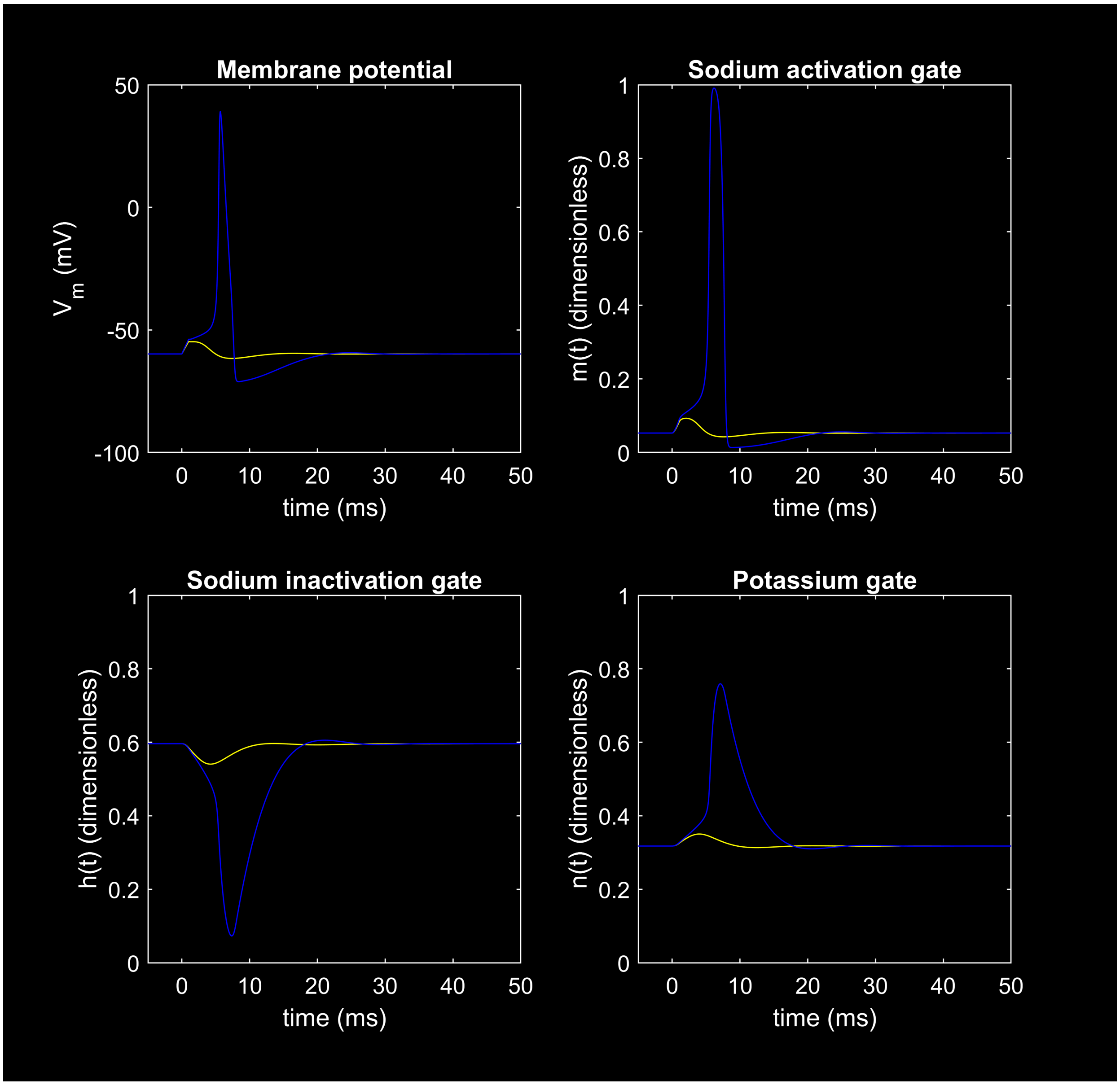
Assignment 3 - 200664P

```
hhconst;
```

Question 1

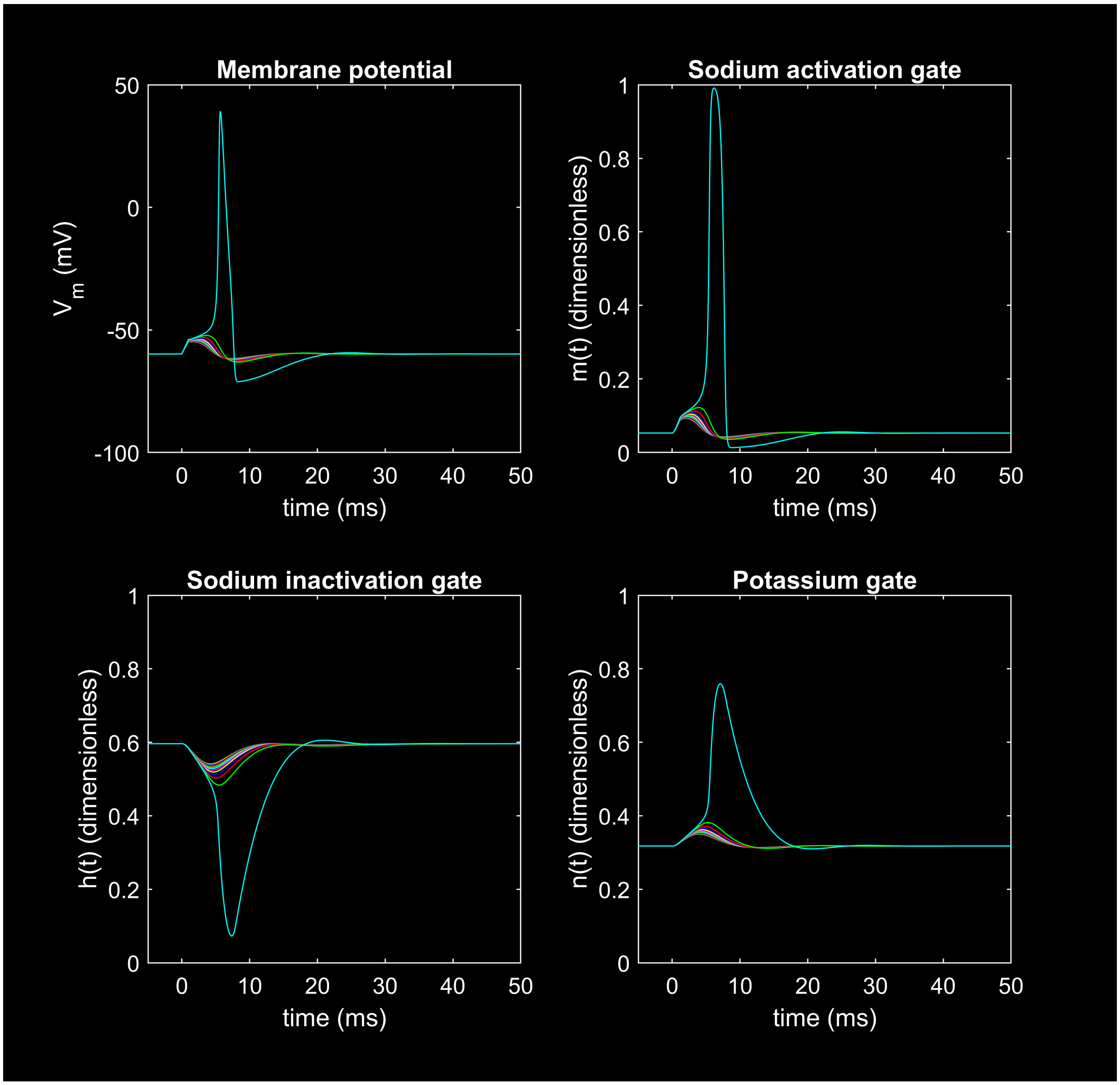
```
amp1 = 6;
width1 = 1;
hhmplot(0,50,0);
amp1 = 7;
hhmplot(0,50,1);
```




```
amp1 = 6;
hhmplot(0,50,0);
```

```
for n = 1 : 10
    amp1 = 6 + ((0.1)*n)
    hhmplot(0,50,1);
end
```

```
amp1 = 6.1000
amp1 = 6.2000
amp1 = 6.3000
amp1 = 6.4000
amp1 = 6.5000
amp1 = 6.6000
amp1 = 6.7000
amp1 = 6.8000
amp1 = 6.9000
amp1 = 7
```

