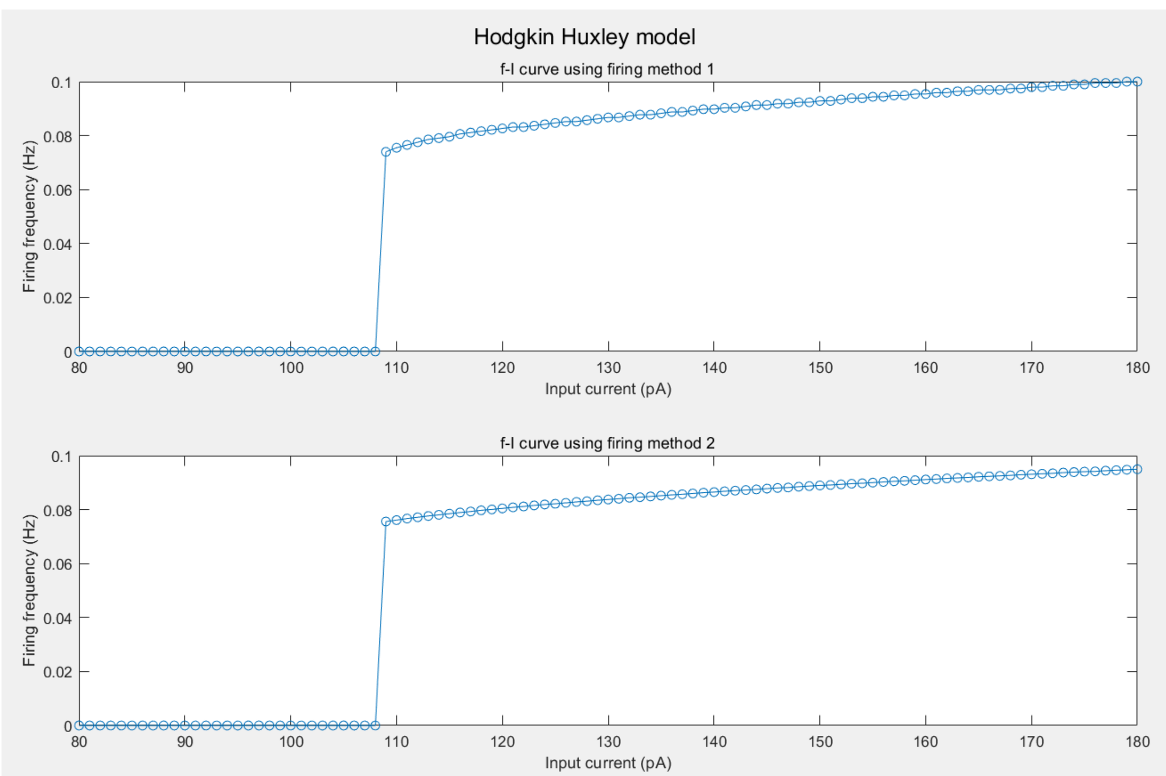


1) This is Type 2 firing behavior. Because the firing rate depending on the increasing input current is discontinuous. In other words, the graph shows that the firing rate jumps from zero to a finite positive value.
The type 2 firing behavior means the only stable point in this HH model turns into an unstable point as the input current ‘Ie’ is applied to the system enough.

