Assignment 4 - Properties of the Hodgkin-Huxley equations

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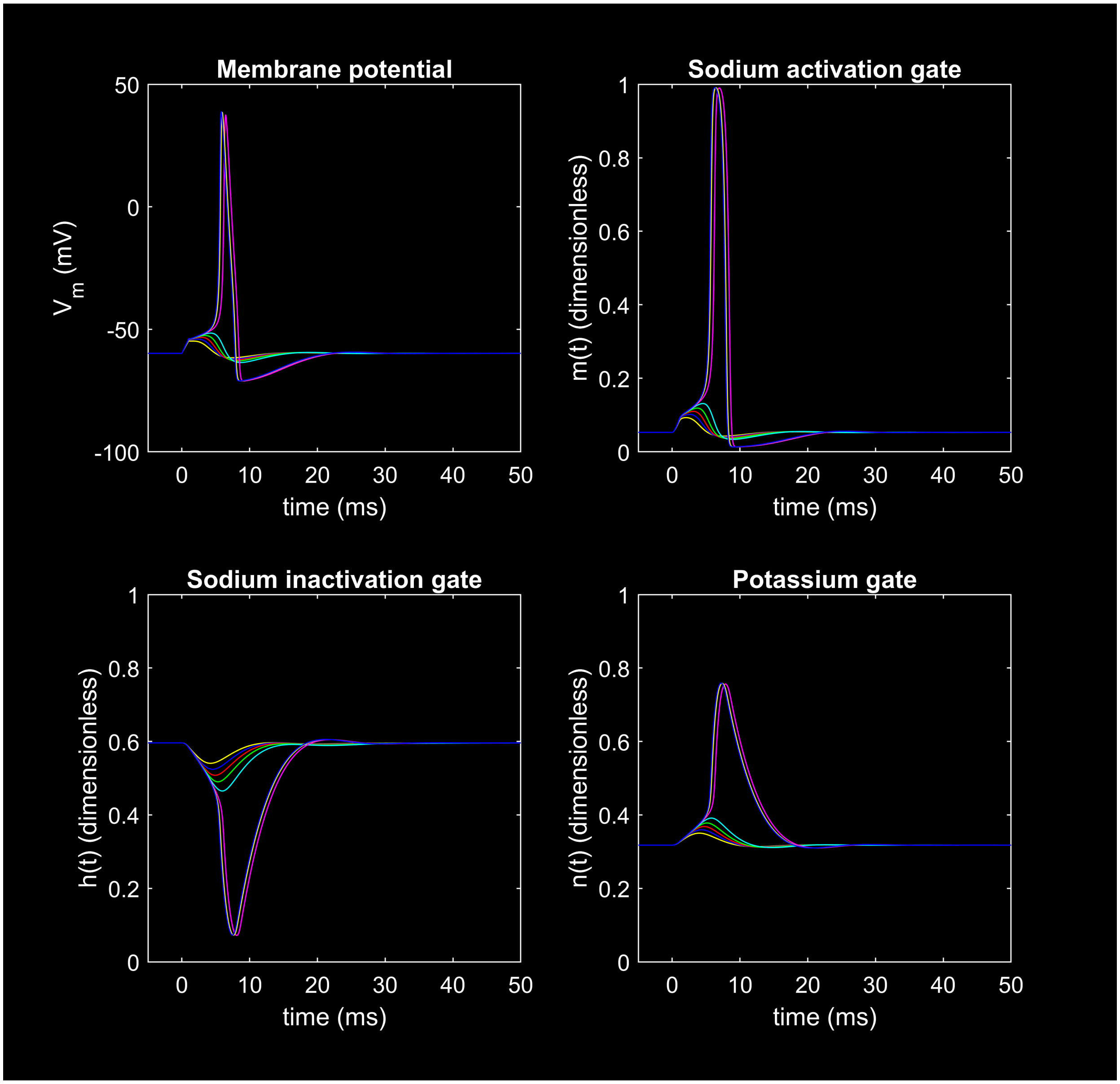
1. Threshold

Question 01

```
hhconst;
amp1 = 6;
width1 = 1;
hhmplot(0,50,0);

for i = 1:7

    display(amp1);
    amp1 = (amp1+7)/2;
    hhmplot(0,50,i)
end
```

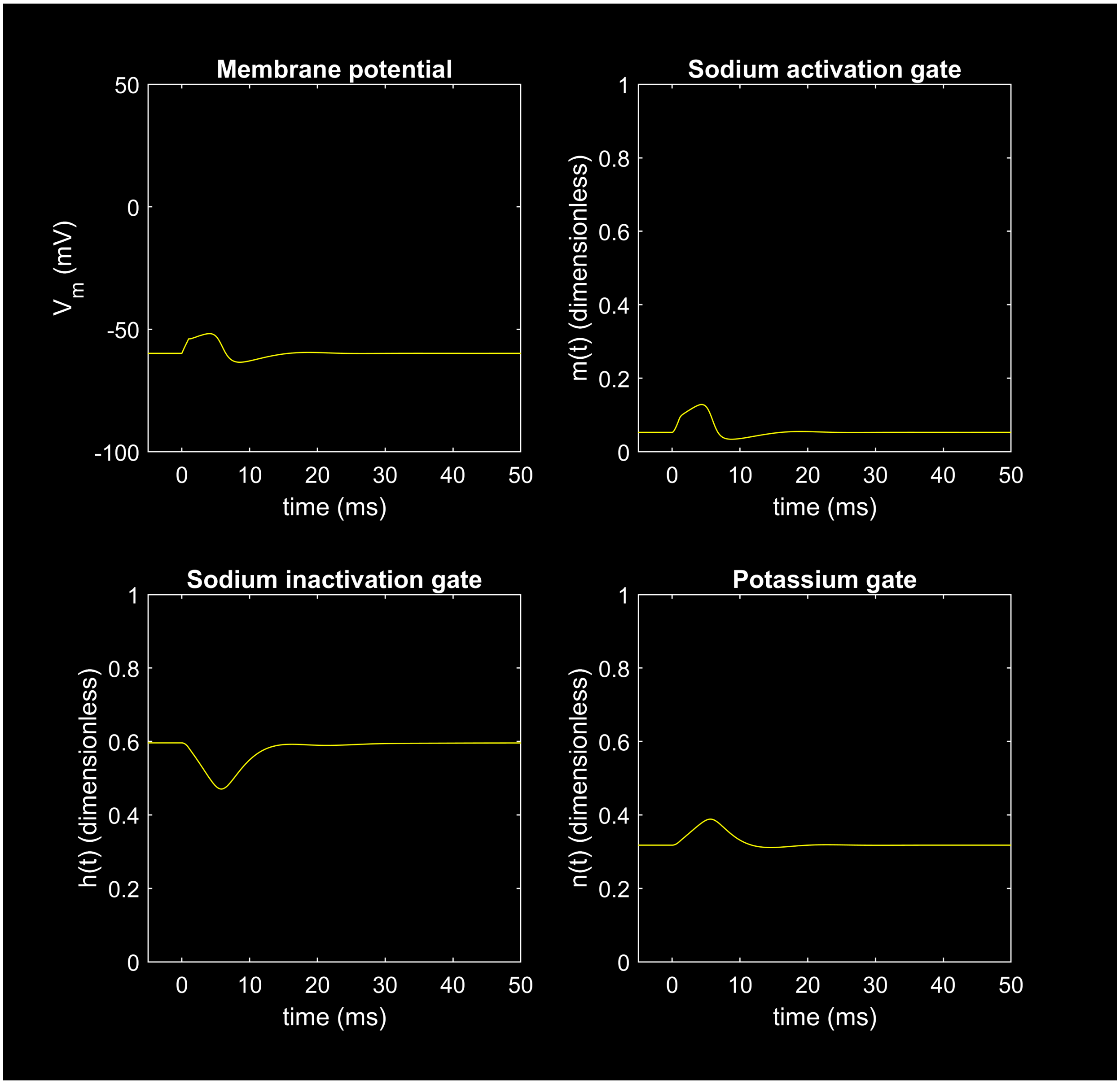
```
amp1 = 6
amp1 = 6.5000
amp1 = 6.7500
amp1 = 6.8750
amp1 = 6.9375
amp1 = 6.9688
amp1 = 6.9844
```



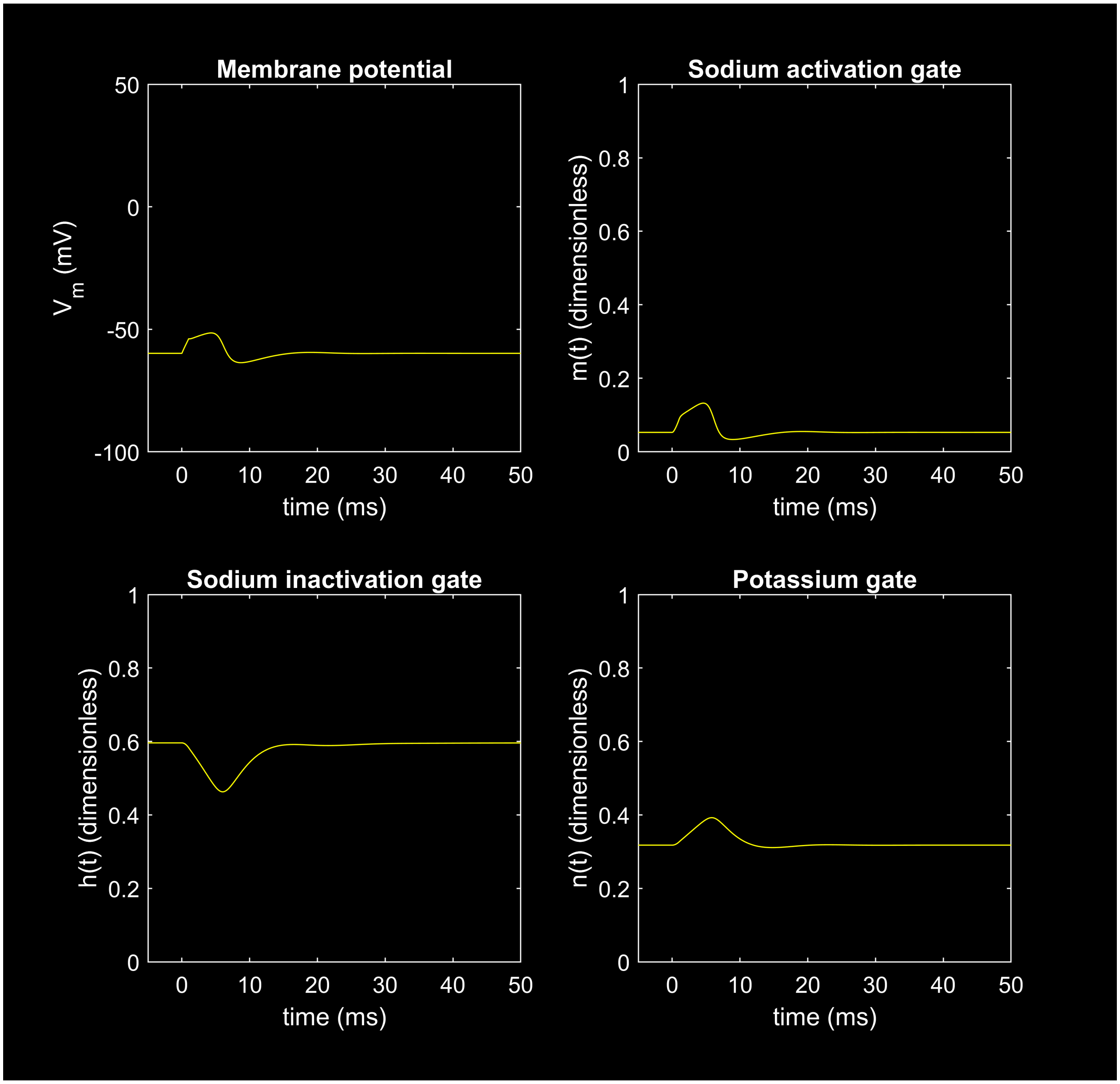
From this graphs we can observe that the amplitudes below 6.9375 are not enough to pass the threshold value and reach the action potential. Therefore the threshold value should closer to 6.9375

Let us now obtain graphs for amp1 = 6.9 and larger values.