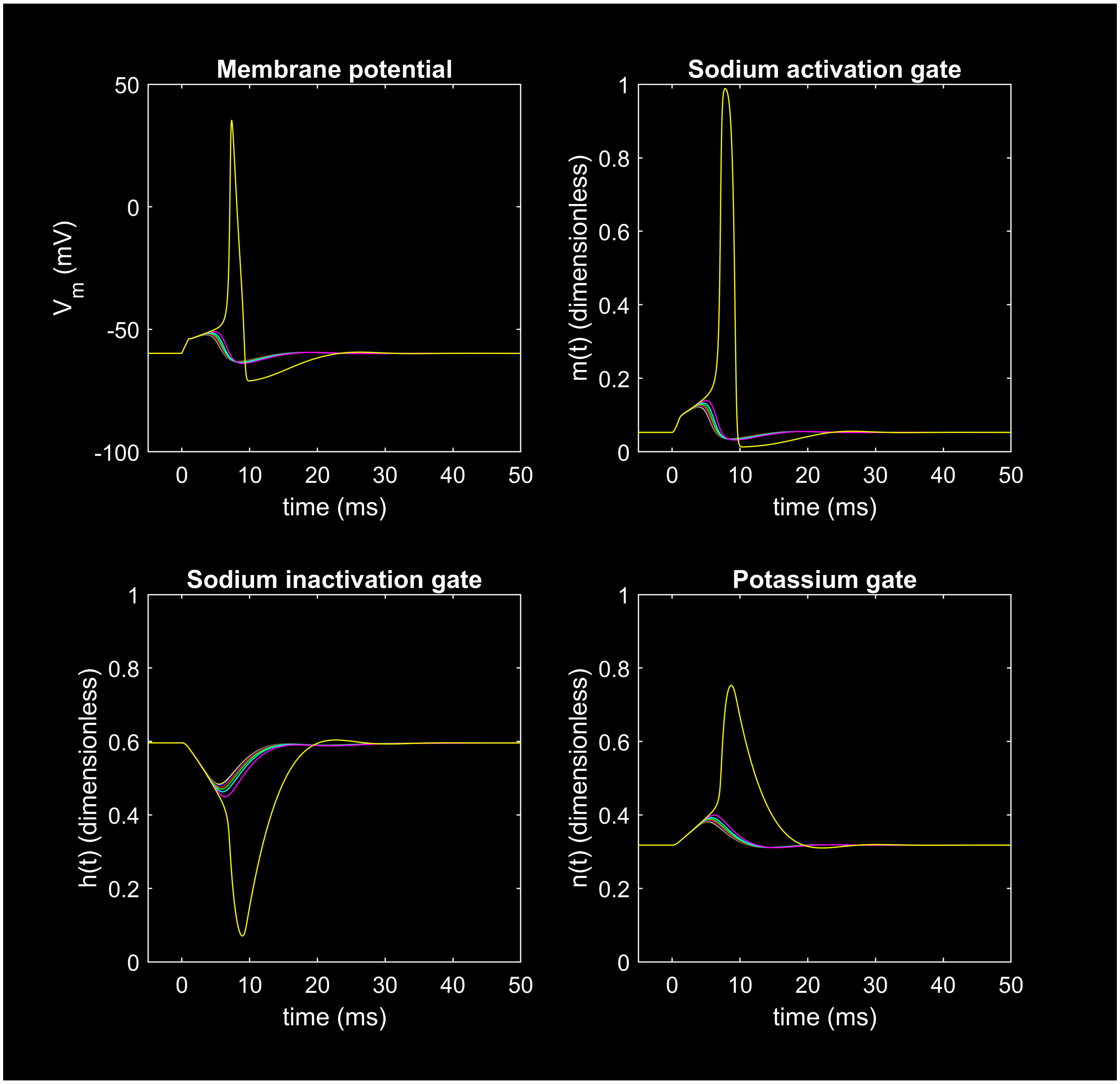


The threshold lies between 6.9 and 7.

```
amp1 = 6.9;
hhmplot(0,50,0);
```

```
for n = 1 : 6
    amp1 = 6.9 + ((0.01)*n)
    hhmplot(0,50,1);
end
```

```
amp1 = 6.9100
amp1 = 6.9200
amp1 = 6.9300
amp1 = 6.9400
amp1 = 6.9500
amp1 = 6.9600
```

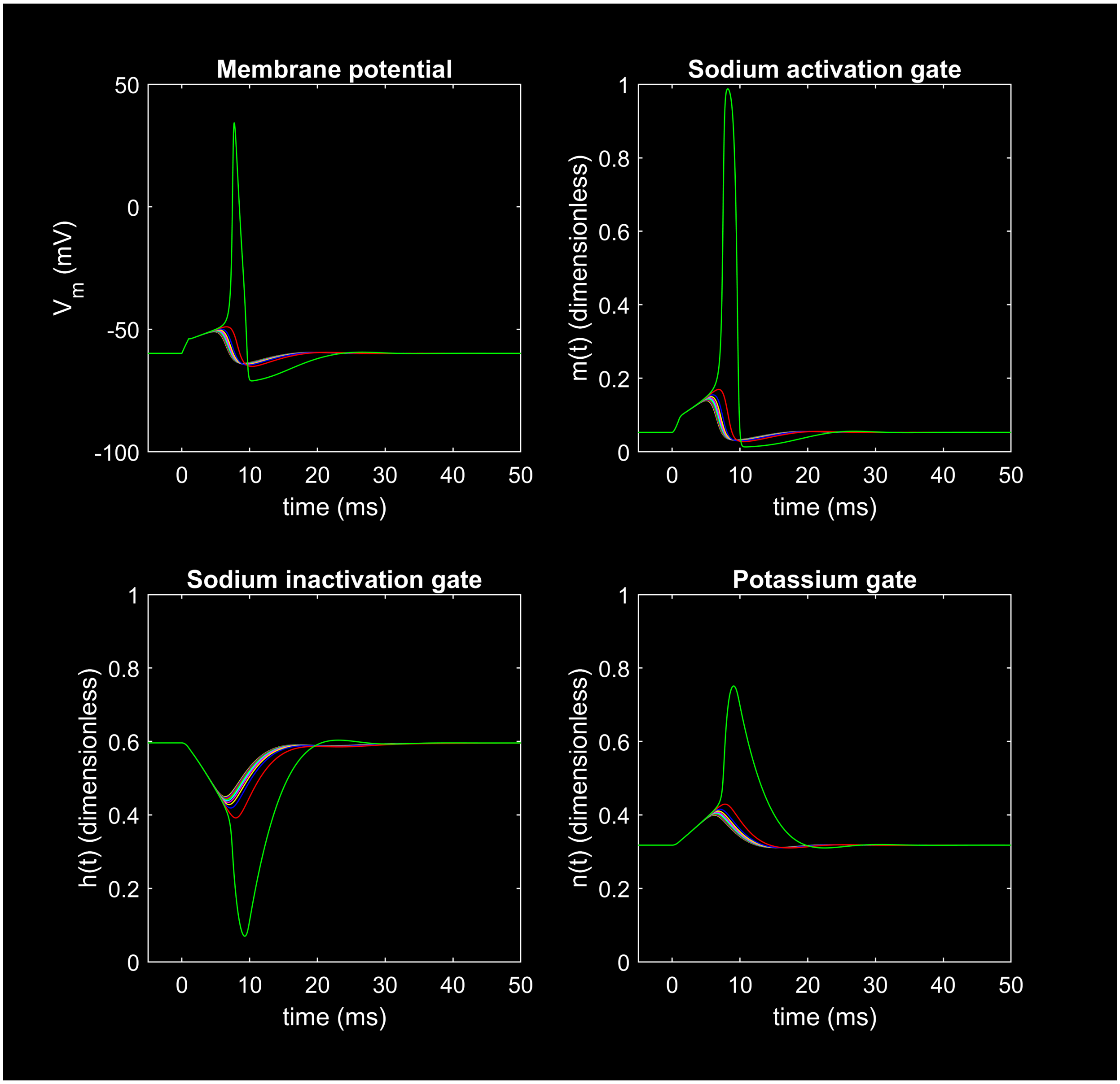


The threshold lies between 6.95 and 6.96

```
amp1 = 6.95;
hhmplot(0,50,0);
for n = 1 : 9
    amp1 = 6.95 + ((0.001)*n)
    hhmplot(0,50,1);
```

```
end
```

```
amp1 = 6.9510
amp1 = 6.9520
amp1 = 6.9530
amp1 = 6.9540
amp1 = 6.9550
amp1 = 6.9560
amp1 = 6.9570
amp1 = 6.9580
amp1 = 6.9590
```



The value is 6.959. Aprroximately,the threshold is 6.96.