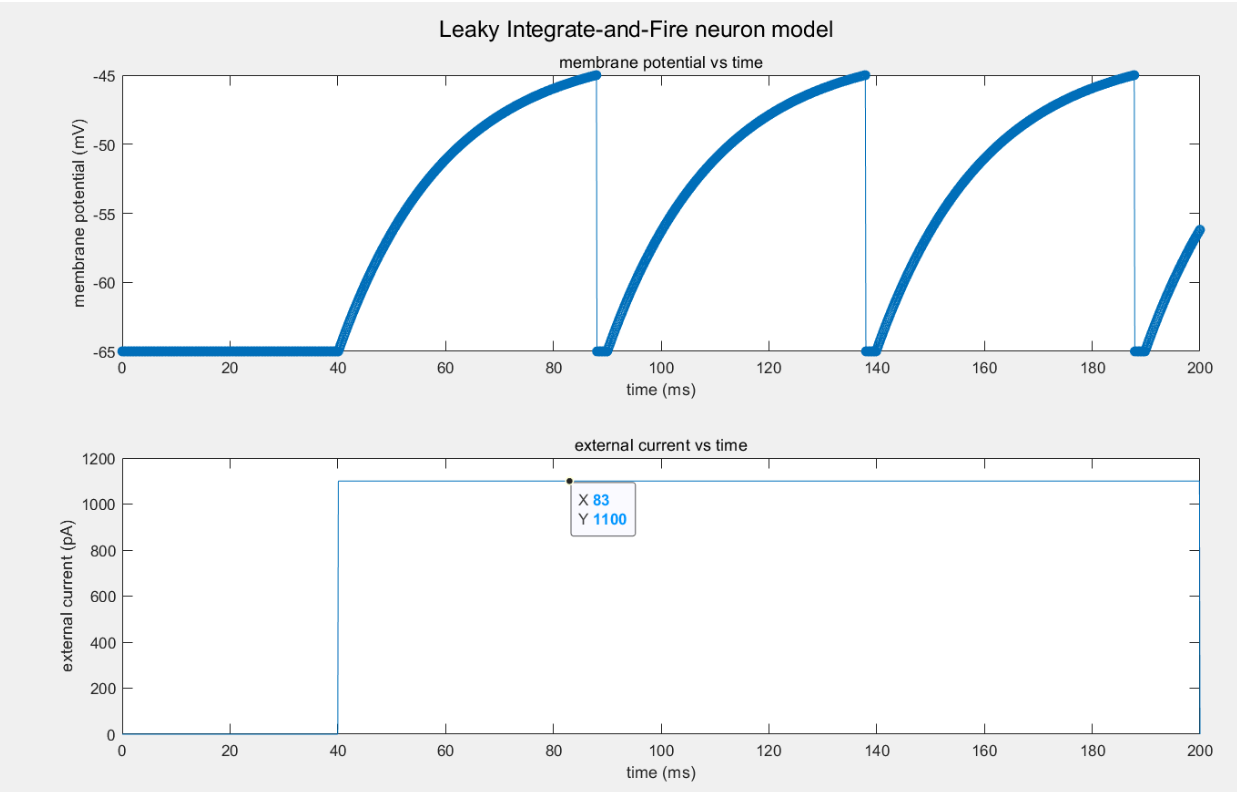
2) Yes. This HH model follows type 2 firing and in the graph above, we arrange all the points in ascending order of input current. As we can see in the graph, the firing rate jumps from zero to a finite positive value. The first point with a non-zero firing rate, in ascending order, means that this point has repetitive firing with a minimum input current. Thus, we can locate ‘I_rh’ as the value of the input current that is applied to this point.

3)
I do not think that this model is efficient. This is because this model follows type 2 firing behavior and therefore has a steep curve change. Although it is good for deciding whether to pass or fail because the critical point is clear, it is generally inefficient in situations where continuous results are needed in order from continuous input grades.

<About using method>
Method 2 is more correct than method 1. This is because if we calculate the firing rate using method 1, it contains meaningless time before the first spike arises and after the last spike ends in a limited time.