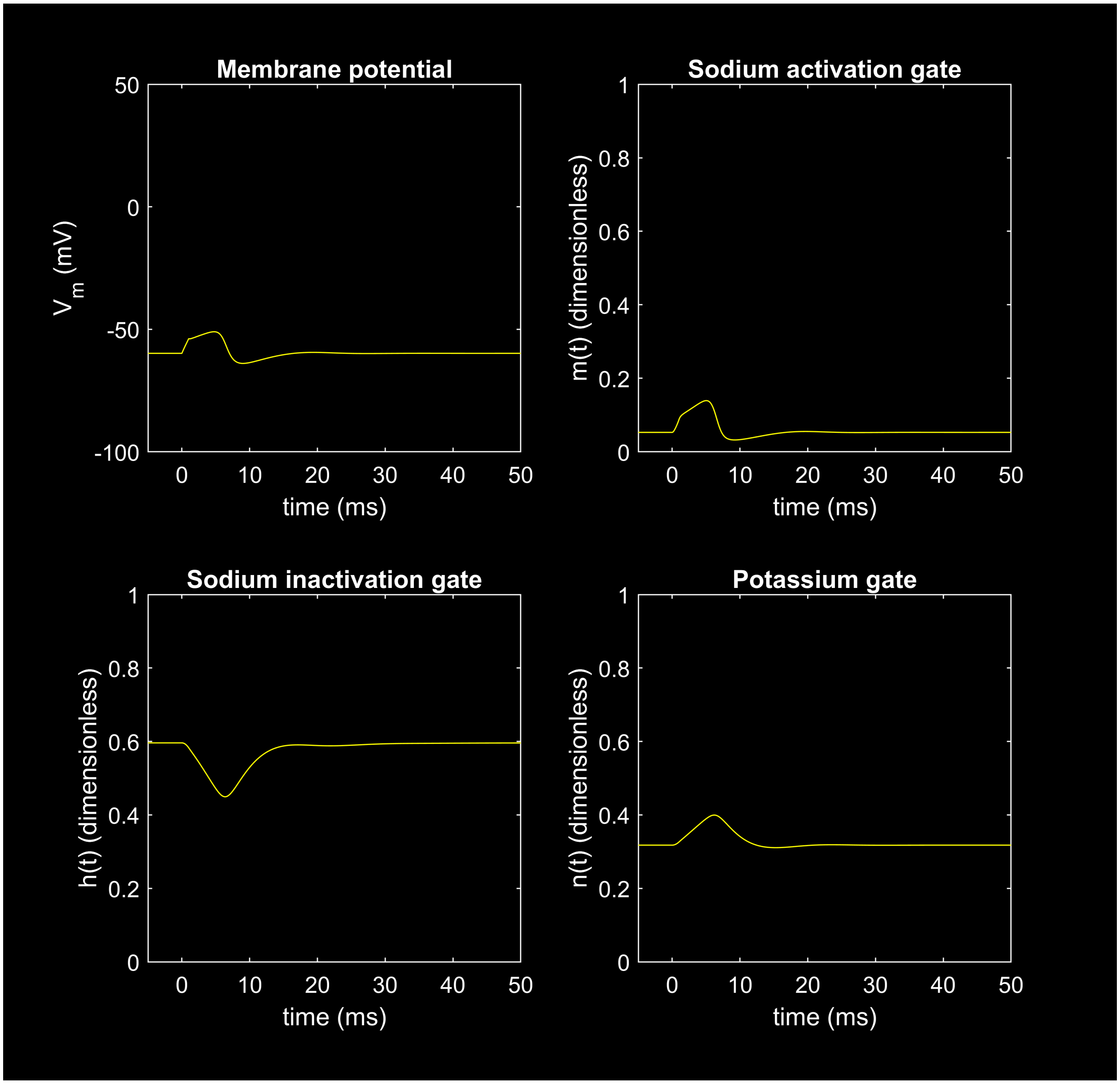
```
amp1 = 6.93;
width1 = 1;
hhmplot(0,50,0);
```



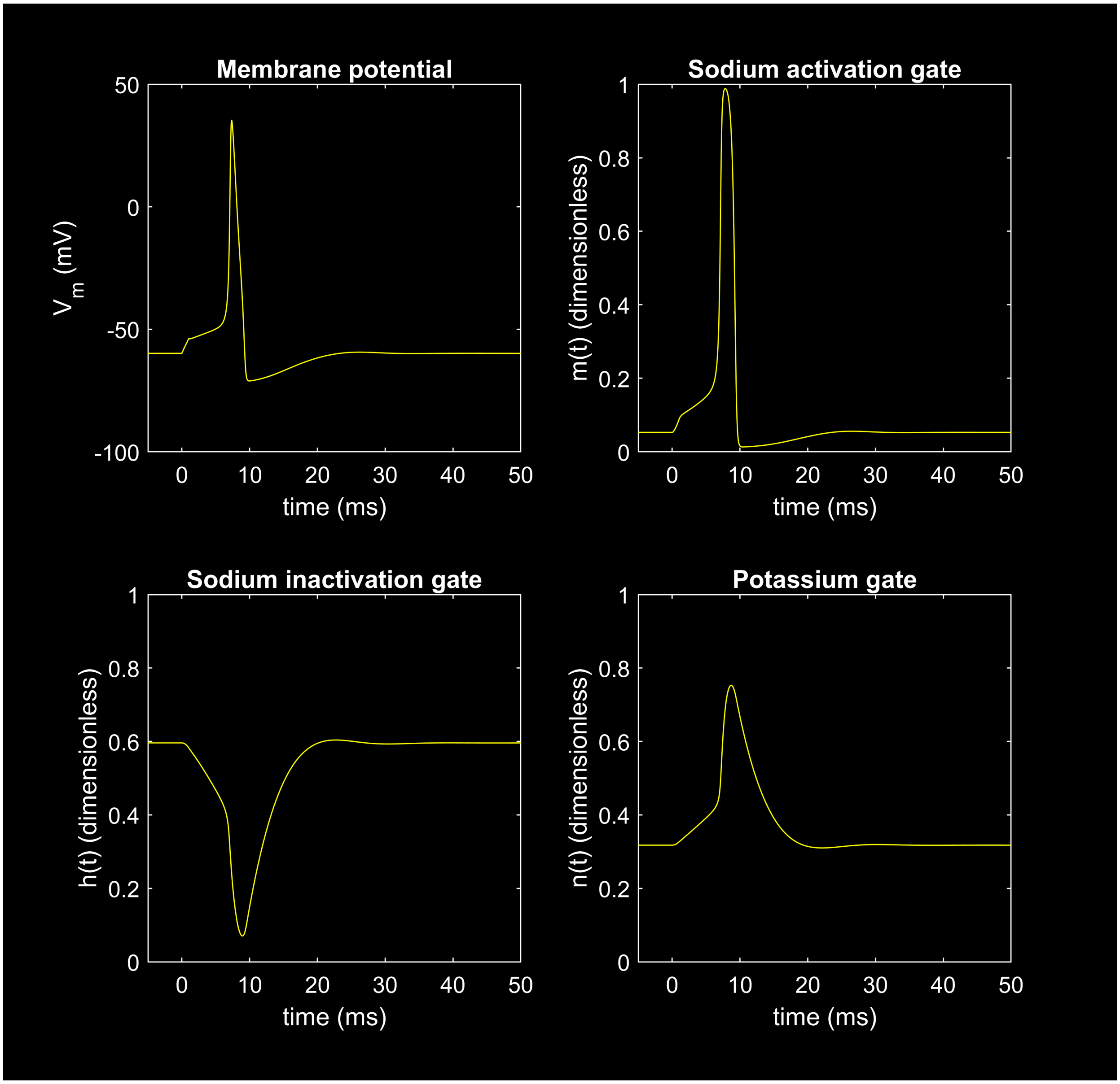

```
amp1 = 6.94;
width1 = 1;
hhmplot(0,50,0);
```




```
amp1 = 6.95;
width1 = 1;
hhmplot(0,50,0);
```




```
amp1 = 6.96;
width1 = 1;
hhmplot(0,50,0);
```

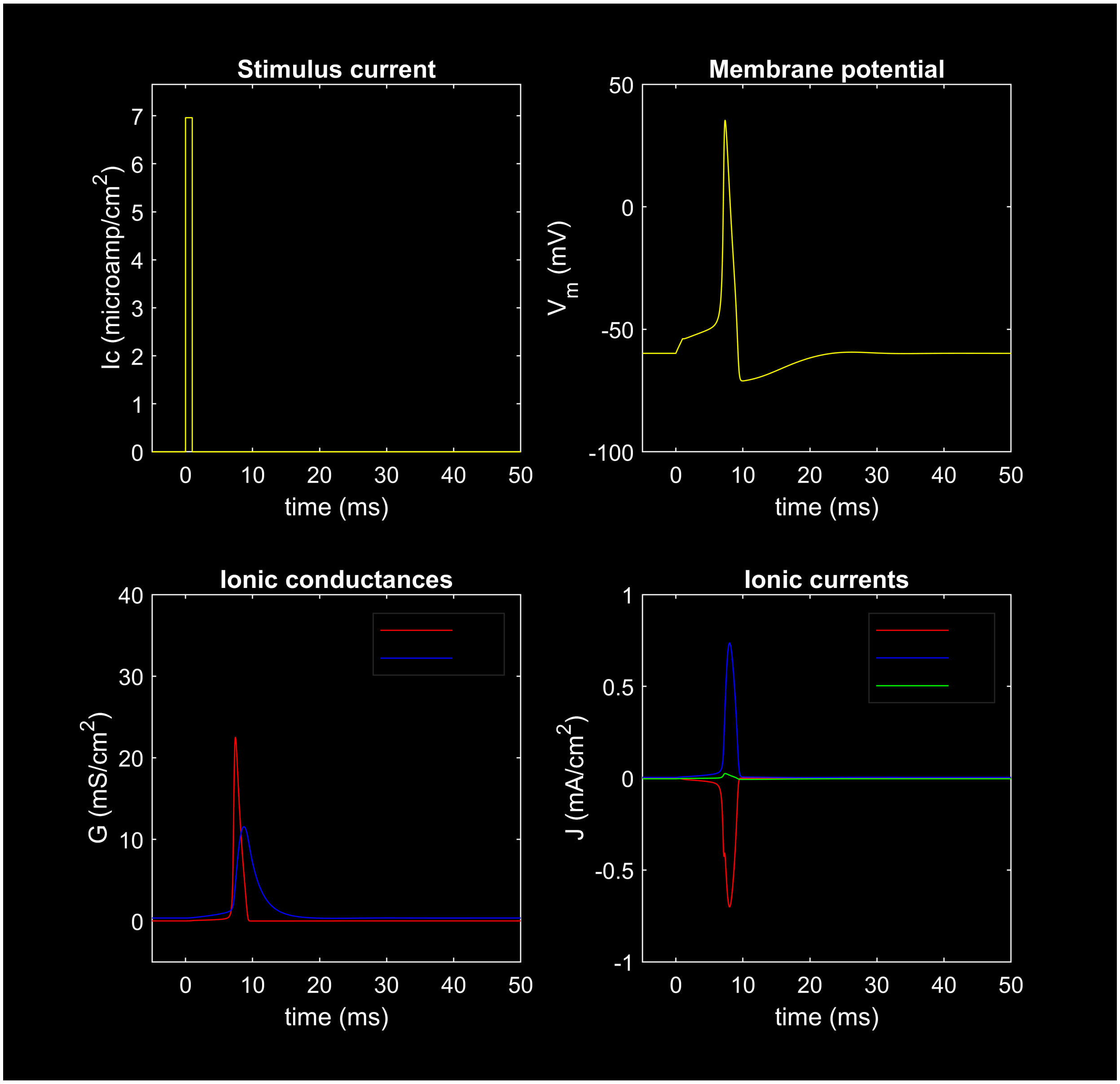


Therefore we can select 6.96 as the threshold value

Question 02

```
hhconst
width1 = 1;
amp1 = 6.9;

for n = 1:7
    [qna, qk, ql] = hhsplot(0, 50);
    disp(amp1);
    sumOfjie = width1 * amp1
    total_current = qna + qk + ql
    disp('----------------------------------------');
    amp1 = amp1 + 0.01;
end
```

```
    6.9000
sumOfjie = 6.9000
total_current = 6.8998
----------------------------------------
    6.9100
sumOfjie = 6.9100
total_current = 6.9100
----------------------------------------
    6.9200
sumOfjie = 6.9200
total_current = 6.9199
----------------------------------------
    6.9300
sumOfjie = 6.9300
total_current = 6.9300
----------------------------------------
    6.9400
sumOfjie = 6.9400
total_current = 6.9399
----------------------------------------
    6.9500
sumOfjie = 6.9500
total_current = 6.9500
----------------------------------------
```




```
    6.9600
sumOfjie = 6.9600
total_current = 6.9620
----------------------------------------
```

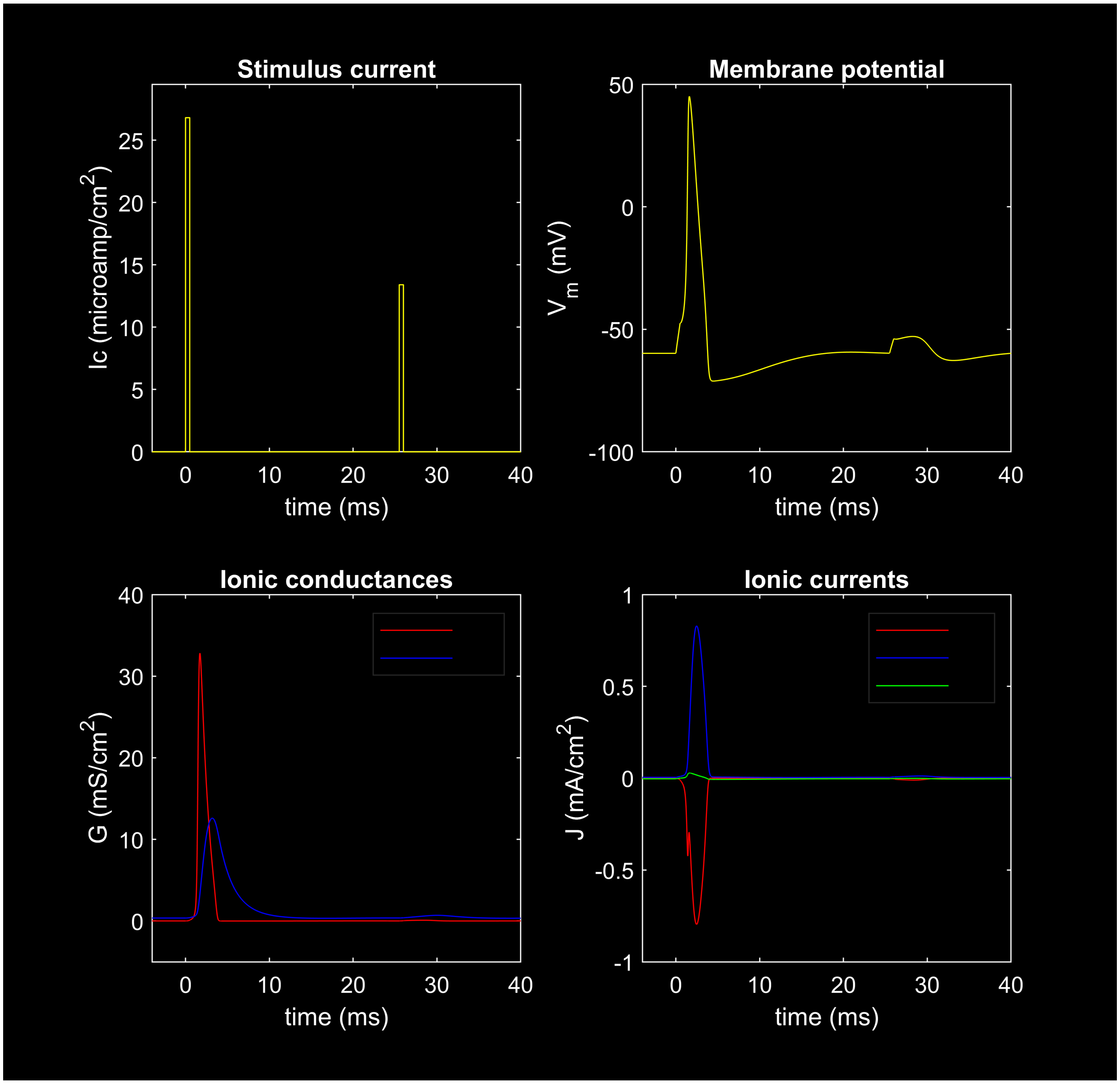
By observing the values we can say that $\int_{t_o}^{t_f} \sum_k J_k \, dt$ and $\int_{t_o}^{t_f} J_{ei} \, dt$ **are nearly equal.**