Question 2

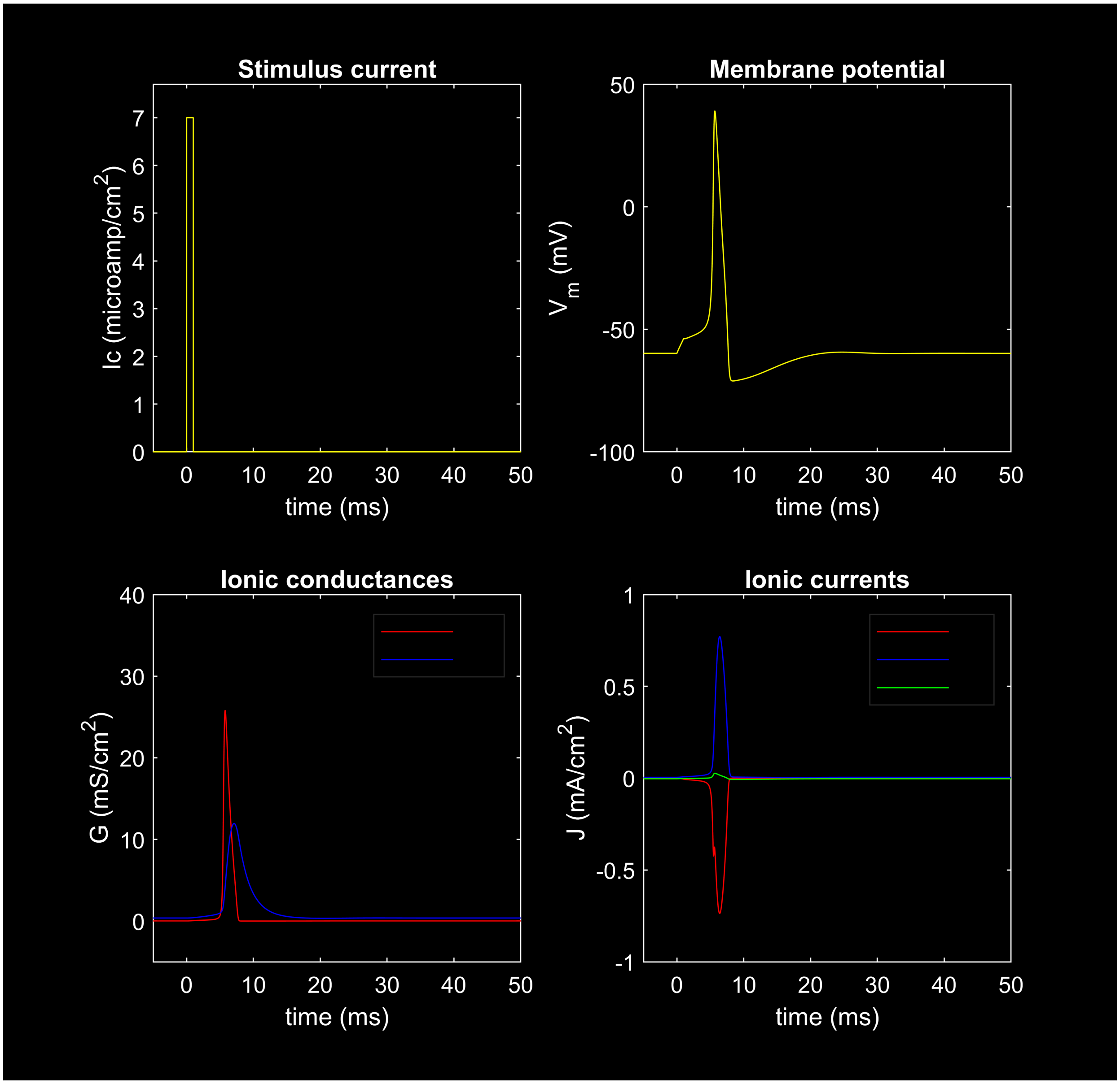
```
amp1 = 6.6
```

```
amp1 = 6.6000
```

```
[qna,qk,ql]=hhsplot(0,50);

for n = 1 : 5
    [qna,qk,ql]=hhsplot(0,50);
    sum_Jei = width1*amp1
    sum_ionic_Jk = qna + qk + ql
    amp1 = amp1 + 0.1
end
```

```
sum_Jei = 6.6000
sum_ionic_Jk = 6.5996
amp1 = 6.7000
sum_Jei = 6.7000
sum_ionic_Jk = 6.6999
amp1 = 6.8000
sum_Jei = 6.8000
sum_ionic_Jk = 6.7997
amp1 = 6.9000
sum_Jei = 6.9000
sum_ionic_Jk = 6.8998
amp1 = 7.0000
```

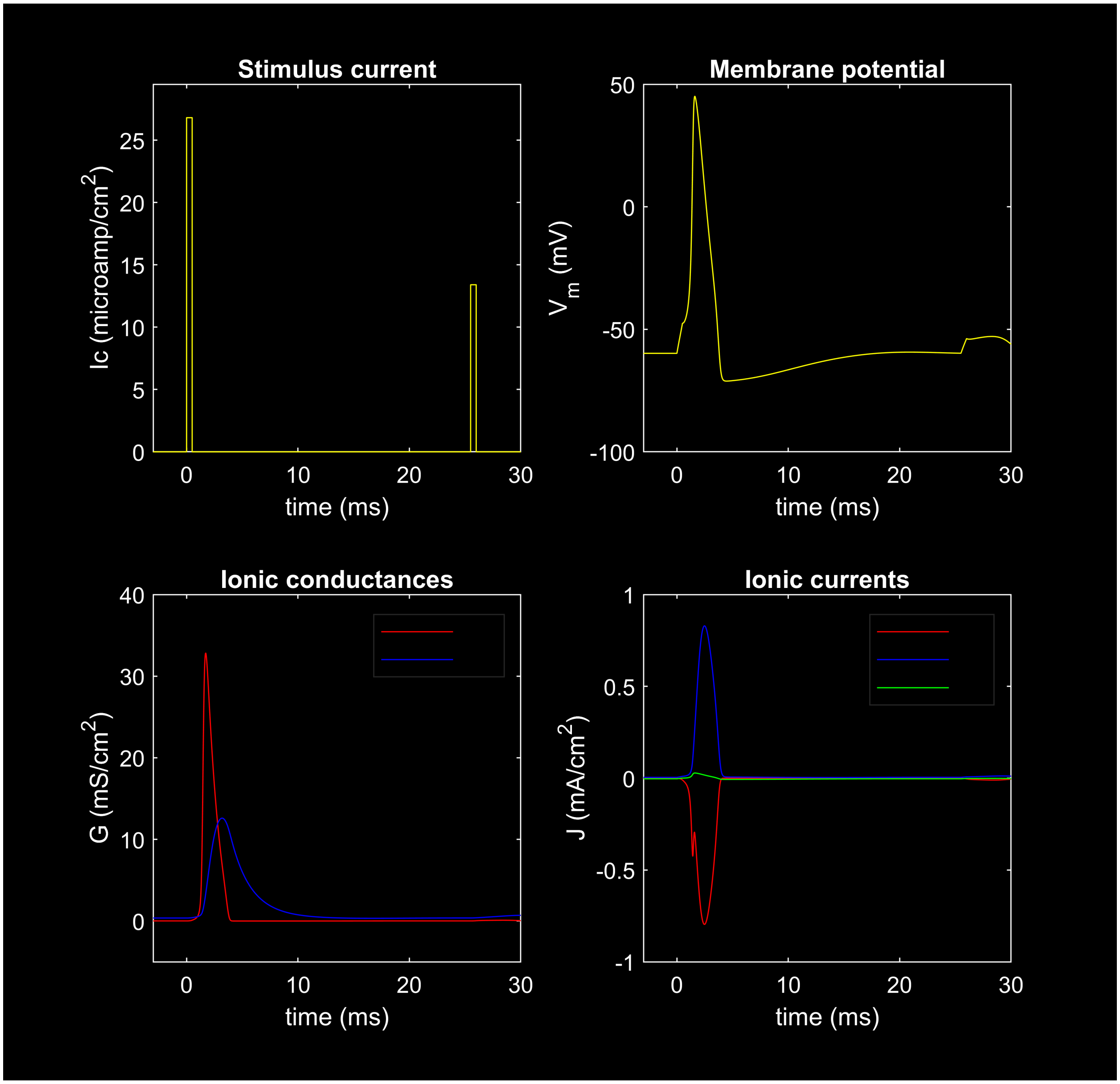



```
sum_Jei = 7.0000
sum_ionic_Jk = 7.0014
amp1 = 7.1000
```

The integration of injected current and the summation of ionic currents is equal.