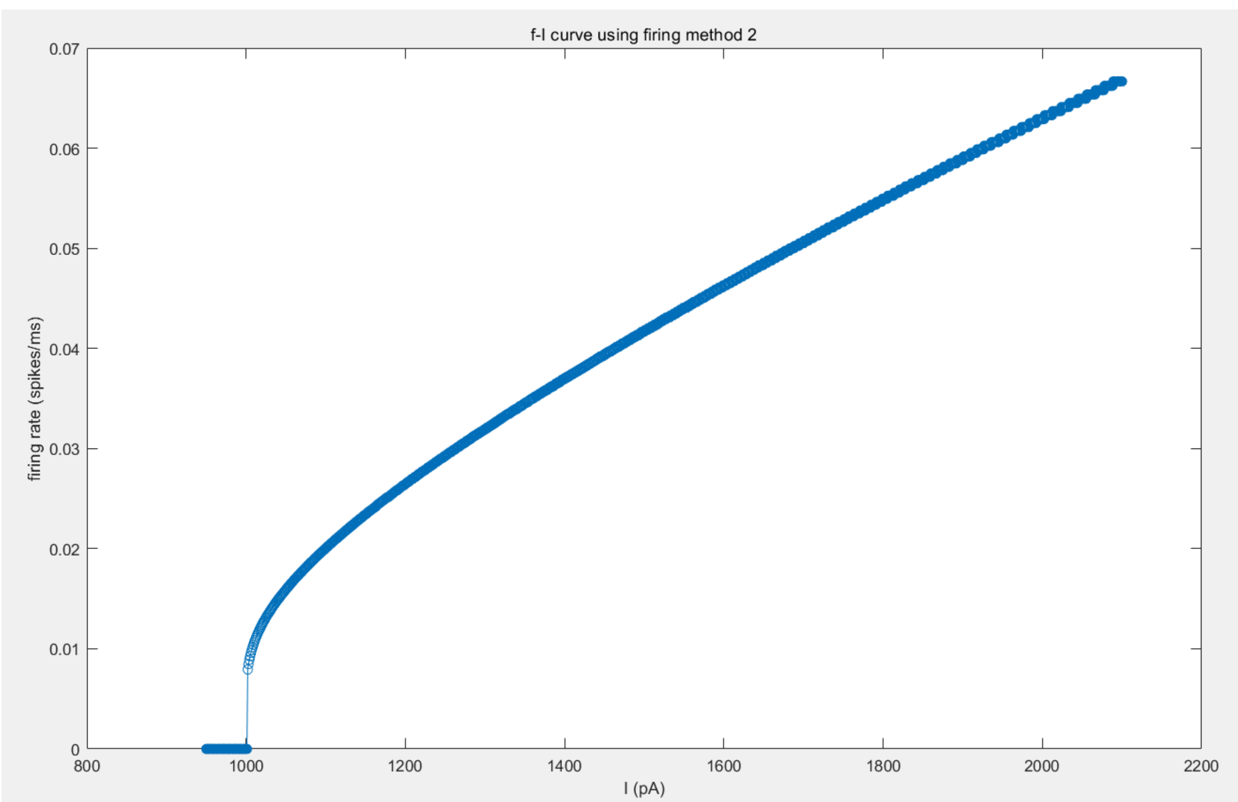
Part B

1.



Leaky Integrate-and-Fire neuron model
membrane potential vs time
membrane potential (mV)
-45
-50
-55
-60
-65
0
20
40
60
80
100
120
140
160
180
200
time (ms)
external current vs time
external current (pA)
1200
1000
800
600
400
200
0
X 83
Y 1100

2. (*)