2.Refractoriness

Question 03

a) Delay = 25ms

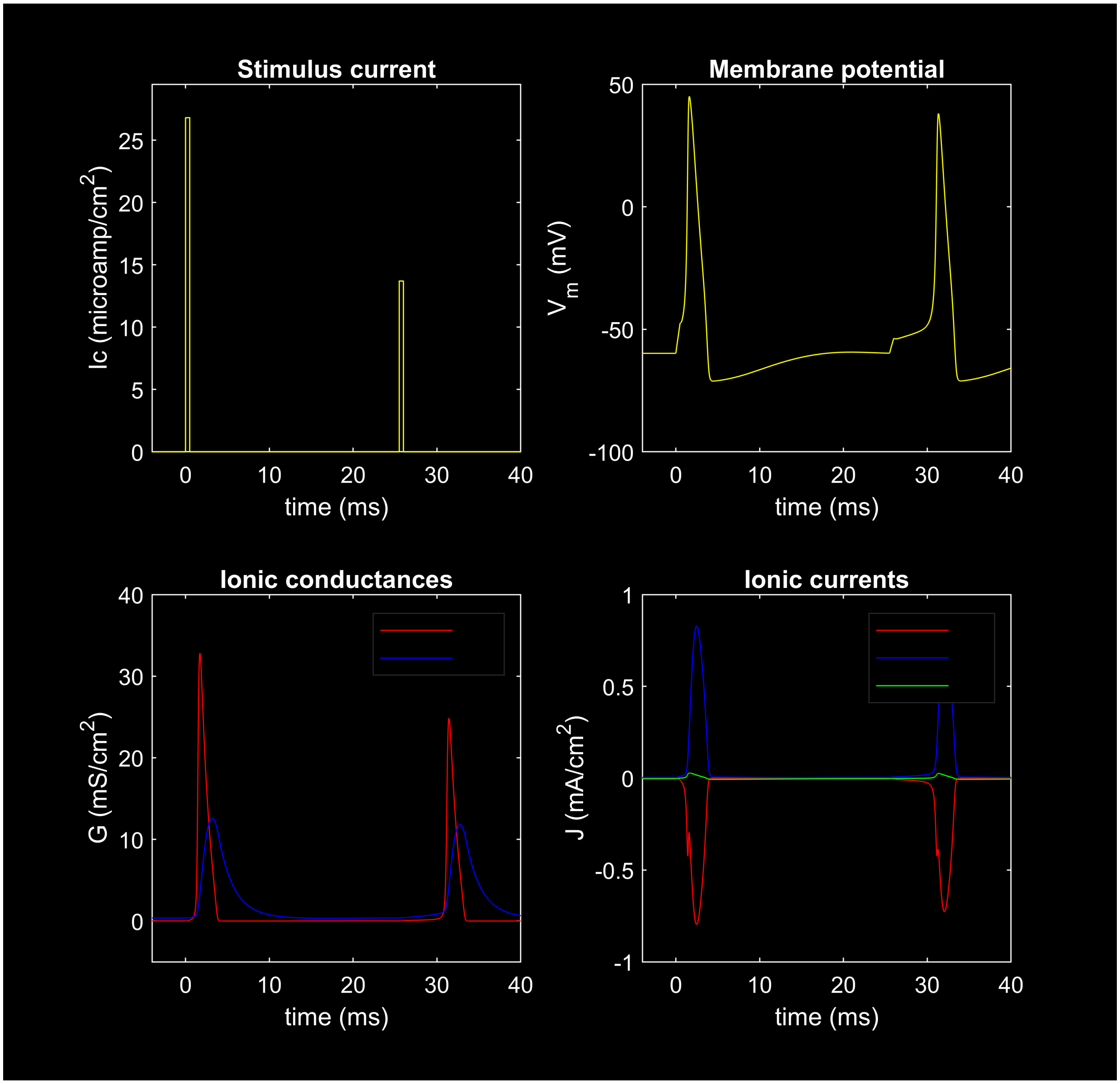
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 25;
amp2 = 13.4;
width2 = 0.5;
hhsplot(0,40);
```



In here 13.4 µAcm^(-2) is not enough to generate action potential for the second pulse. Therefore we will use 13.7 µAcm^(-2).

```
amp1 = 26.8;
width1 = 0.5;
delay2 = 25;
amp2 = 13.7;
```

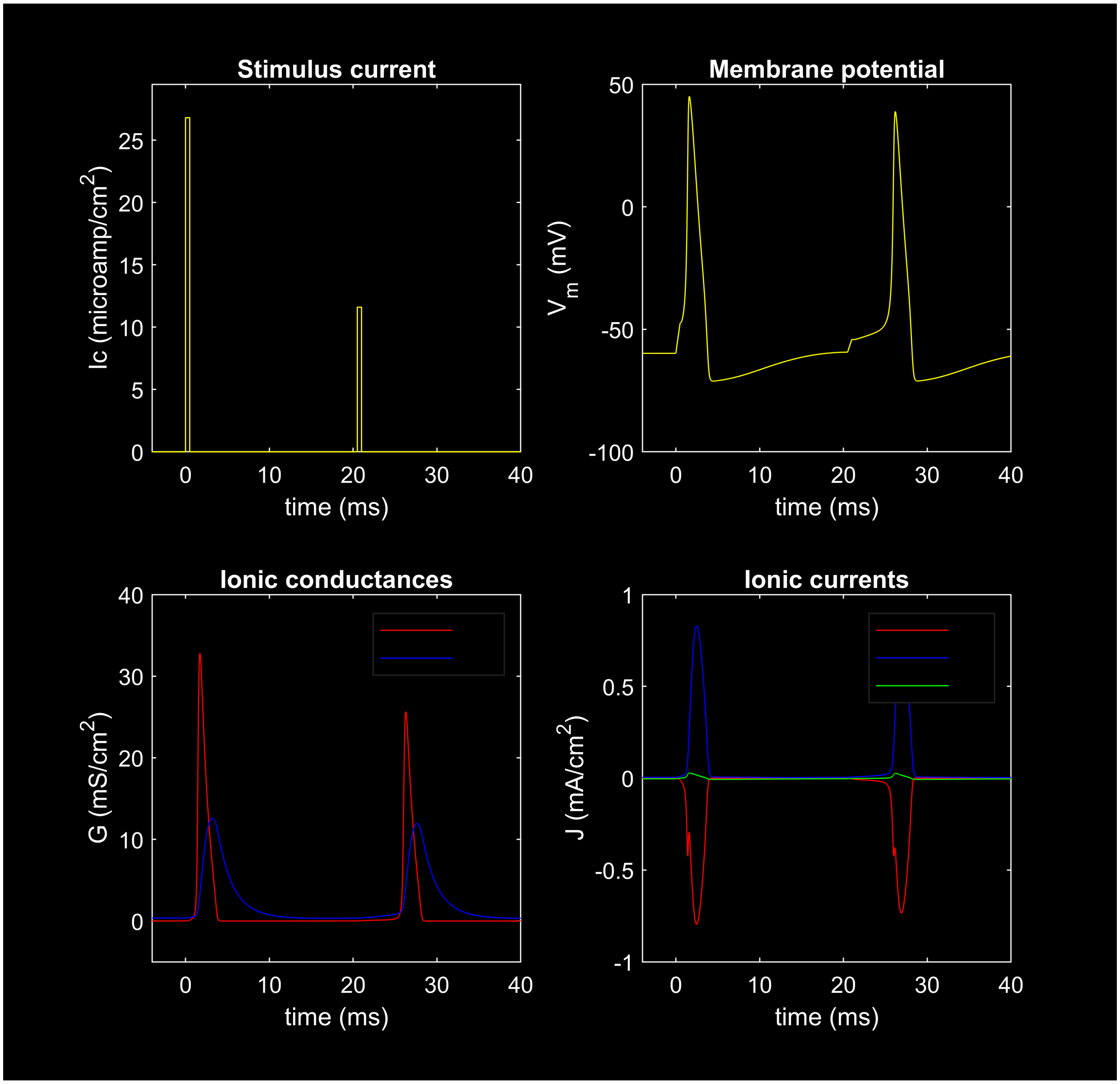
```
width2 = 0.5;
hhsplot(0,40);
```



When we use 13.7 μAcm^(-2) as the second impulse it generated an action potential .

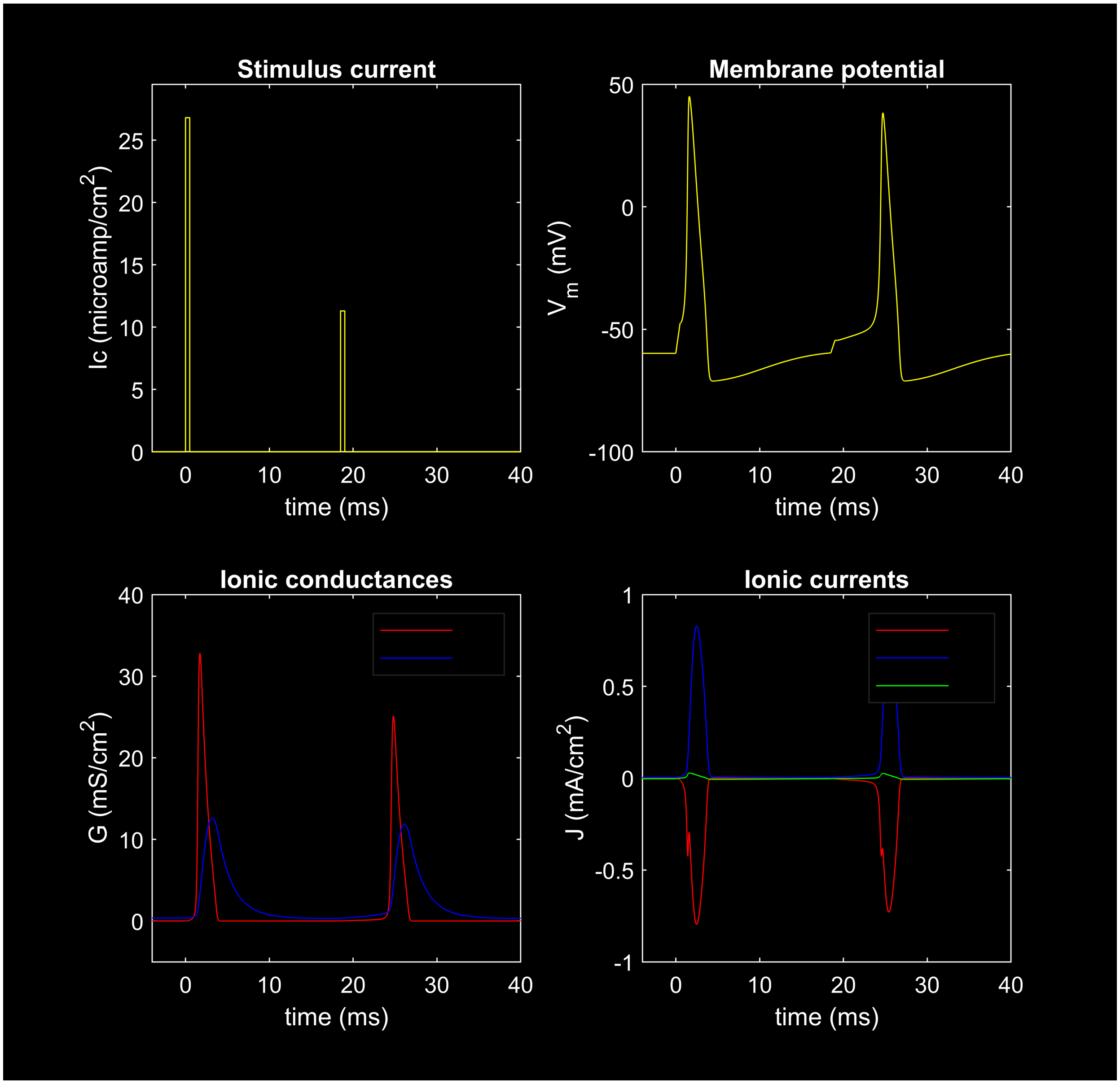
b)Delay = 20ms