Question 3

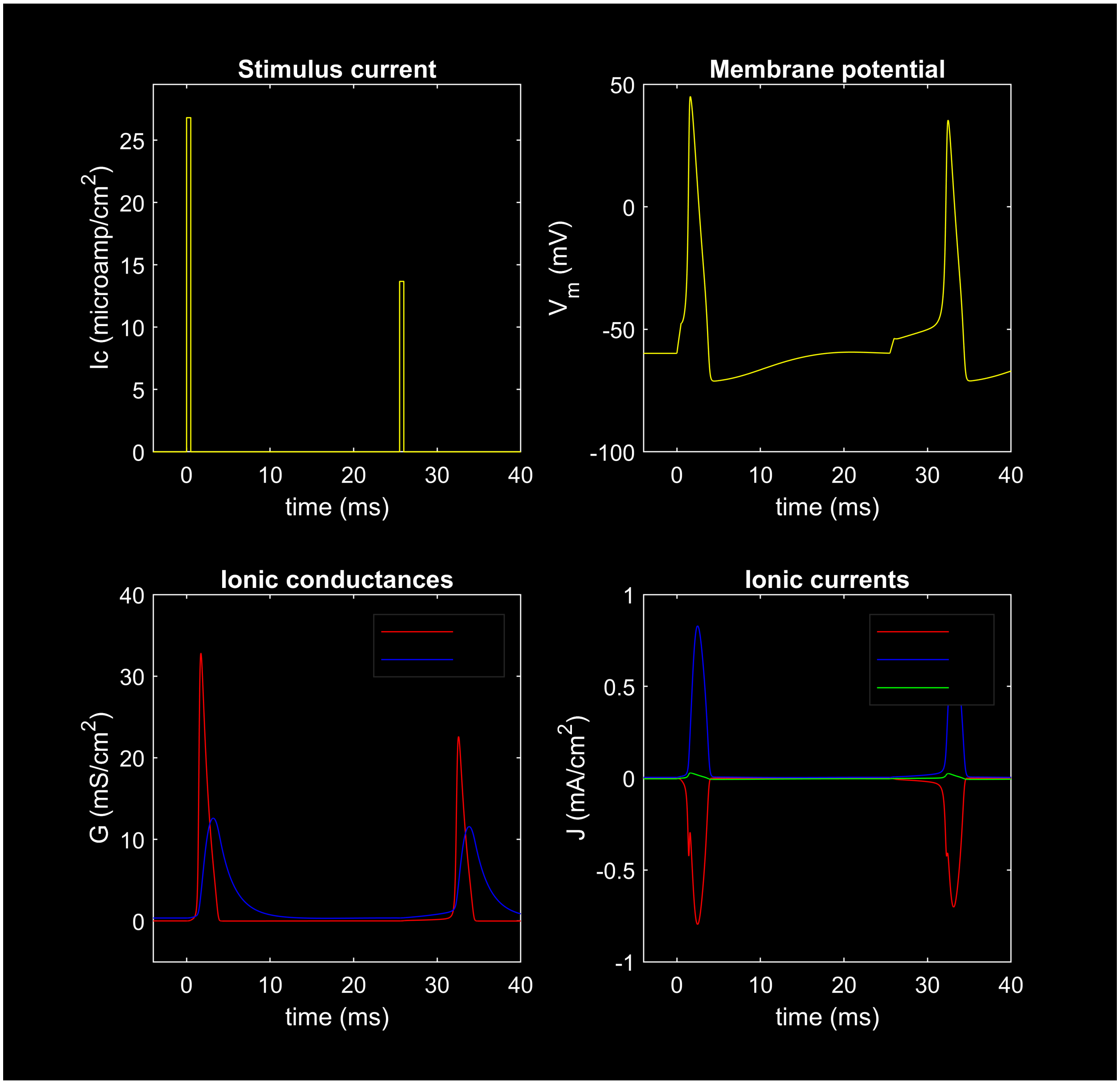
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 25;
amp2 = 13.4;
width2 = 0.5;
hhsplot(0,30);
```



The threshold value is not enough for the 25ms delay.

Delay = 25 ms

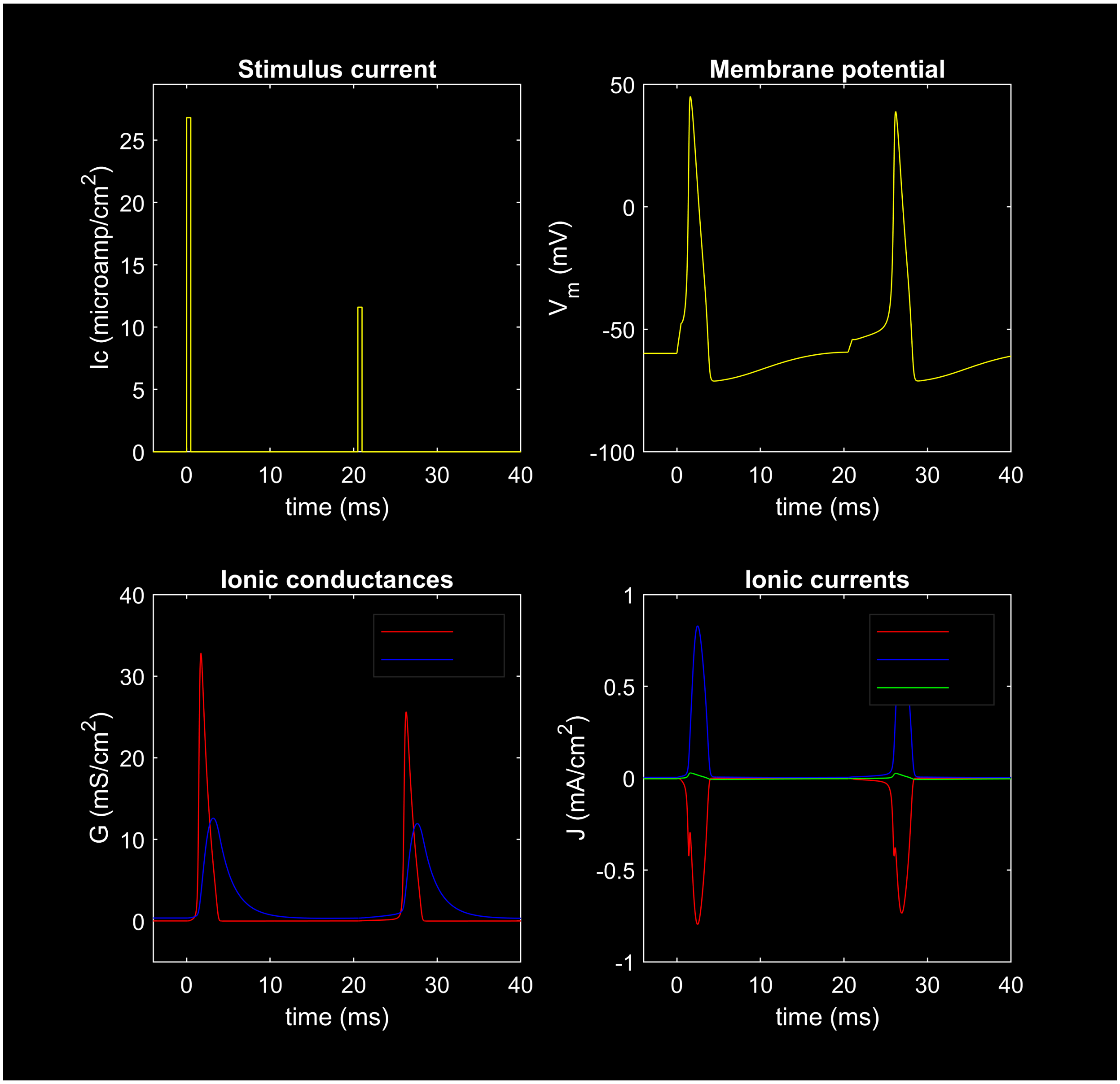
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 25;
amp2 = 13.67;
width2 = 0.5;
hhsplot(0,40);
```



An AP is generated when the amplitude is 13.67. It is 13.7 to one decimal place.