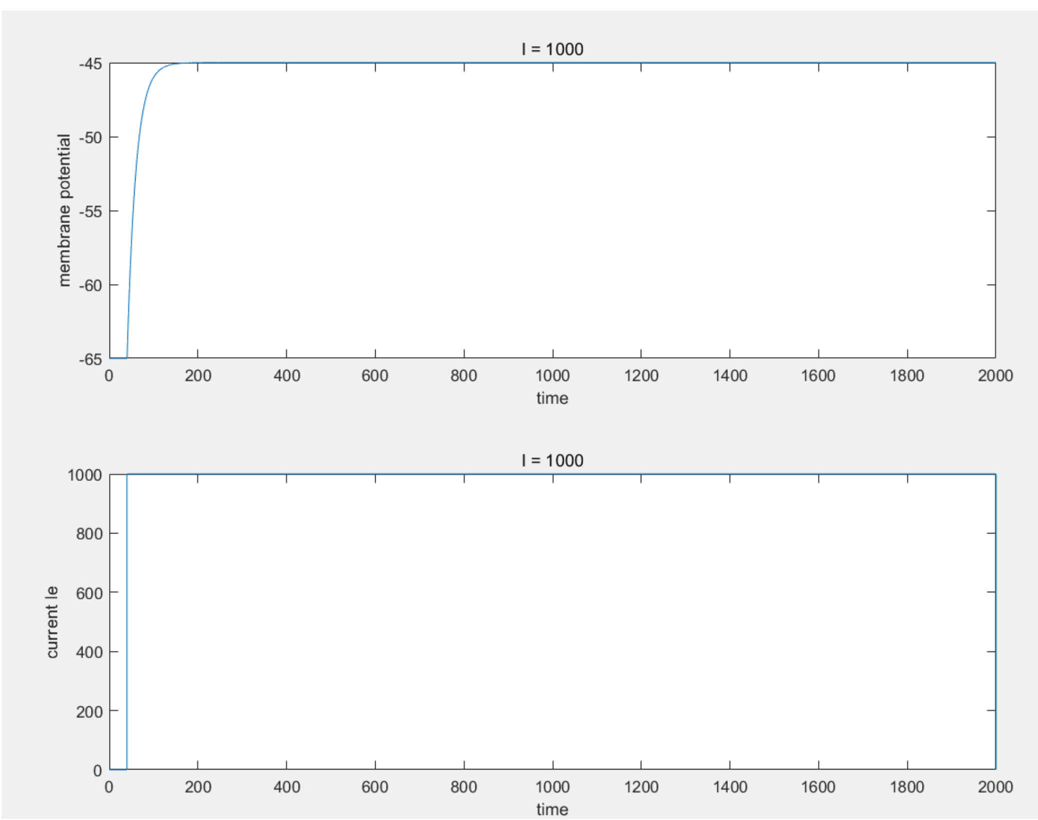


f-I curve using firing method 2
firing rate (spikes/ms)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
800
1000
1200
1400
1600
1800
2000
2200
I (pA)

1s = 1000ms. Making firing rates from zero to at least 60-70 spikes/s means making firing rates from zero to at least 0.06-0.07 spikes/ms.

1) This model is a type 1 firing behavior. This is because, unlike the f-I curve of type 2 firing behavior, the neuron's firing rate gradually increases from zero with increasing input current; This means it is continuous. Thus, this is different from the f-I curve of the HH model, which is a type 2 firing. Also, type 1 firing behavior implies that, unlike type 2, as it passes the bifurcation point the input current, from three equilibrium points which it has, becomes to one equilibrium point.