```
amp1 = 26.8;
width1 = 0.5;
delay2 = 20;
amp2 = 11.6;
width2 = 0.5;
hhsplot(0,40);
```



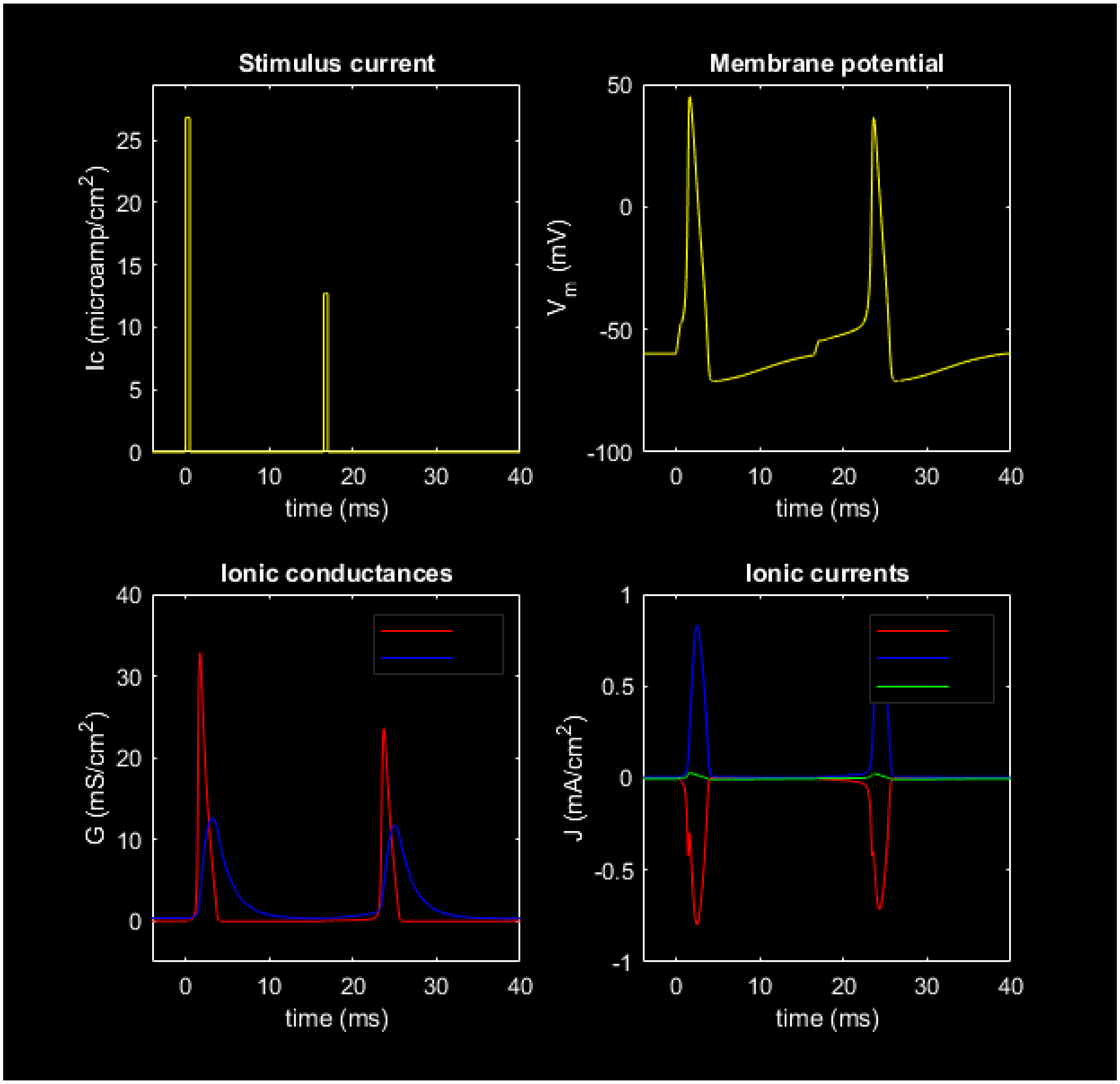
b)Delay = 18ms

```
hhconst;

amp1 = 26.8;
width1 = 0.5;
delay2 = 18;
amp2 = 11.3;
width2 = 0.5;
hhsplot(0,40);
```



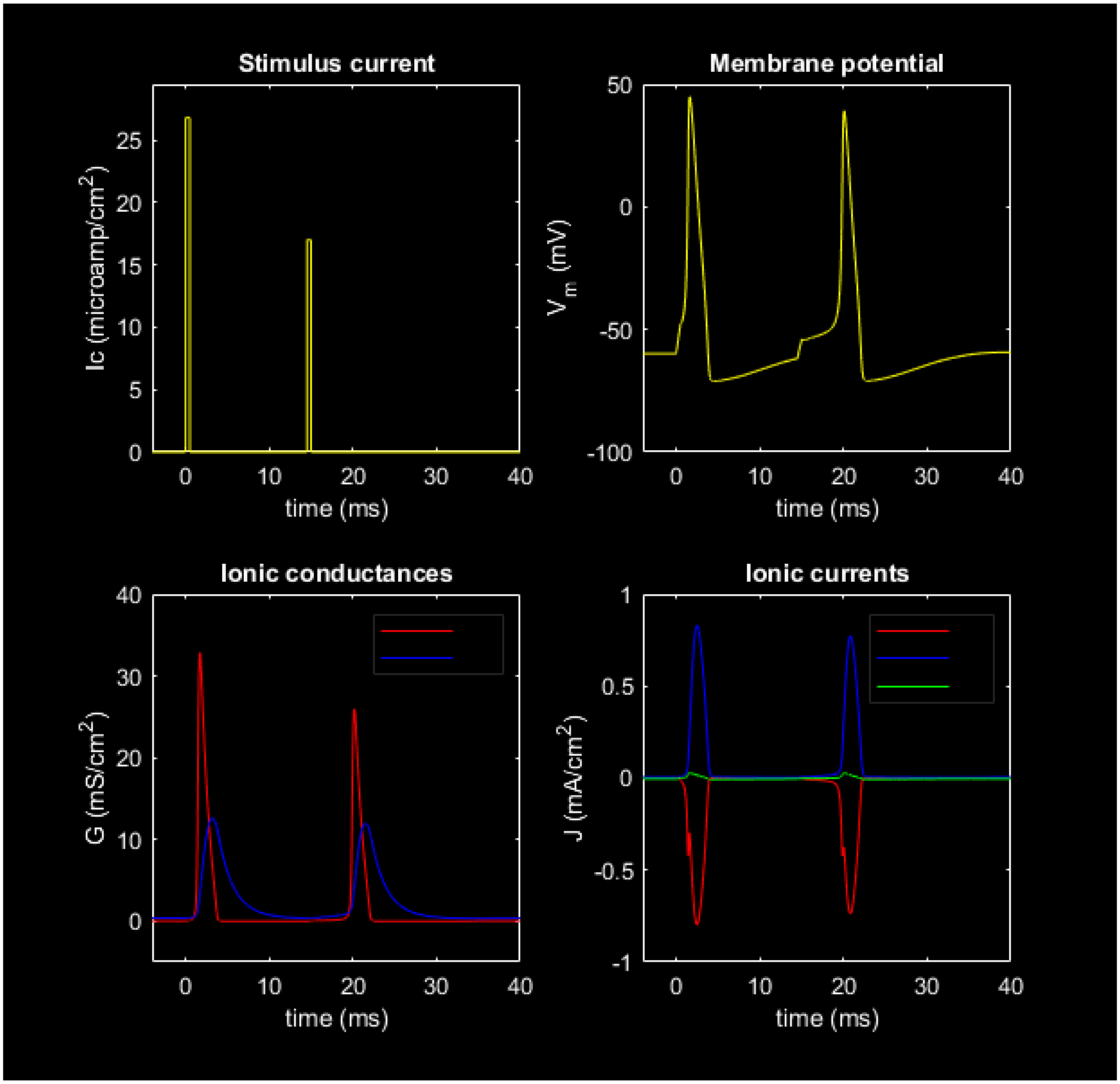
c)Delay = 16ms

```
amp1 = 26.8;
width1 = 0.5;
delay2 = 16;
amp2 = 12.7;
width2 = 0.5;
hhsplot(0,40);
```



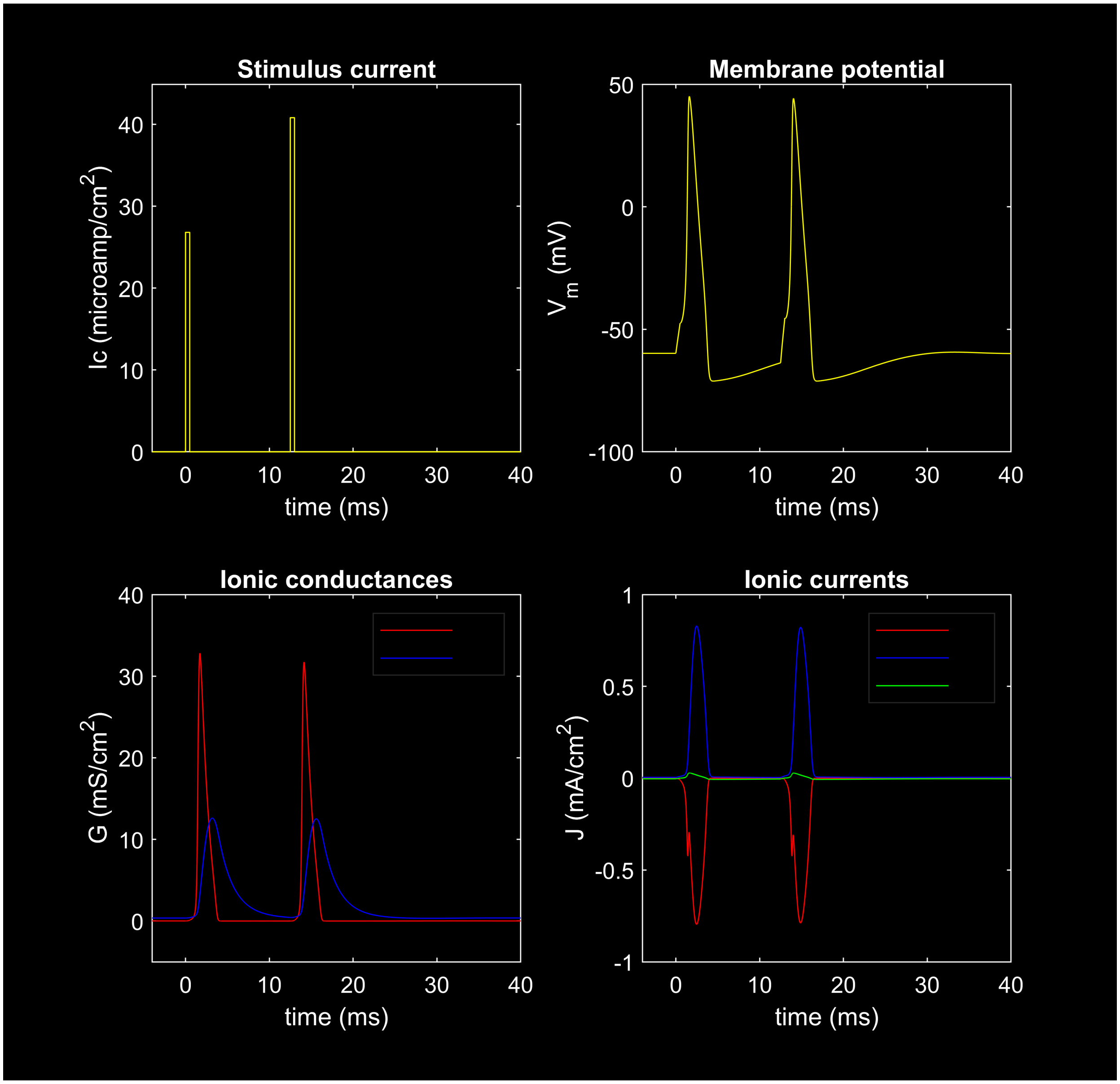
d)Delay = 14ms

```
amp1 = 26.8;
width1 = 0.5;
delay2 = 14;
amp2 = 17;
width2 = 0.5;
hhsplot(0,40);
```



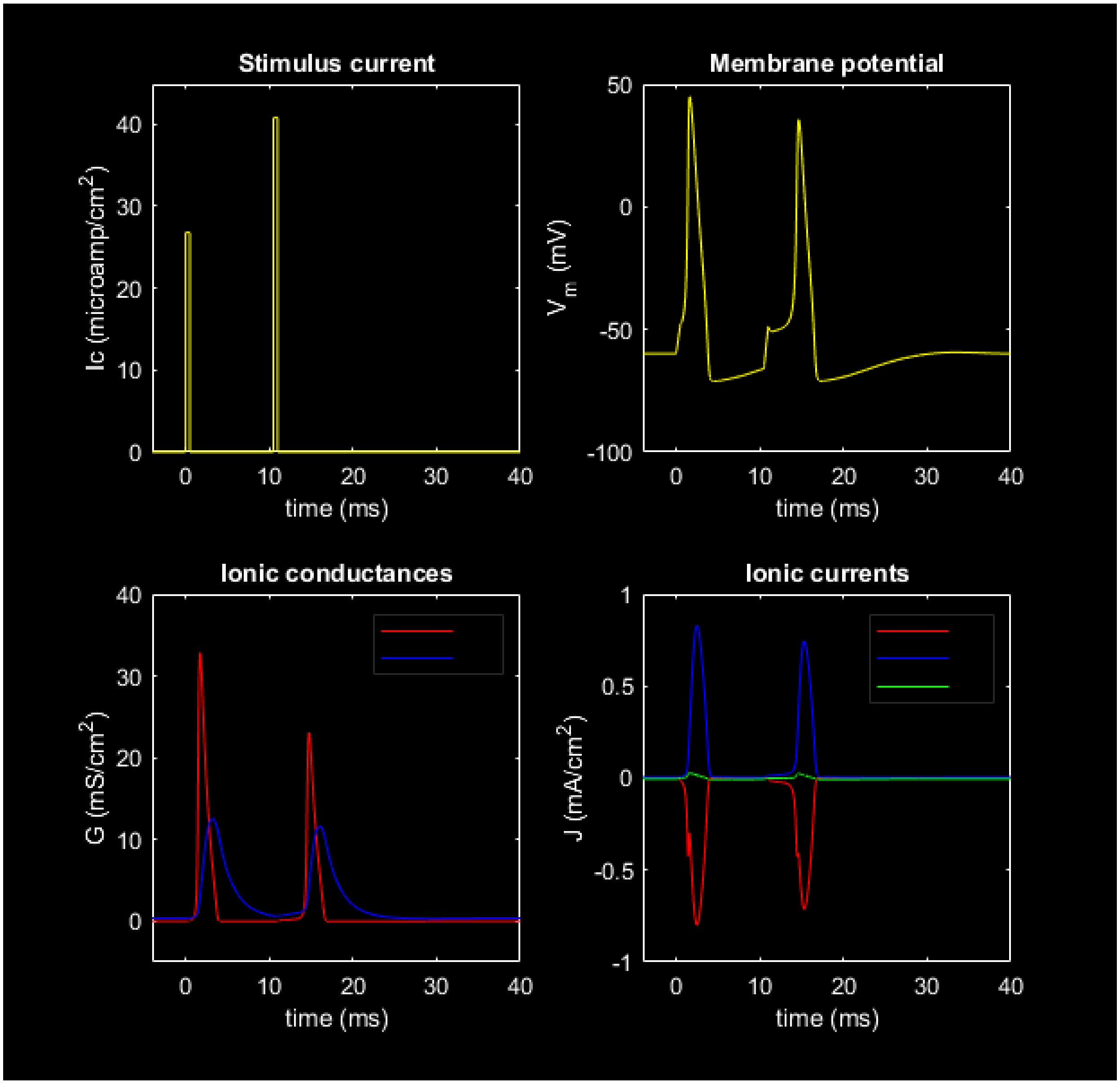
e)Delay = 12ms