Delay 20 ms

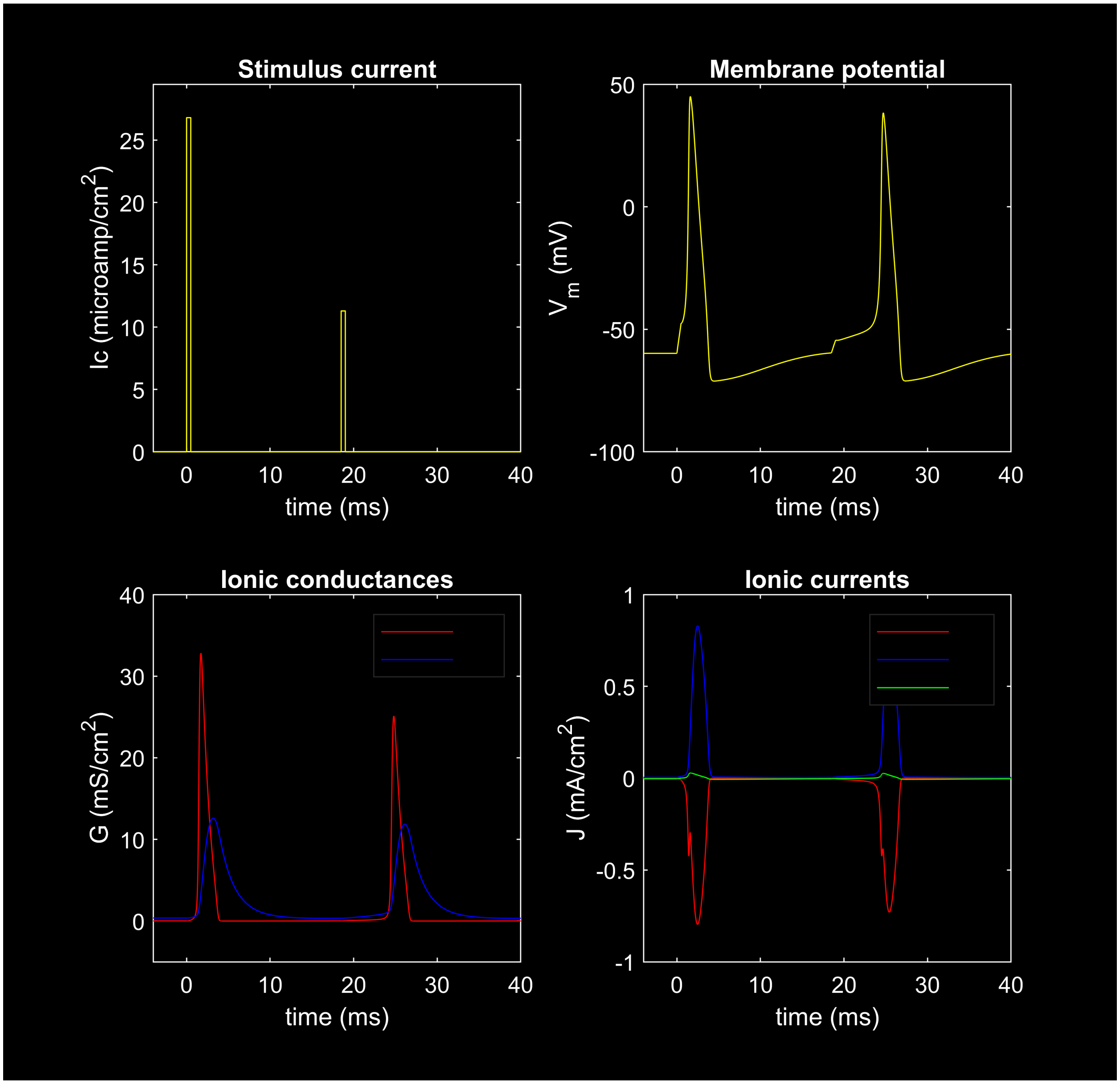
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 20;
amp2 = 11.6;
width2 = 0.5;
hhsplot(0,40);
```



The required amplitude is 11.6

Delay 18 ms

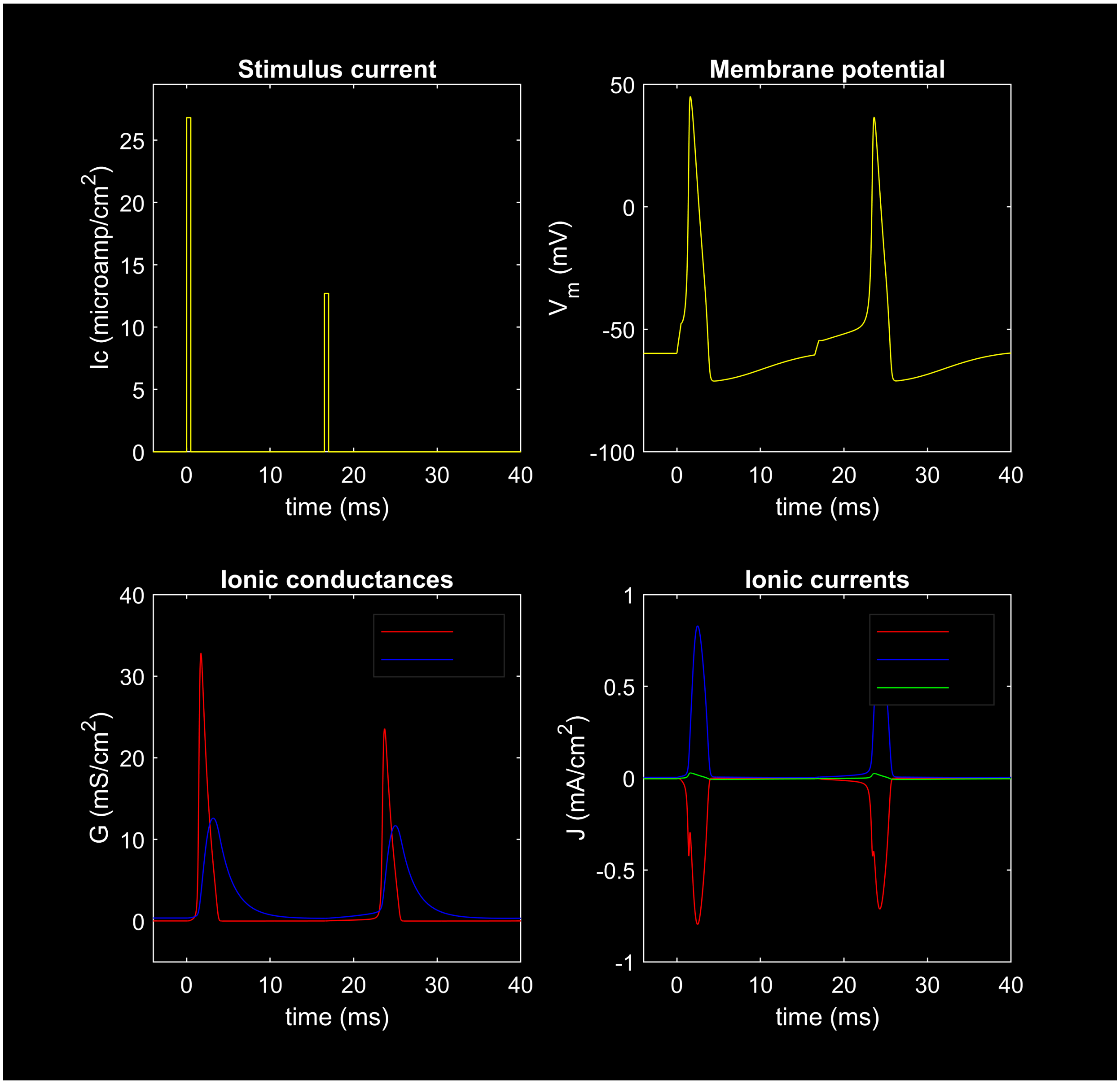
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 18;
amp2 = 11.3;
width2 = 0.5;
hhsplot(0,40);
```