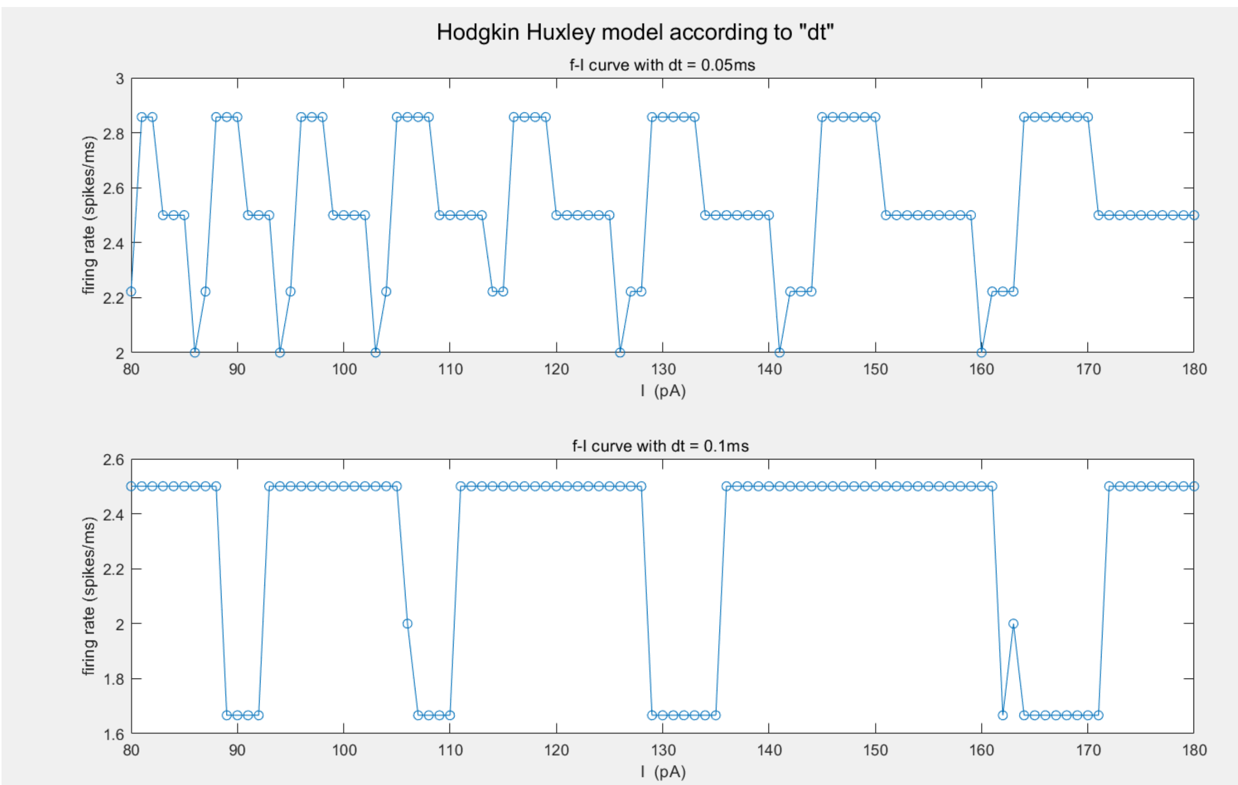
2) No, it is not possible. I simulated the LIF model to find 'I_rh' which is the smallest value of the current making repetitive firing ignites. In the above case, I_rh is 1001pA. I simulated this model to compare the number of spikes elicited in (I_rh) and (I_rh-1). It turns out that if 'Ie' is below I_rh, no spike occurs. When we plot the graph like below, It shows us that the membrane potential keeps going to the V_spk but does not arrive at the value. I set a code that automatically goes to the Vr if it arrives V_spk, -45mv. Since it does not become the V_r, we can say that it does not arrive at the V_spk.



3) As we can see in the f-I curve graph(*) above, the first point with a non-zero firing rate, in ascending order, means that this point has repetitive firing with a minimum input current. Therefore, from the f-I plot, an external current of approximately 1000 can be said to be the value of 'I_rh'.
The theoretical rheobase current: GL(V_spk - VL) = 1000. Since the obtained values from the graph and theory are similar, we can say they do match.

3.

1)