```
amp1 = 26.8;
width1 = 0.5;
delay2 = 12;
amp2 = 40.8;
width2 = 0.5;
hhsplot(0,40);
```



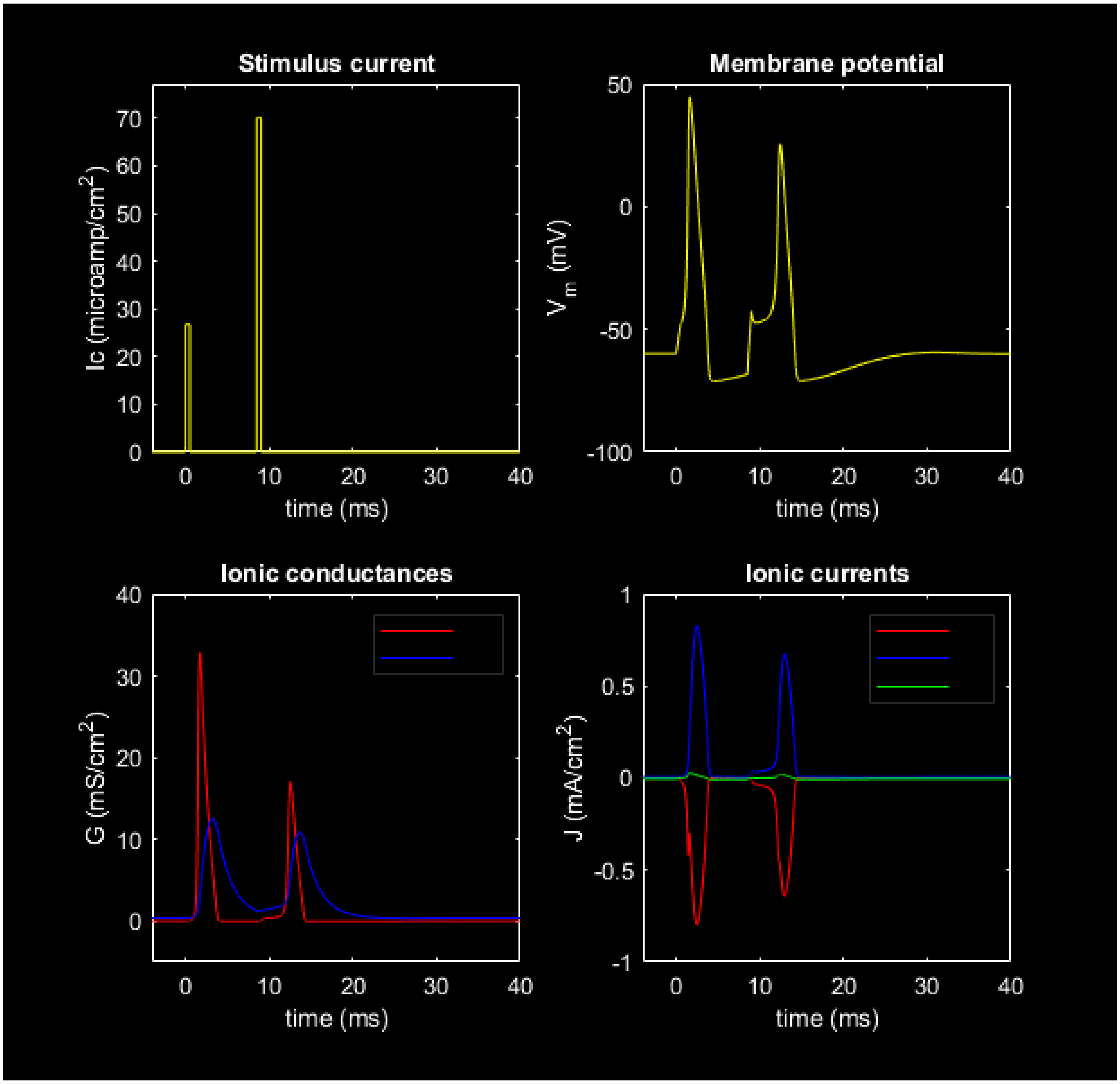
f)Delay = 10ms

```
amp1 = 26.8;
width1 = 0.5;
delay2 = 10;
amp2 = 40.8;
width2 = 0.5;
hhsplot(0,40);
```



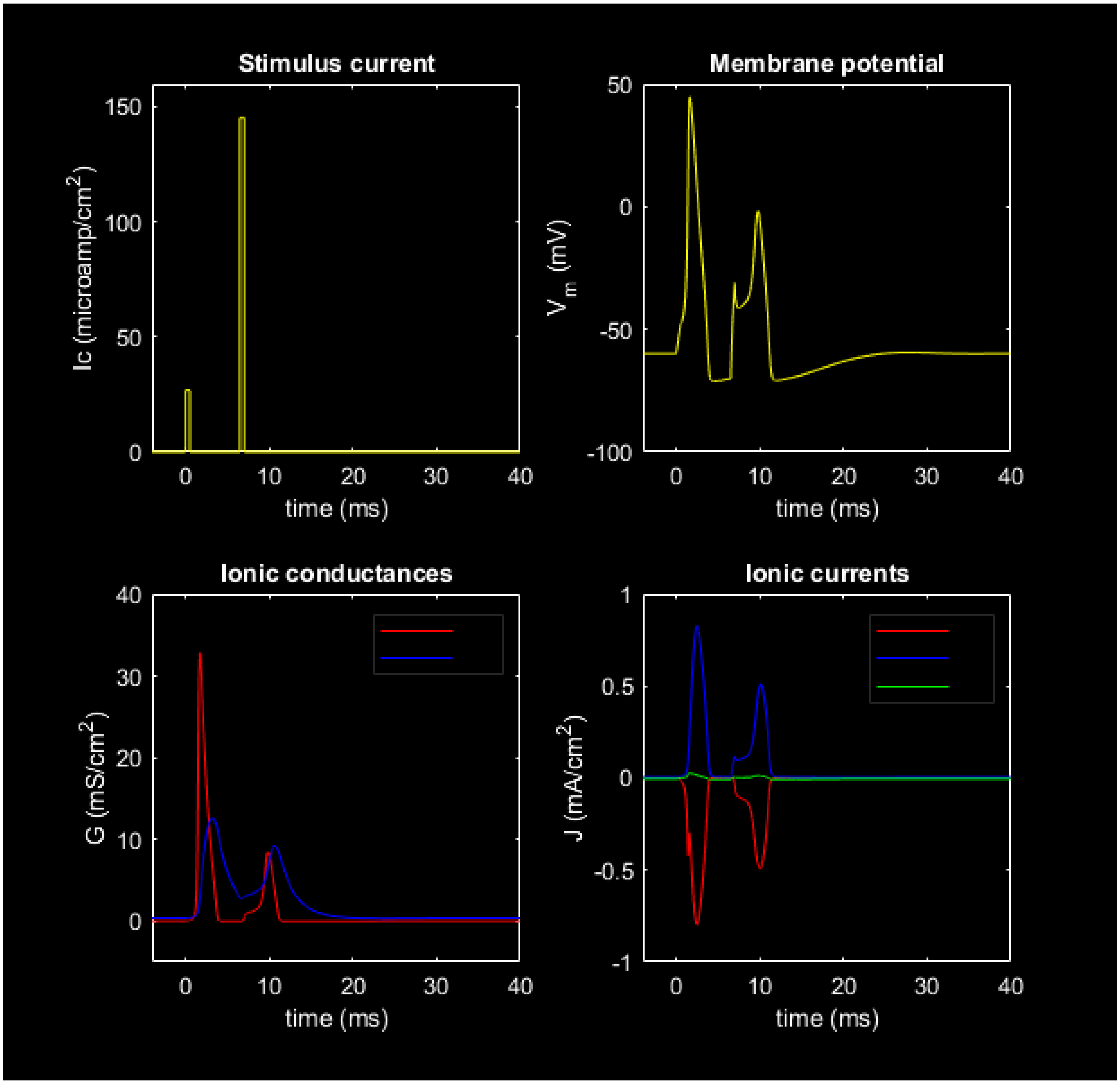
g)Delay = 8ms

```
amp1 = 26.8;
width1 = 0.5;
delay2 = 8;
amp2 = 70.1;
width2 = 0.5;
hhsplot(0,40);
```



h)Delay = 6 ms

```
amp1 = 26.8;
width1 = 0.5;
delay2 = 6;
amp2 = 145.2;
width2 = 0.5;
hhsplot(0,40);
```



Above calculations and results in summary

```
delay = [6;8;10;12;14;16;18;20;25];
I2 = [145.2;70.1;40.8;25.5;17;12.7;11.3;11.6;13.7]
```

```
I2 = 9×1
  145.2000
   70.1000
   40.8000
   25.5000
   17.0000
   12.7000
   11.3000
   11.6000
   13.7000
```

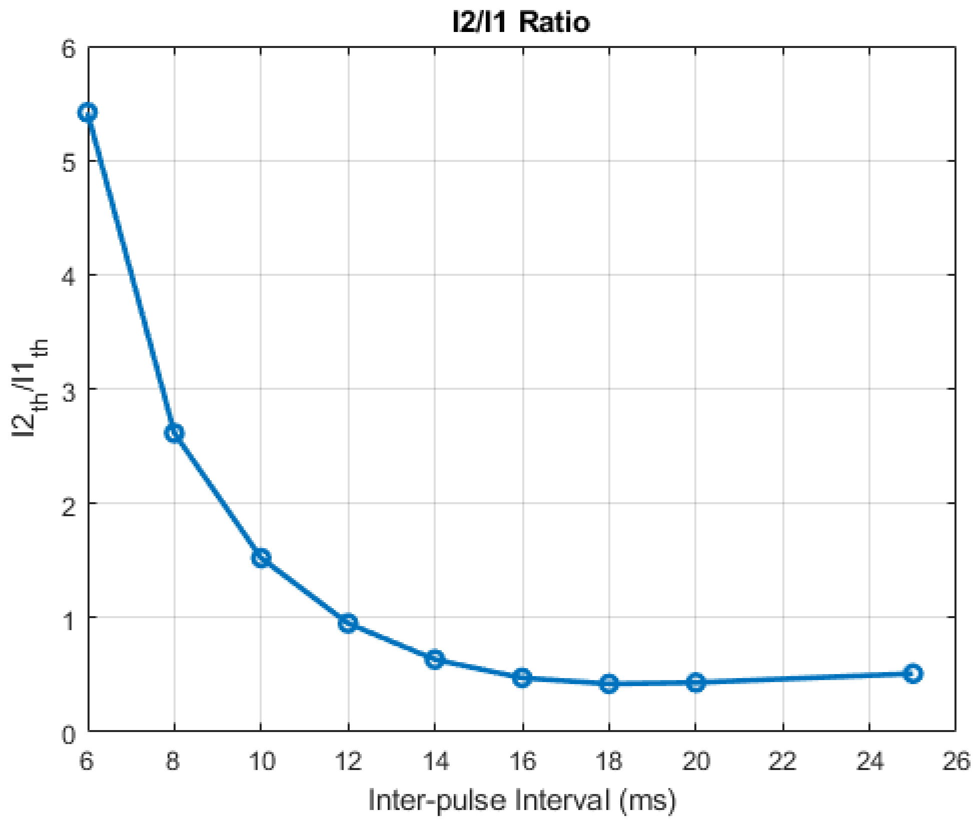
```
T = table(delay,I2)
```

T = 9×2 table

	delay	I2
1	6	145.2000
2	8	70.1000
3	10	40.8000
4	12	25.5000
5	14	17
6	16	12.7000
7	18	11.3000
8	20	11.6000
9	25	13.7000

Question 03

```
delay = [6; 8; 10; 12; 14; 16; 18; 20; 25];
I2 = [145.2; 70.1; 40.8; 25.5; 17; 12.7; 11.3; 11.6; 13.7];
I1 = 26.8; % Constant value for all delays

% Calculate the ratio I2th/I1th
ratio = I2 / I1;