The required amplitude is 11.3

Delay 16 ms

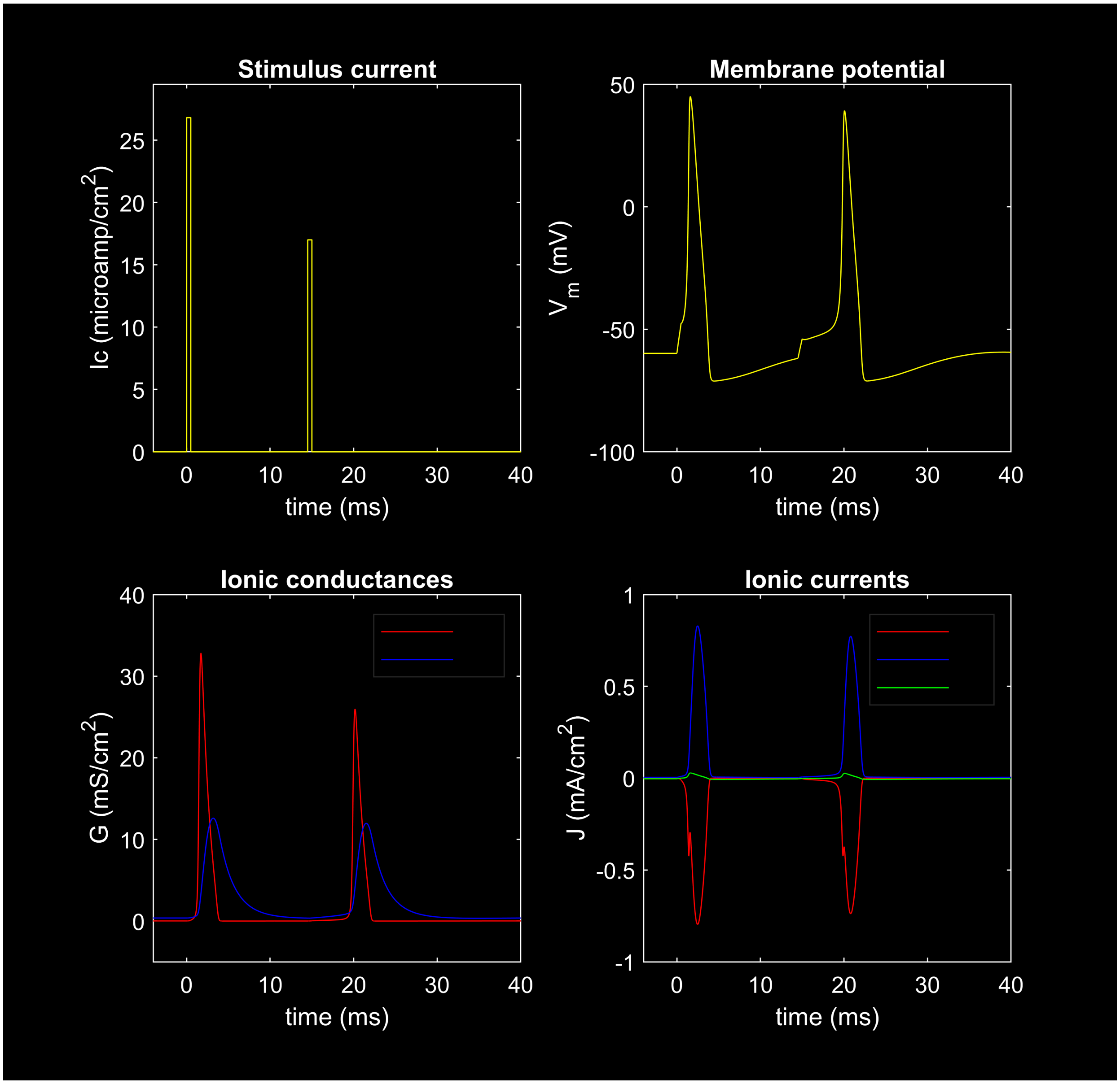
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 16;
amp2 = 12.7;
width2 = 0.5;
hhsplot(0,40);
```



The required amplitude is 12.7

Delay 14 ms

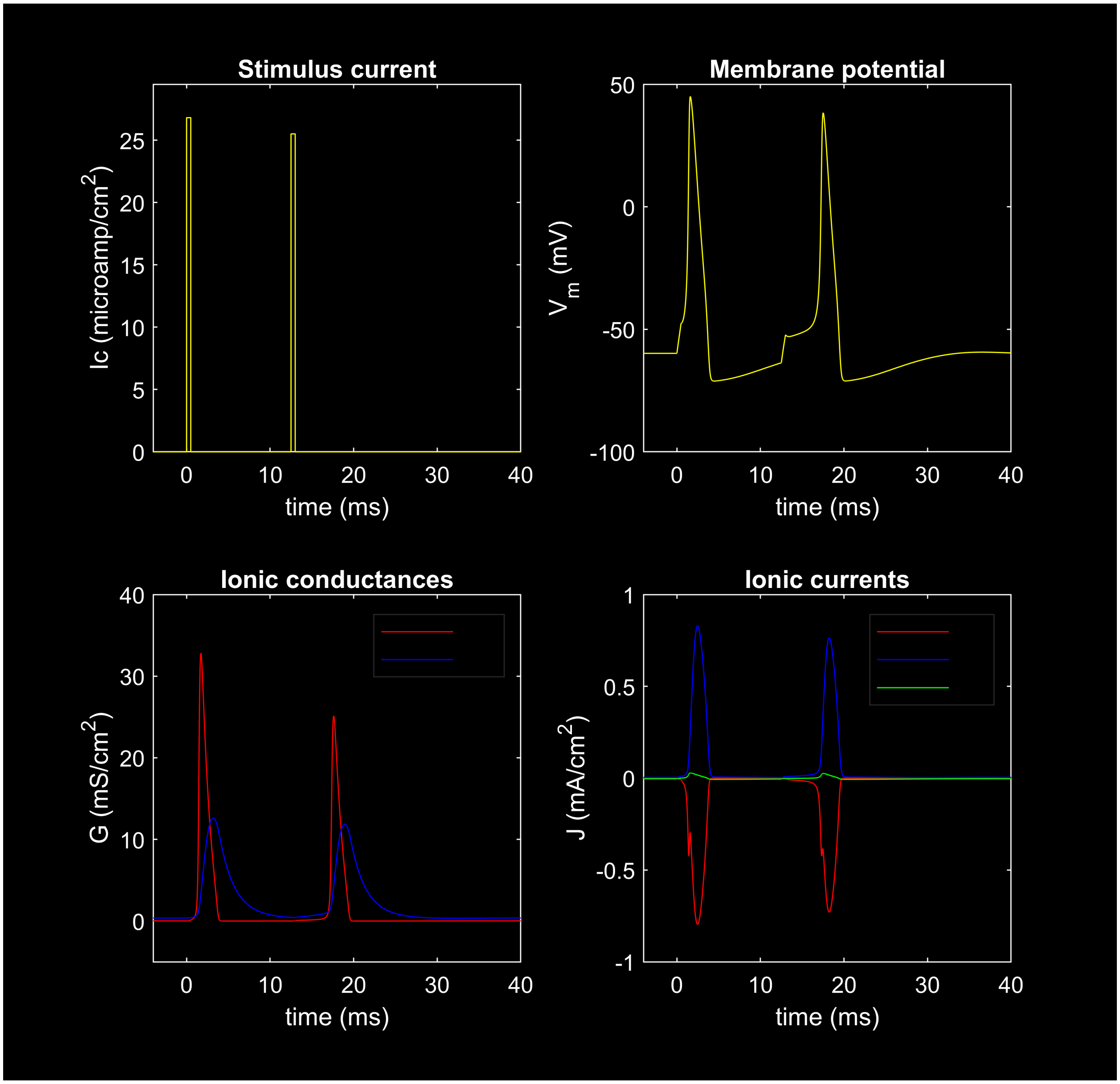
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 14;
amp2 = 17;
width2 = 0.5;
hhsplot(0,40);
```



The required amplitude is 17.0

Delay 12 ms

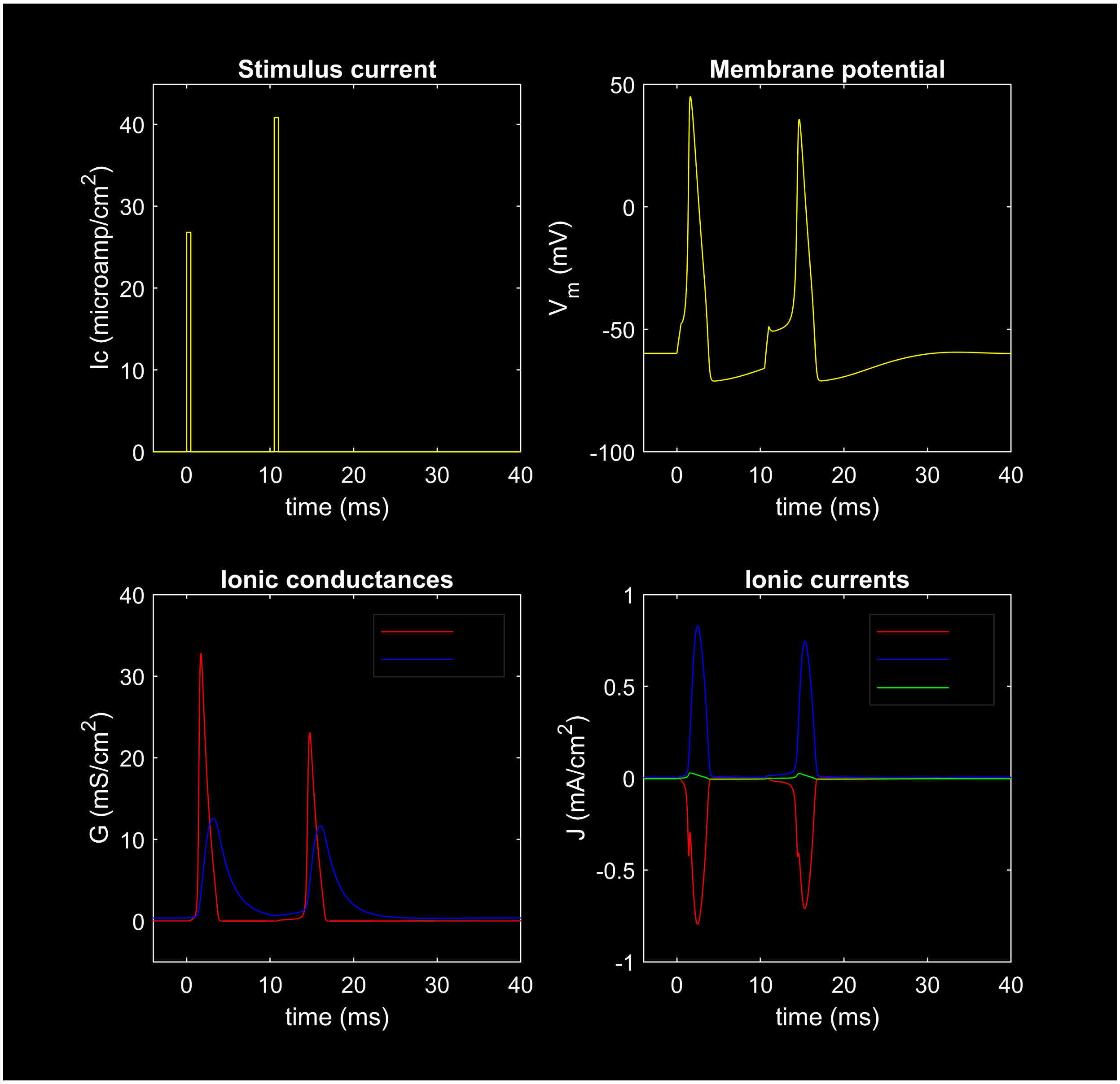
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 12;
amp2 = 25.5;
width2 = 0.5;
hhsplot(0,40);
```



The required amplitude is 25.5

Delay 10 ms

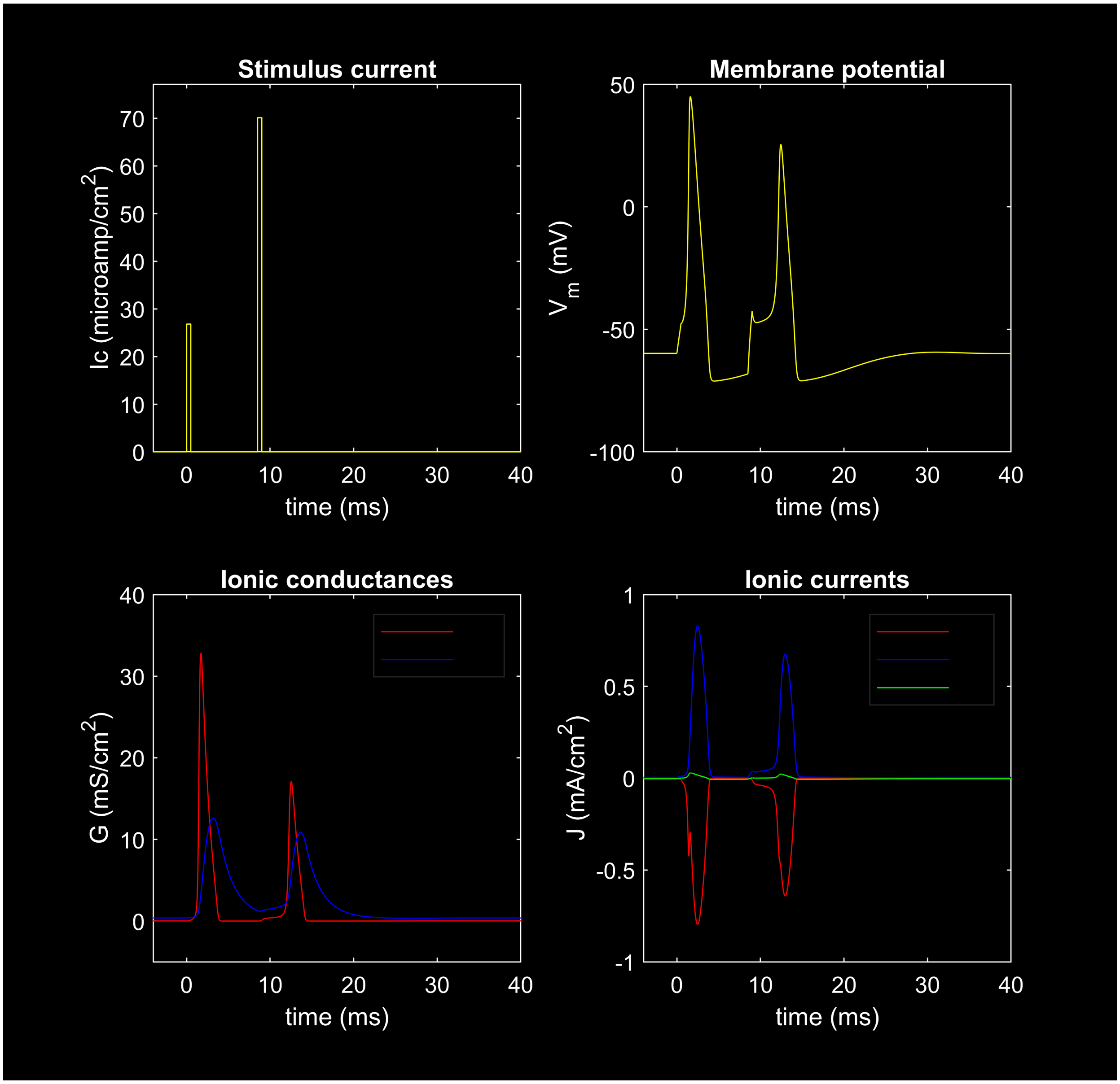
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 10;
amp2 = 40.8;
width2 = 0.5;
hhsplot(0,40);
```