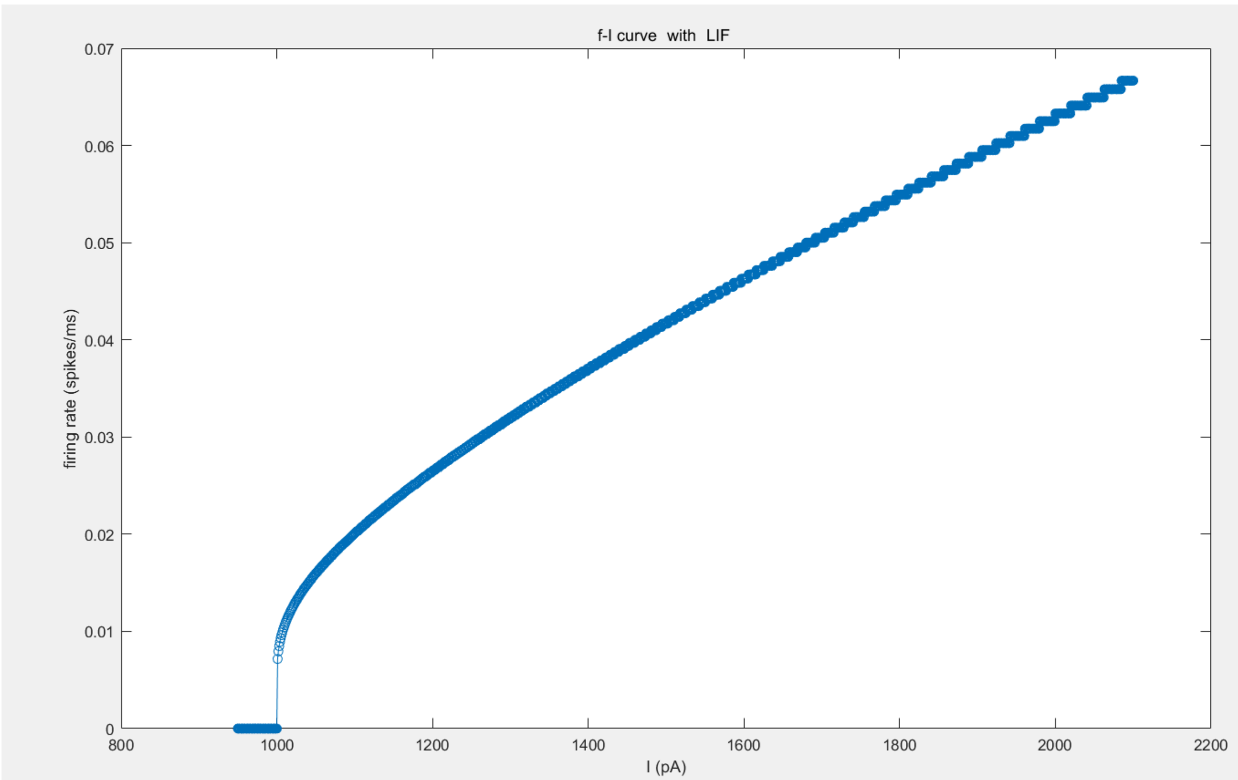


My simulation HH model does not work if I use the time step as 0.1 and 0.05. This is because 'dt' relates to my method in Matlab which is to check the 'I_rh'. If the number of spikes changes rapidly after a one-time step (dt) (this time we set it to 3 or more), the 'Ie' of this step is considered to be one current-step lower than I_rh. Also, I set that if the applied external current is below the 'I_rh', the firing rate equals zero. However, even if all cases are in repetitive firing, if the time step is large like this, the number of spikes can be changed more dramatically (by more than three).

So, my model recognized these changes caused by the large time step as a disappearance of Rheobase current and set the firing rate as zero. This was the reason for the wrong output. Thus, when we make a model to check the spike, we should consider the time step.

2)

(**)