% Plot the ratio as a function of the inter-pulse interval
figure;
plot(delay, ratio, 'o-', 'LineWidth', 2);
xlabel('Inter-pulse Interval (ms)');
ylabel('I2_{th}/I1_{th}');
title('I2/I1 Ratio');
grid on;
```



Question 04

It is clear from looking at the graph that the required current is more than five times more than the initial threshold value at a 6 ms delay.

This suggests a 0–6 ms absolute refractory time. Furthermore, the necessary pulse drops below the original threshold value after 12 ms.

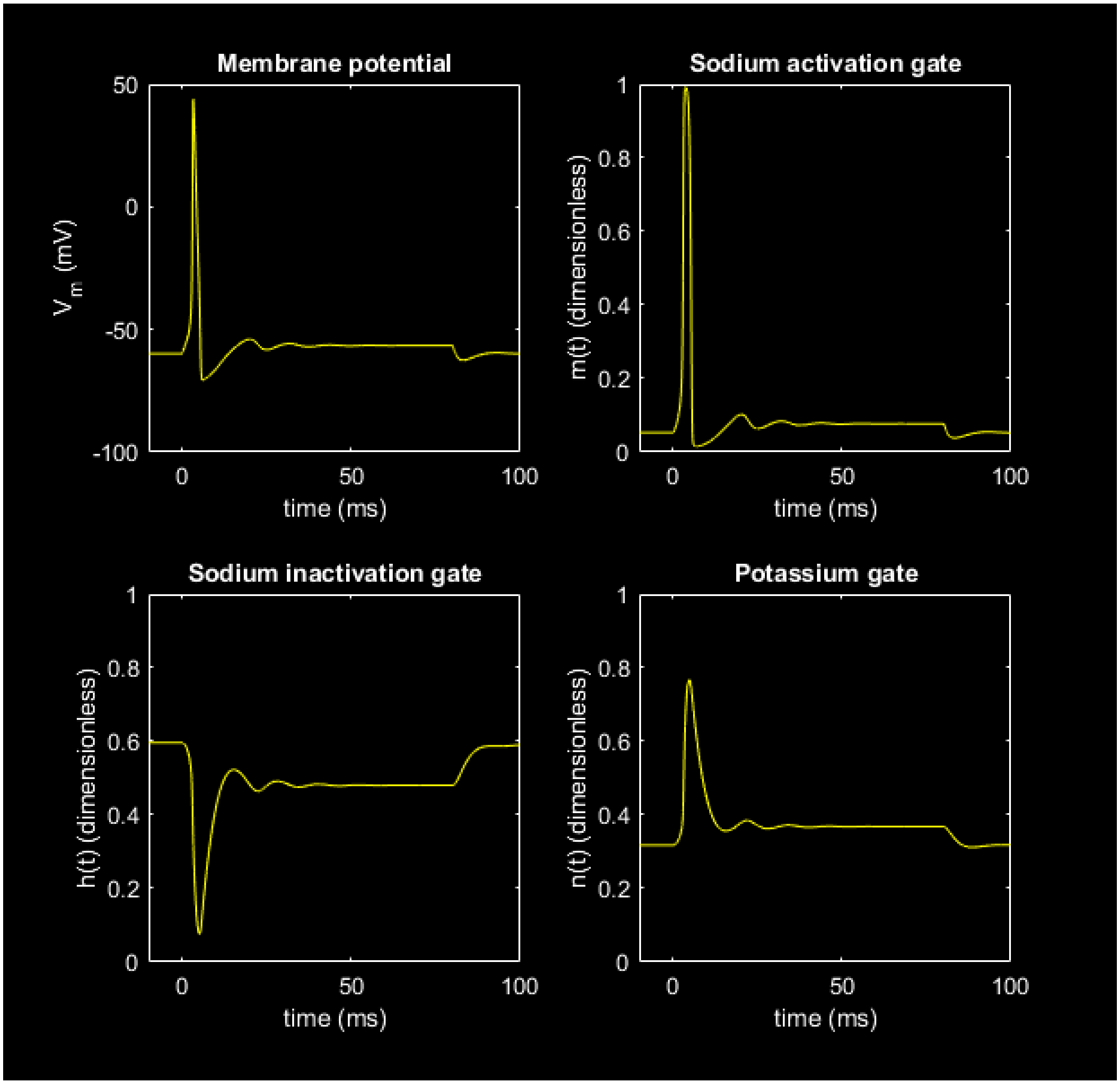
As a result, we may say that the relative refractory period is between 6 and 12 ms.

3.Repetitive Activity

Question 05

a)Amplitude = 5 µAcm^(-2)

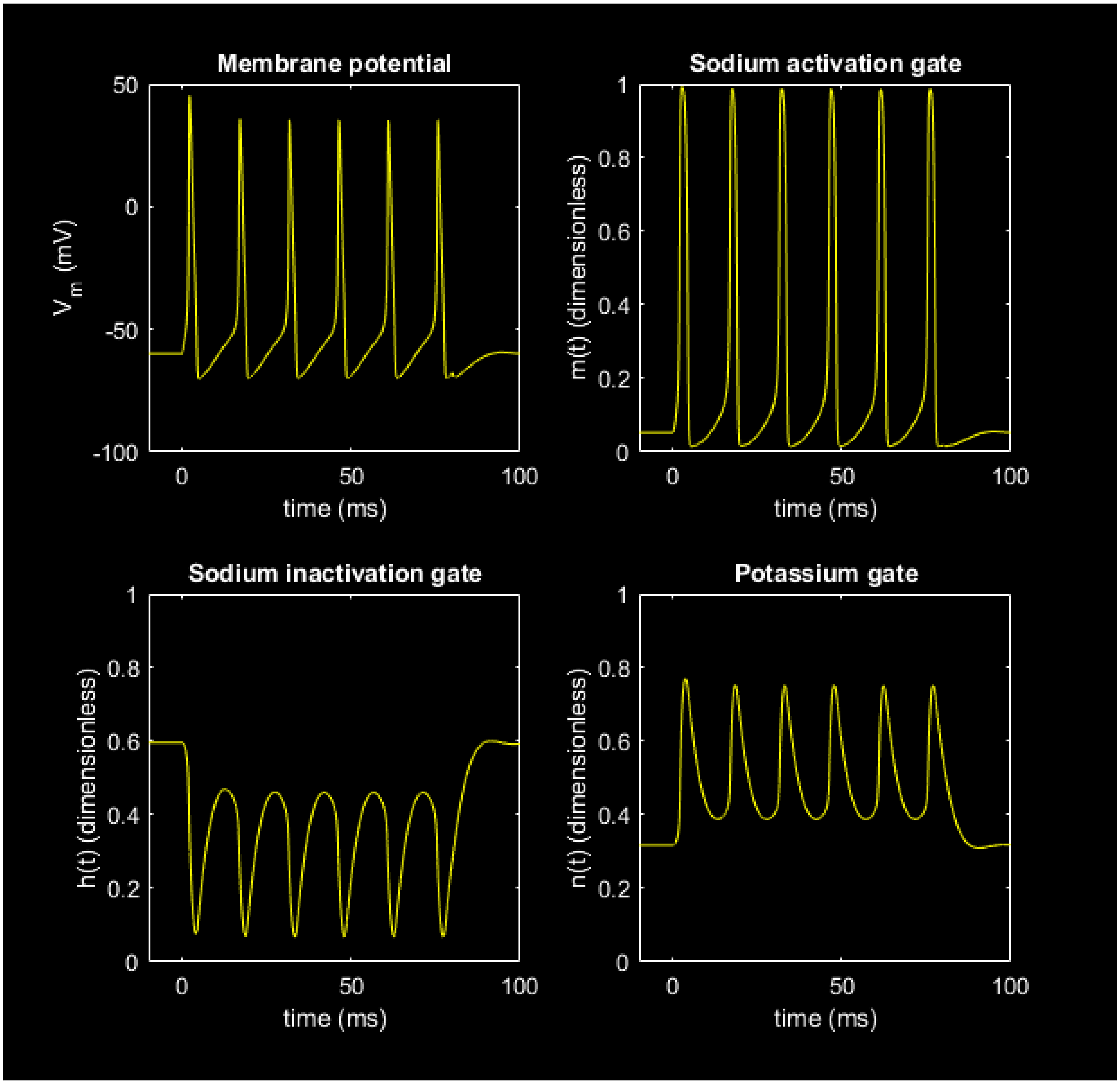
```
amp1 = 5;
width1 = 80;
delay2 = 0;
amp2 = 0;
width2 = 0;
hhmplot(0,100,0);
```



Number of Action Potentials = 1

b)Amplitude = 10 μAcm^(-2)

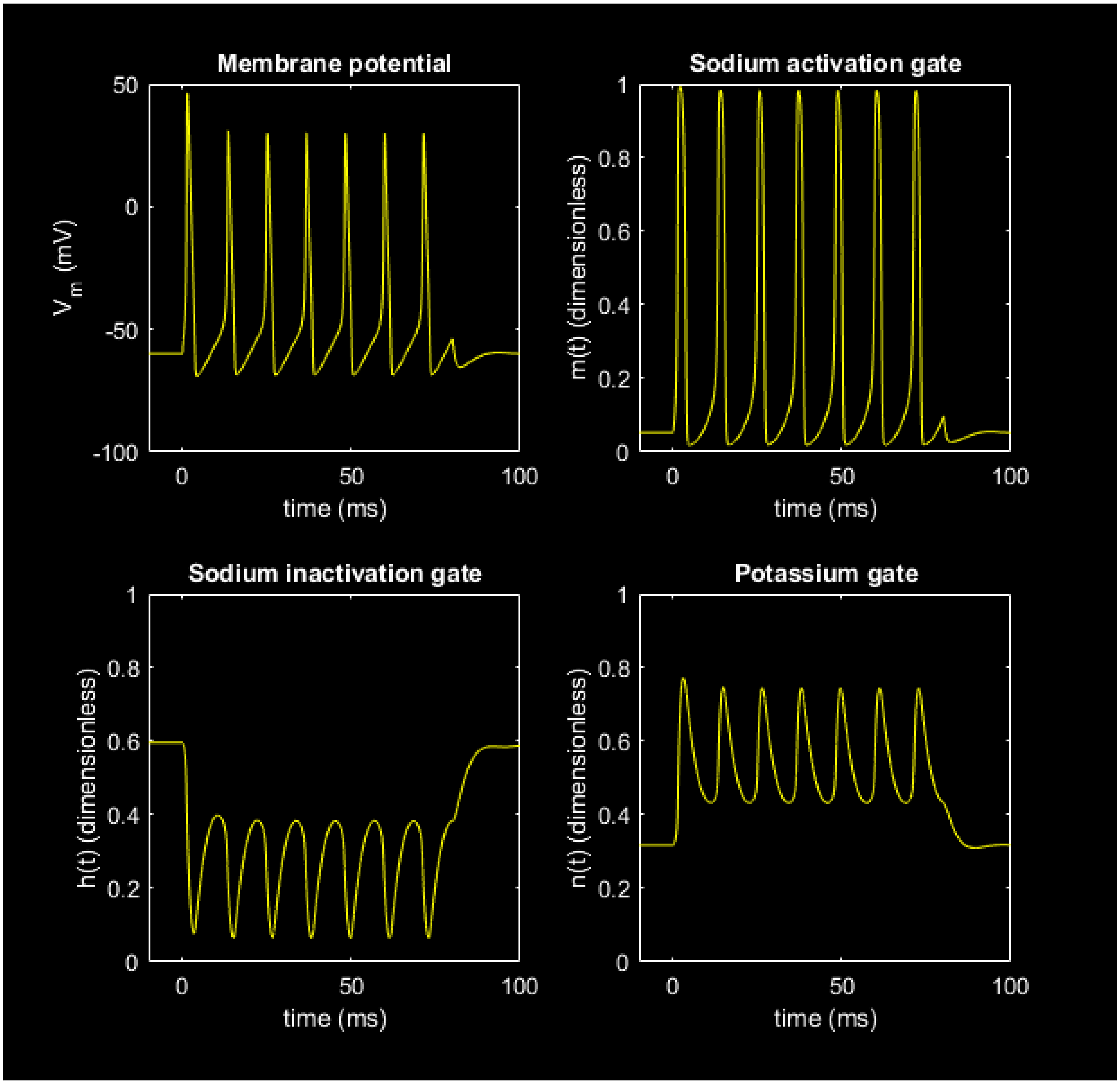