The required amplitude is 40.8

Delay 8 ms

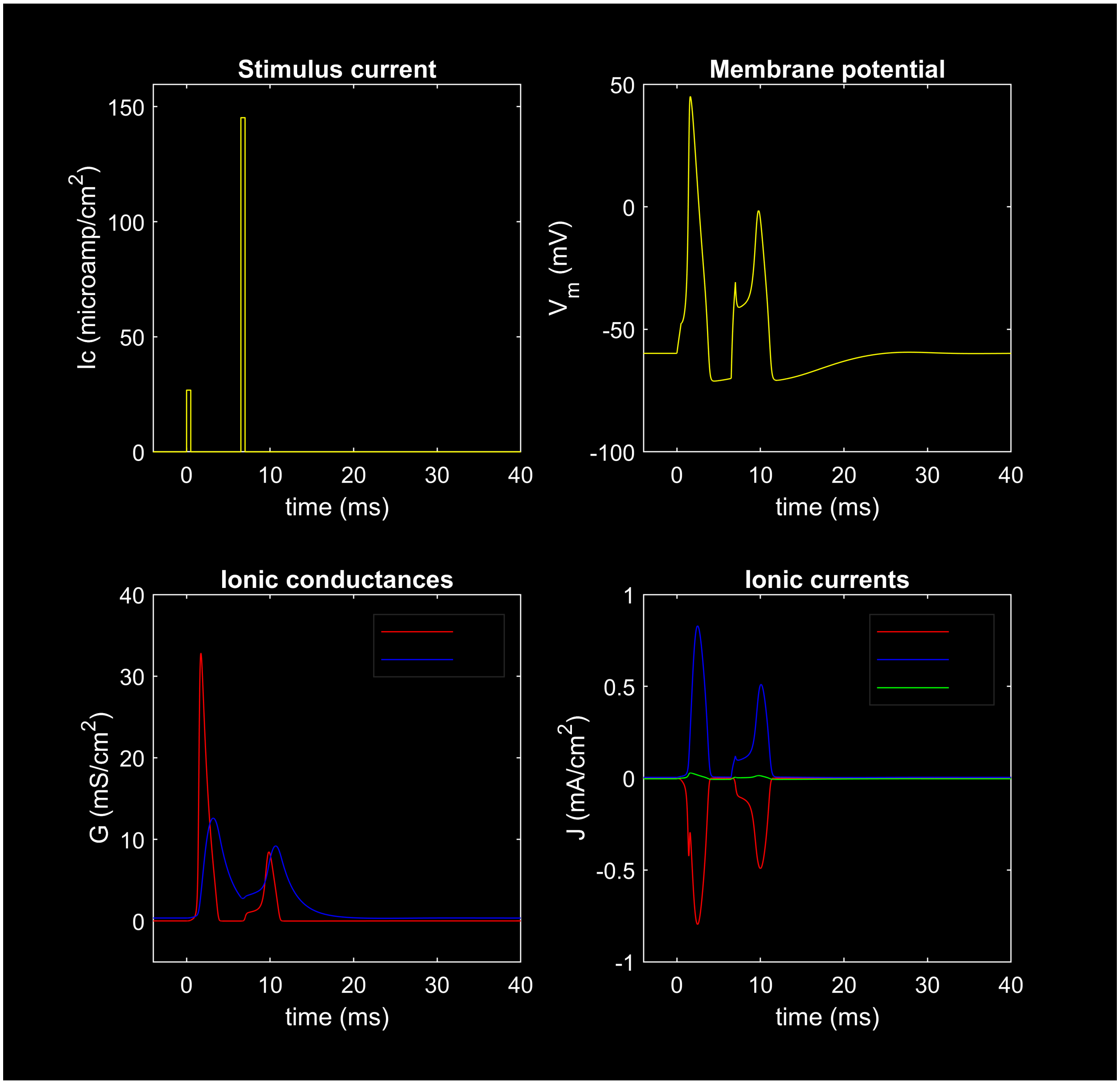
```
amp1 = 26.8;
width1 = 0.5;
delay2 = 8;
amp2 = 70.1;
width2 = 0.5;
hhsplot(0,40);
```



The required amplitude is 70.1

Delay 6 ms

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



The required amplitude is 145.2

Question 4

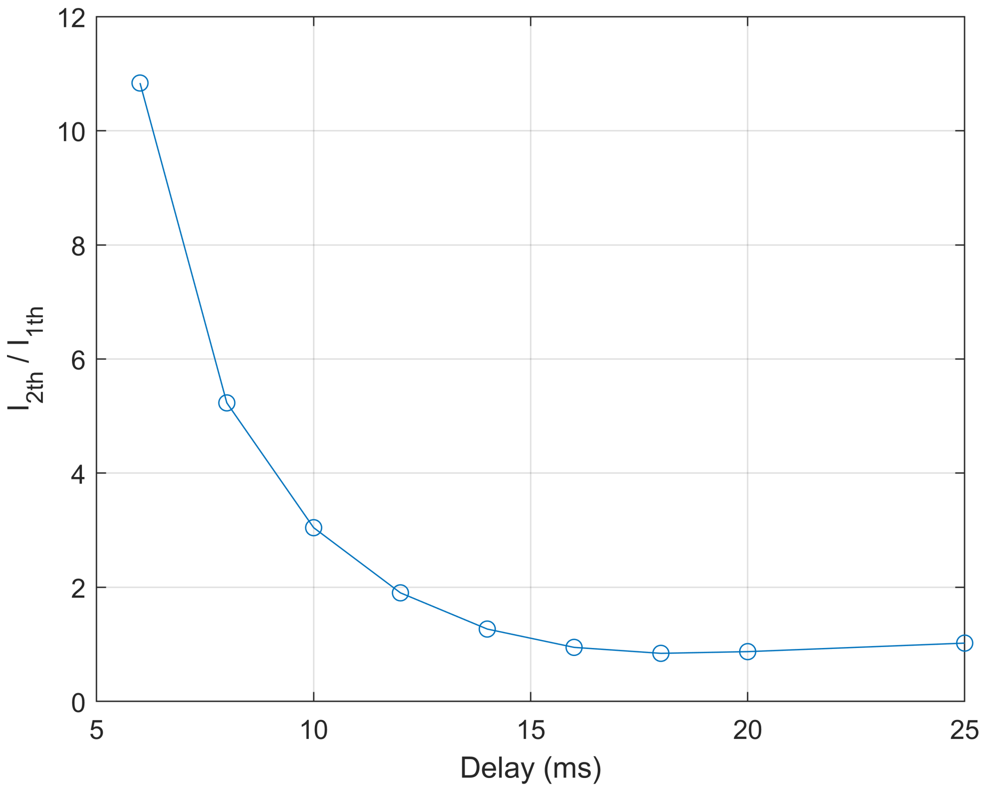
```
Delays = [6, 8, 10, 12, 14, 16, 18, 20, 25];
amps = [145.2, 70.1, 40.8, 25.5, 17.0, 12.7, 11.3, 11.7, 13.7];

I2I1 = zeros(1, length(amps));

for i = 1:length(amps)
    I2I1(i) = amps(i) / 13.4;
end

figure;
plot(Delays, I2I1, 'o-');
xlabel('Delay (ms)')
```

```
ylabel('I_{2th} / I_{1th}')
grid on
```