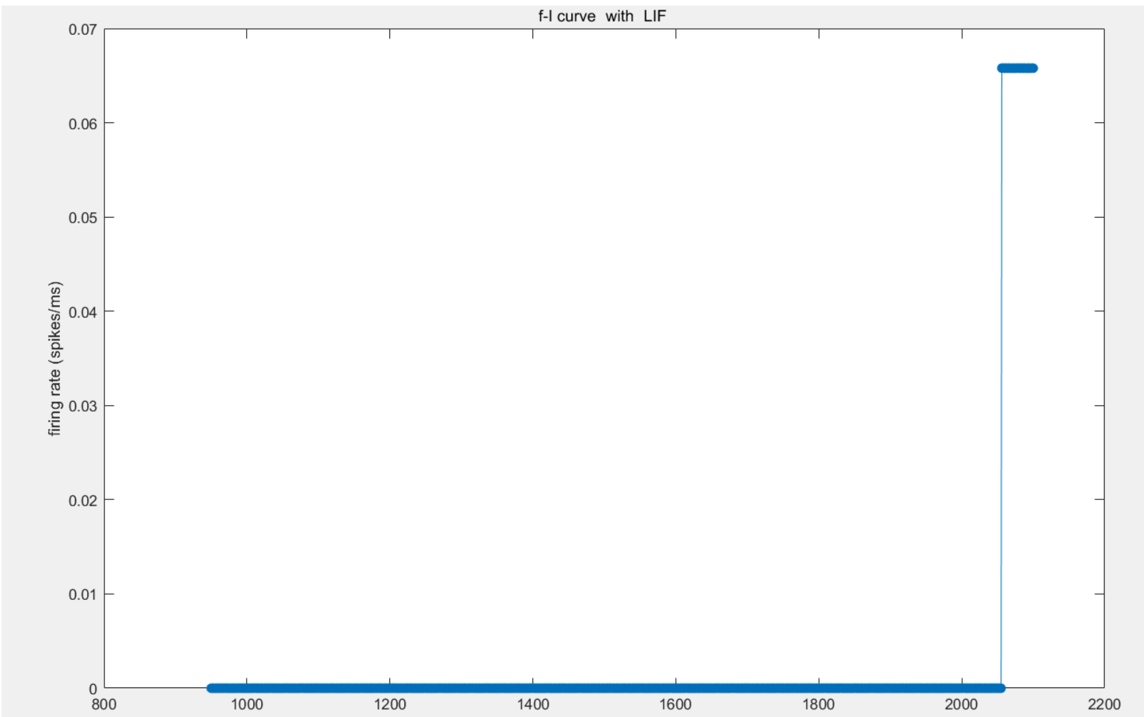
(**)

No, the result does not change significantly. This is because, in this LIF model, it is not possible to have only a few spikes and then stop firing. More specifically, the number of spikes in the model caused by currents higher than I_rh and currents lower than I_rh are very different. Because the number of spikes caused by currents lower than I_rh is always zero in this model.

My method to find the ‘I_rh’ relates to ‘dt’. If the number of spikes changes rapidly after a one-time step (dt) (this time we set it to 10 or more), the 'Ie' of this step is considered to be one current-step lower than I_rh. Since the number of spikes different a lot before and after the I_rh, we could set the criterion large enough, this time ‘10’. So that even if we double the time step, we could get a good graph.

However, if the time step is larger like 0.4, the number of spikes can be changed more dramatically (by more than 10). Then we can not get a good graph and it would be like this (***). This is because my model recognized these changes caused by the large time step as a disappearance of Rheobase current and set the firing rate as zero. This was the reason for the wrong output. This also means that If I change the allowing-change number larger properly(be careful), it can work well again. Thus, when we make a model to check the spike, we should consider the time step.

(***)



a)

<HH model>
The running time with dt = 0.01 is 19.402217 seconds.
The running time with dt = 0.002 is 119.287774 seconds.
<LIF model>
The running time with dt = 0.01 is 2.792088 seconds.
The running time with dt = 0.002 is 10.897712 seconds.

There is an appreciable big difference in running times between the HH model and the LIF model neurons, at parity of ‘dt’. The LIF model is faster than HH when each of the ‘dt’ and total time is the same. This is because the LIF model is a ‘simplified’ model with fewer elements to calculate.
As the time step becomes shorter in the same total time, the amount of calculation increases. Naturally, the more calculations each model requires, the more time it takes. Because the HH model has more elements to calculate in a loop than the LIF, the HH model takes much longer time than the LIF model even if the time step is reduced to the same as the LIF model. This is why when the ‘dt’ is 0.002, the difference in time consumption between LIF and HH becomes bigger than when the ‘dt’ is 0.01. Therefore, as the time step decreases, the amount of calculation increases, and the time difference between the two models becomes larger.