```
amp1 = 10;
width1 = 80;
delay2 = 0;
amp2 = 0;
width2 = 0;
hhmplot(0,100,0);
```



Number of Action Potentials = 6

c)Amplitude = 20 μAcm^(-2)

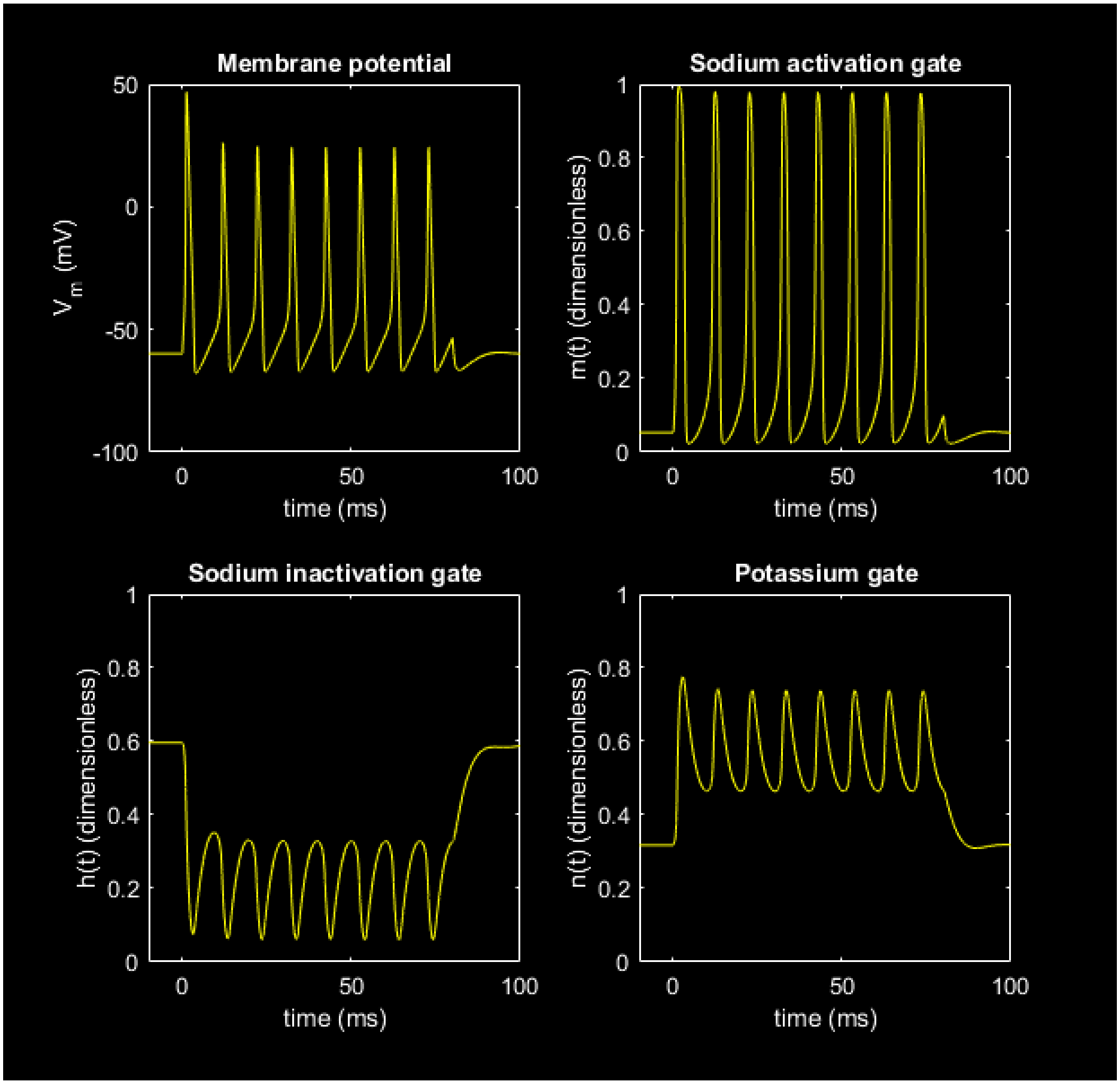
```
amp1 = 20;
width1 = 80;
delay2 = 0;
amp2 = 0;
width2 = 0;
hhmplot(0,100,0);
```



Number of Action Potentials = 7

d)Amplitude = 30 μAcm^(-2)

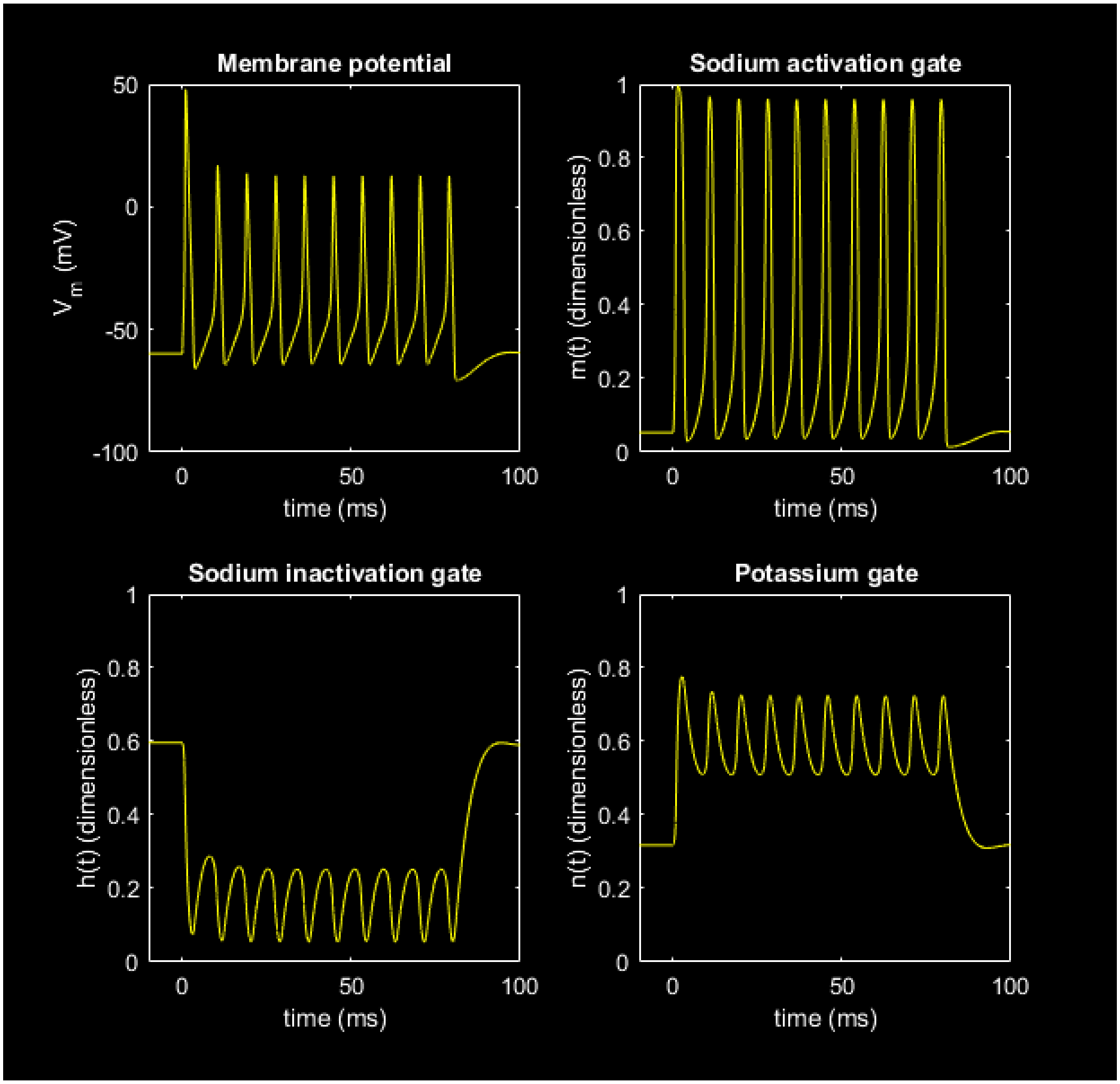
```
amp1 = 30;
width1 = 80;
delay2 = 0;
amp2 = 0;
width2 = 0;
hhmplot(0,100,0);
```



Number of Action Potentials = 8

e)Amplitude = 50 μAcm^(-2)

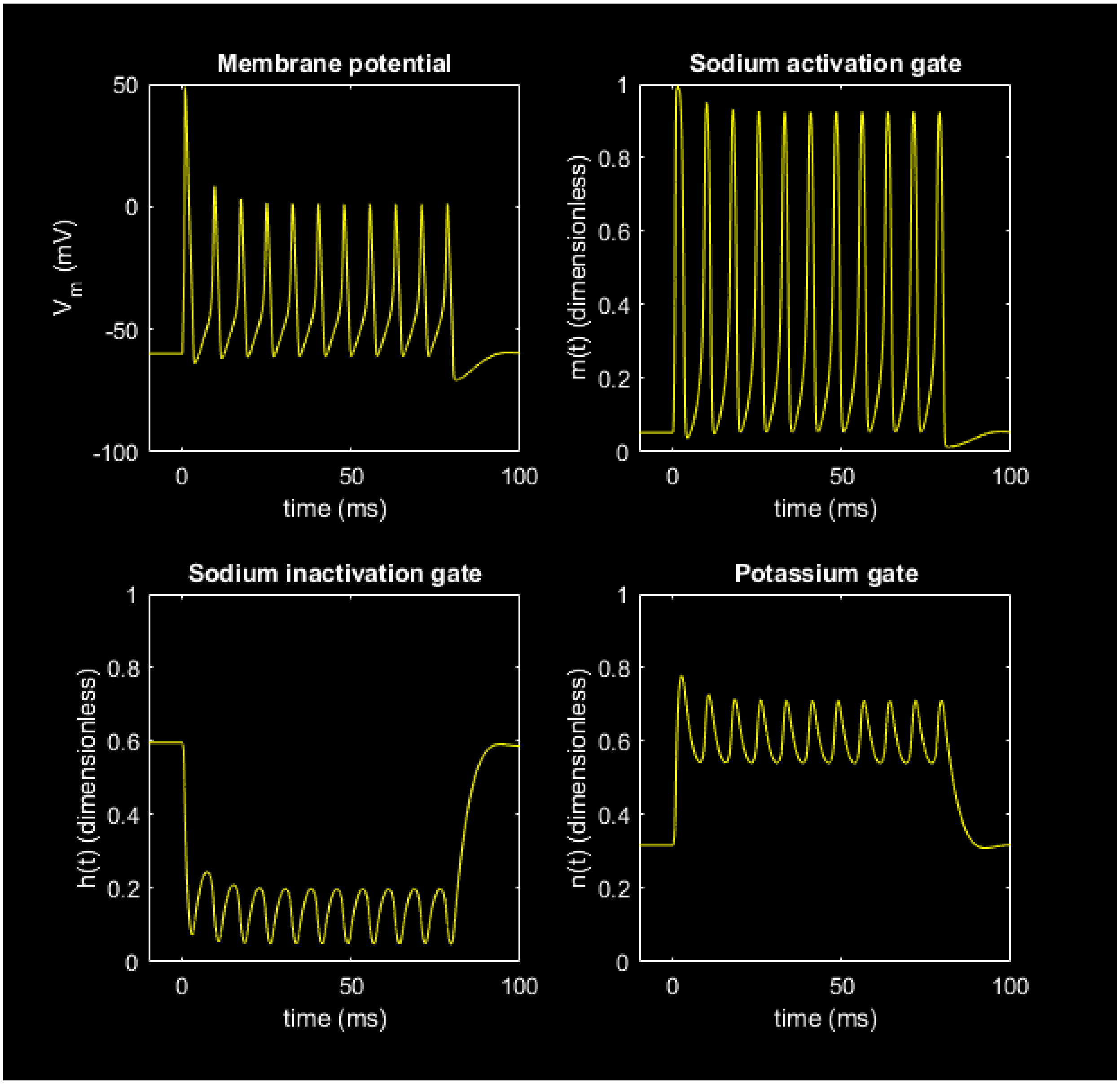
```
amp1 = 50;
width1 = 80;
delay2 = 0;
amp2 = 0;
width2 = 0;
hhmplot(0,100,0);
```



Number of Action Potentials = 10

f)Amplitude = 70 μAcm^(-2)

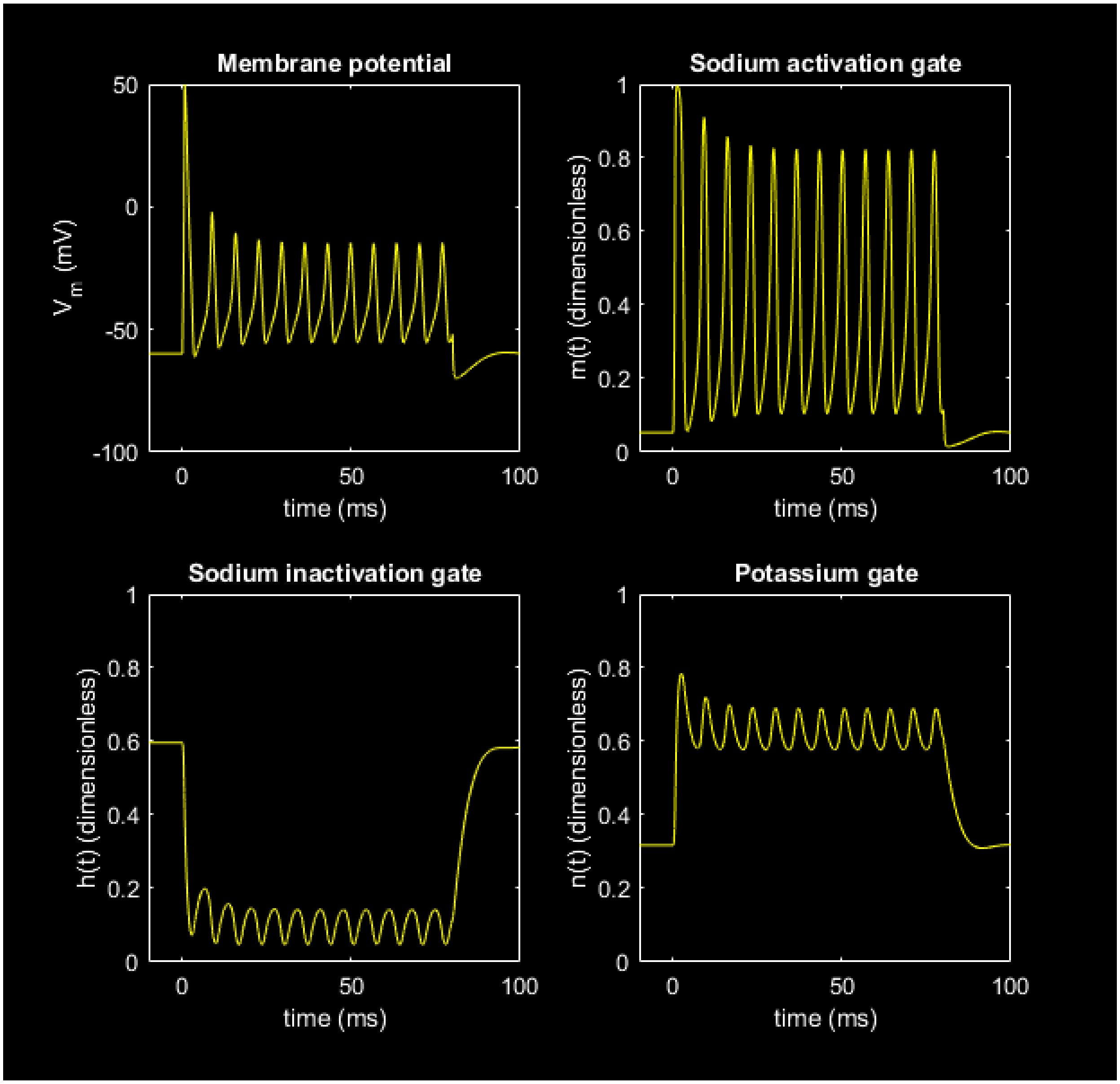
```
amp1 = 70;
width1 = 80;
delay2 = 0;
amp2 = 0;
width2 = 0;
hhmplot(0,100,0);
```



Number of Action Potentials = 11

g)Amplitude = 100 μAcm^(-2)

```
amp1 = 100;
width1 = 80;
delay2 = 0;
amp2 = 0;
width2 = 0;
hhmplot(0,100,0);
```



Number of Action Potentials = 12

Above results in summary

```
Amp = [5;10;20;30;50;70;100];
Number_of_Action_potentials =[1;6;7;8;10;11;12];
Table = table(Amp,Number_of_Action_potentials)
```

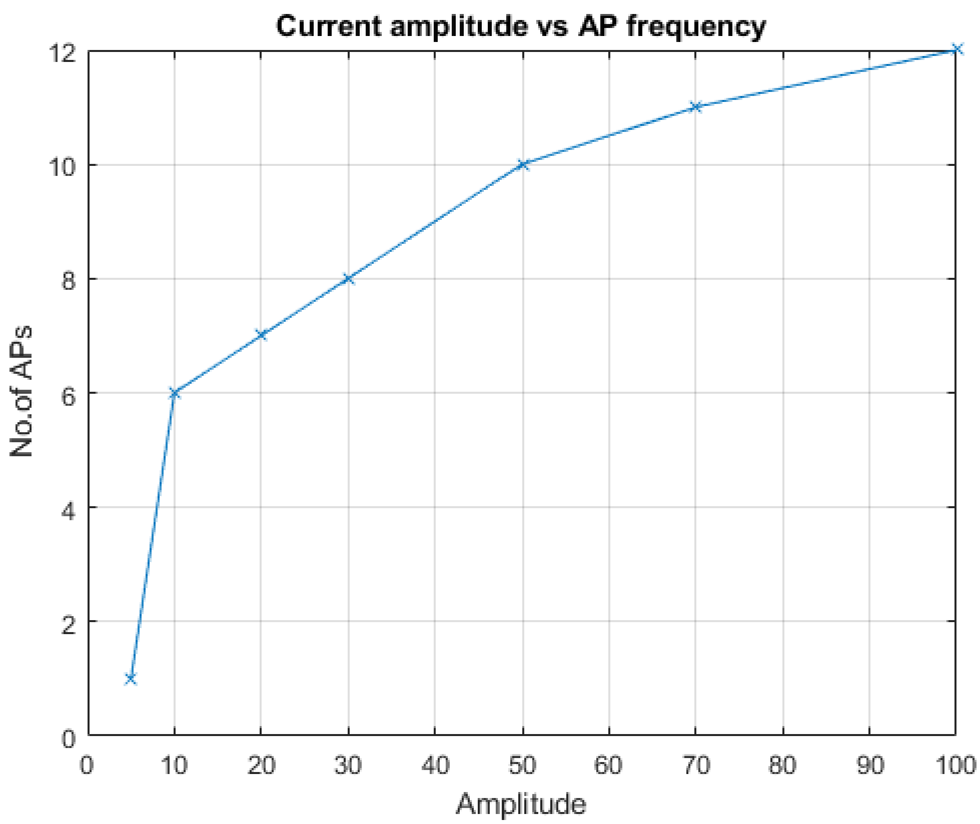
Table = 7×2 table

	Amp	Number_of_Action_potentials
1	5	1
2	10	6
3	20	7
4	30	8

	Amp	Number_of_Action_potentials
5	50	10
6	70	11
7	100	12

Question 05

```
Amplitudes = [5, 10, 20, 30, 50, 70, 100];
No_of_Aps = [1, 6, 7, 8, 10, 11, 12];
figure;
plot(Amplitudes,No_of_Aps,'x-');
xlabel('Amplitude')
ylabel('No.of APs')
title('Current amplitude vs AP frequency')
grid on
```



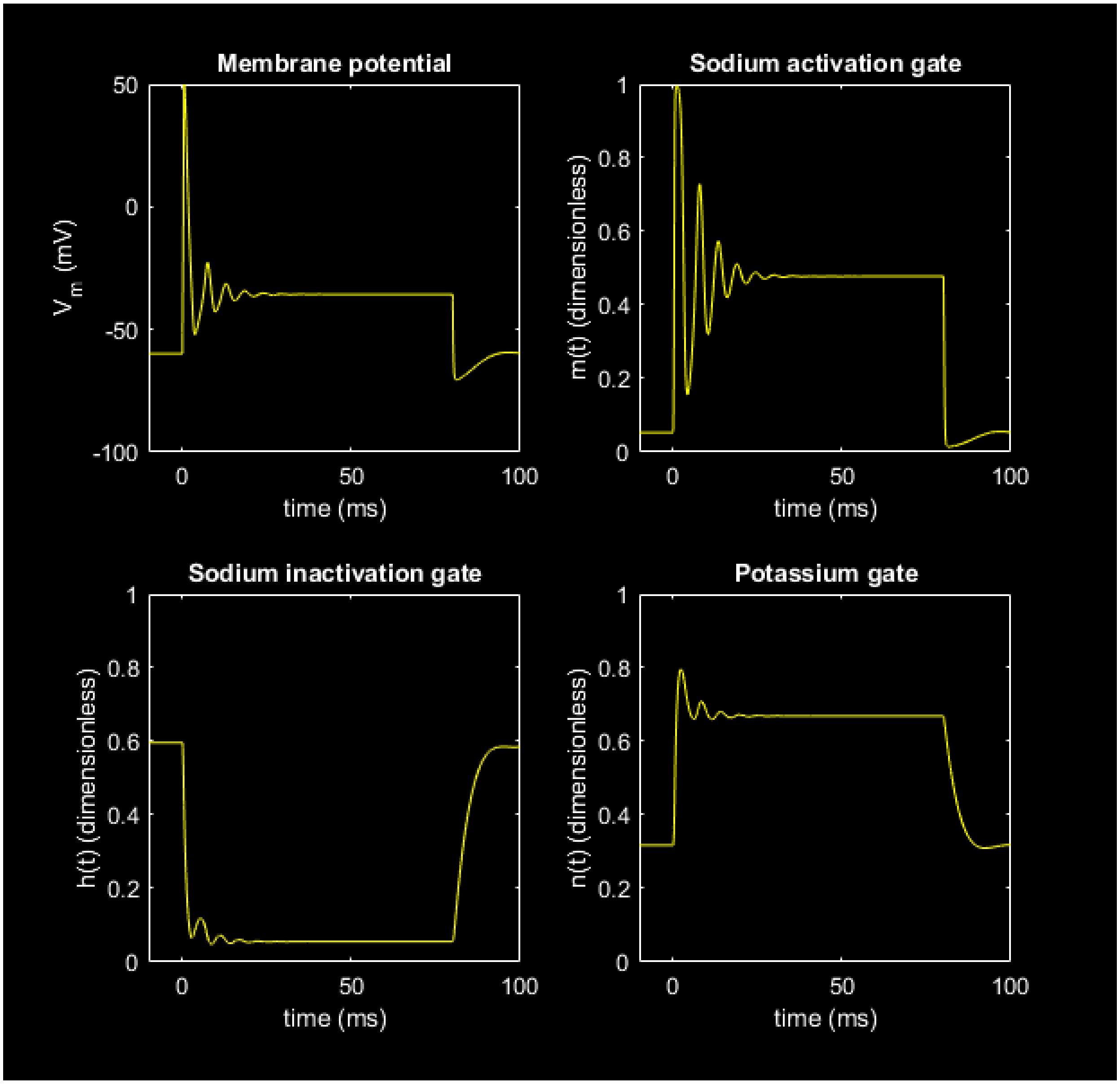
Looking at the above graph, we can determine that:

a)The action potentials' amplitude falls as the stimulus intensity's amplitude rises.

b)The frequency of action potentials rises in proportion to the amplitude of the stimulus intensity.

Question 06

```
amp1 = 200;
width1 = 80;
delay2 = 0;
amp2 = 0;
width2 = 0;
hhmplot(0,100,0);
```



Sustained Depolarization: The membrane potential stays excessively depolarized for a considerable amount of time at such large amplitudes. Action potentials may not be produced as a result of this prolonged depolarization because voltage-gated sodium channels may become inactivated.

Dependence of Gating Variables on Voltage: The Hodgkin-Huxley equations' h and n factors are essential in determining the membrane's excitability. The h and n factors can

quickly move to inactivated states at very depolarized potentials, hence preventing the start of action potentials.

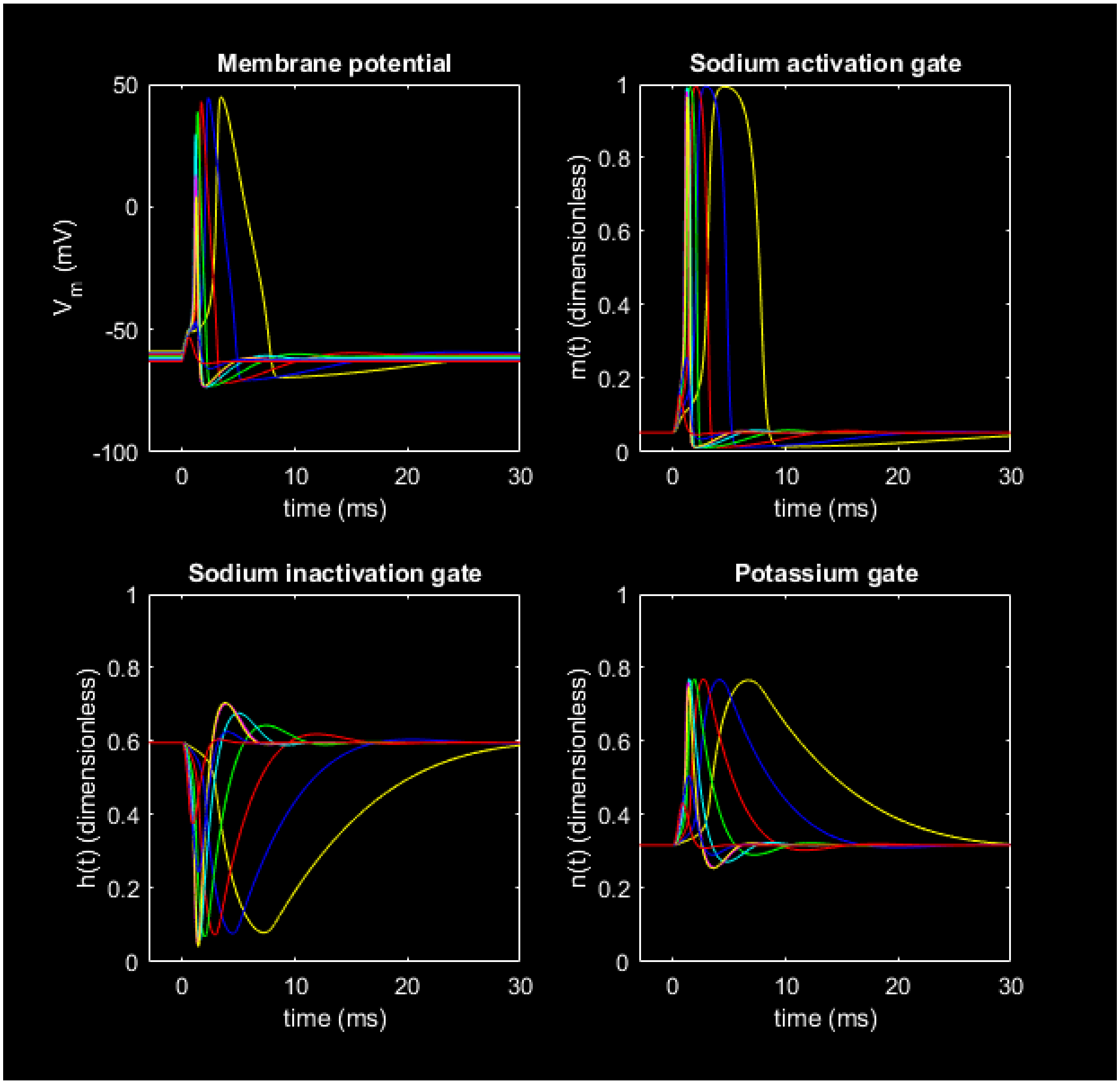
In the Hodgkin-Huxley model, the voltage-dependent conductances of potassium and sodium play a major role in determining the amplitude of action potentials.

Sodium Channels (m and h): The membrane potential depolarizes more noticeably with increasing stimulus intensity and amplitude. As a result, there is a greater chance that sodium channels will open, increasing the inward sodium current during the action potential's upstroke. As so, when the magnitude of the stimulus increases, the amplitude of the action potentials tends to decrease.

Potassium Channels (n): Conversely, when the membrane potential decreases, potassium channel activity rises. The action potential amplitude could be negatively impacted if the increased potassium conductance is unable to offset the increased sodium influx.

4.Temperature Dependance

```
vclamp = 0;
amp1 = 20;
width1 = 0.5;
tempc = 0;
hhmplot(0,30,0);

tempc = 5;
hhmplot(0,30,1);

tempc = 10;
hhmplot(0,30,2);


tempc = 15;
hhmplot(0,30,3);


tempc = 20;
hhmplot(0,30,4);

tempc = 24;
hhmplot(0,30,5);

tempc = 25;
hhmplot(0,30,6);

tempc = 26;
hhmplot(0,30,7);

tempc = 30;
hhmplot(0,30,8);
```



a) Threshold and Resting Membrane Potential: As temperature rises, the resting membrane potential somewhat decreases. The sodium-potassium ATPase pump, which aids in preserving the ionic gradients across the membrane, is operating at a higher level. Furthermore, there may be a decrease in the threshold for eliciting an action potential, resulting in increased excitability of neurons.

b) Ionic Current Speed: Voltage-gated ion channels open and close more quickly at higher temperatures. As a result, during the depolarization phase, sodium ions (Na+) enter the system more quickly, and during the repolarization phase, potassium ions (K+) exit the system more quickly. As a result, the action potential's rising and falling phases steepen, increasing the action potential's amplitude and reducing its duration.

c) Conduction Velocity: A significant increase in the speed at which the action potential travels through the axon. This is because a higher temperature shortens the time it takes for the membrane to recover to its resting potential following the passage of an action potential and speeds up ion exchange across the neuronal membrane.

d) Refractory Periods: As temperature rises, both the absolute and relative refractory periods get shorter. This decrease is brought about by sodium channels that reactivate and inactivate more quickly, enabling neurons to generate action potentials more quickly in succession.

e) Synaptic Transmission: Because of higher vesicular fusion rates, higher temperatures can facilitate the release of neurotransmitters at synaptic terminals. Increased postsynaptic responses and improved synaptic transmission may result from this.