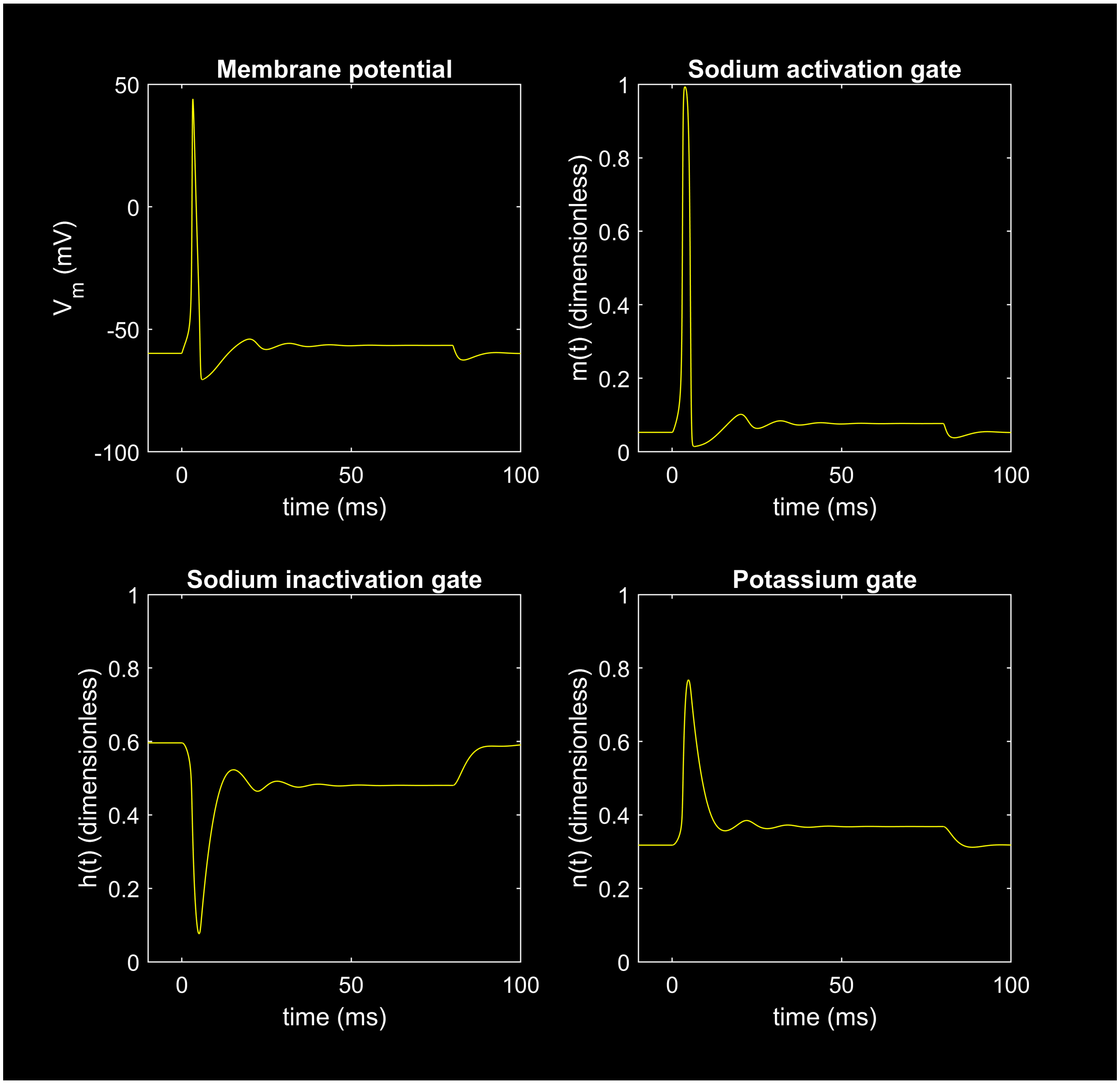
The threshold is lower than the I_1th when the time is greater than 16 ms. Therefore, the refractory period is less than that.

Since the threshold increases when further time decreases, we can take that the relative refractory period is between 6ms - 16 ms.

The threshold is way higher as time reduces that 6 ms, assuming from the direction of the graph. Therefore, we can conclude that the absolute refractory period is 0 - 6 ms.

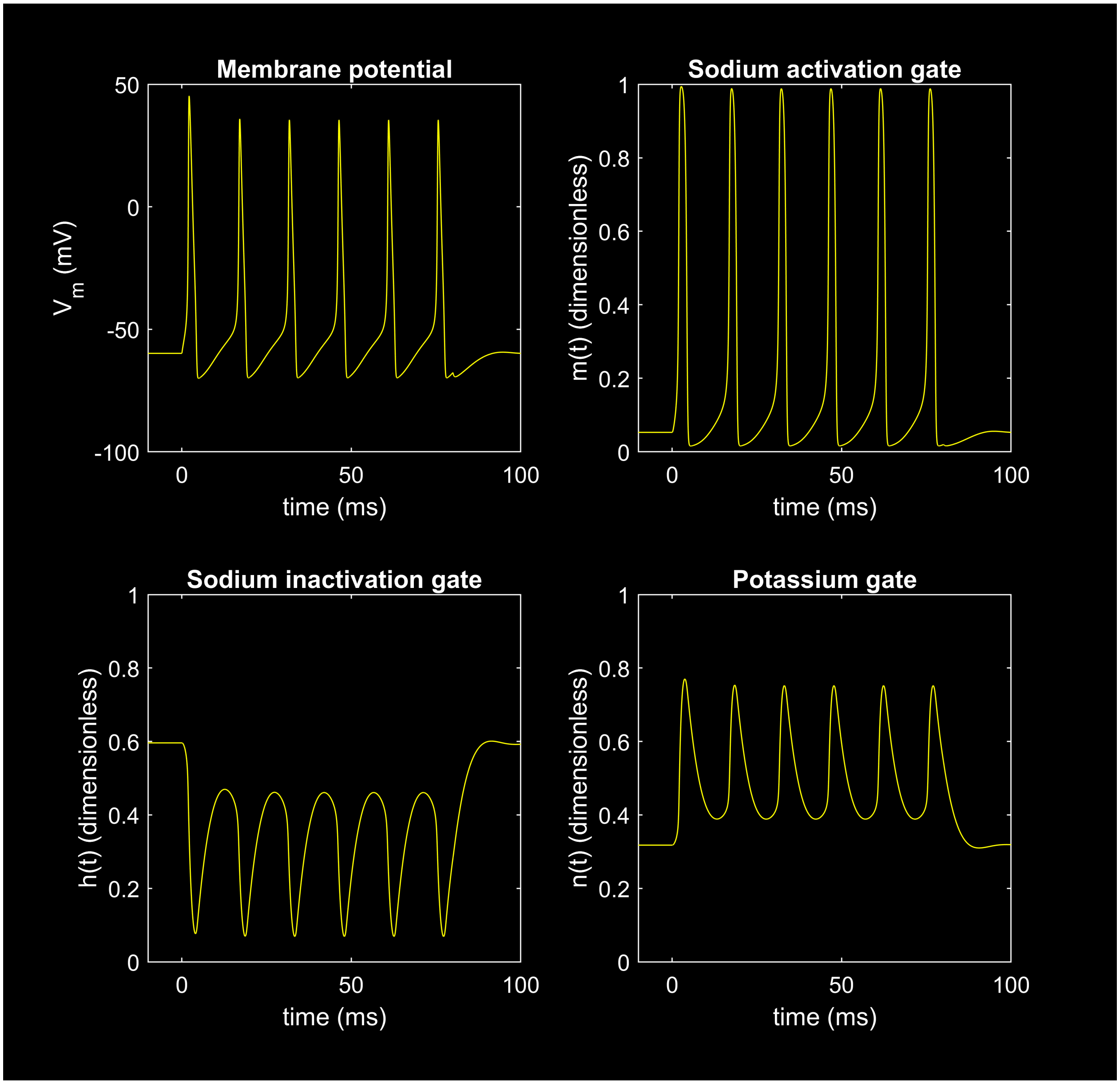
Question 5

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



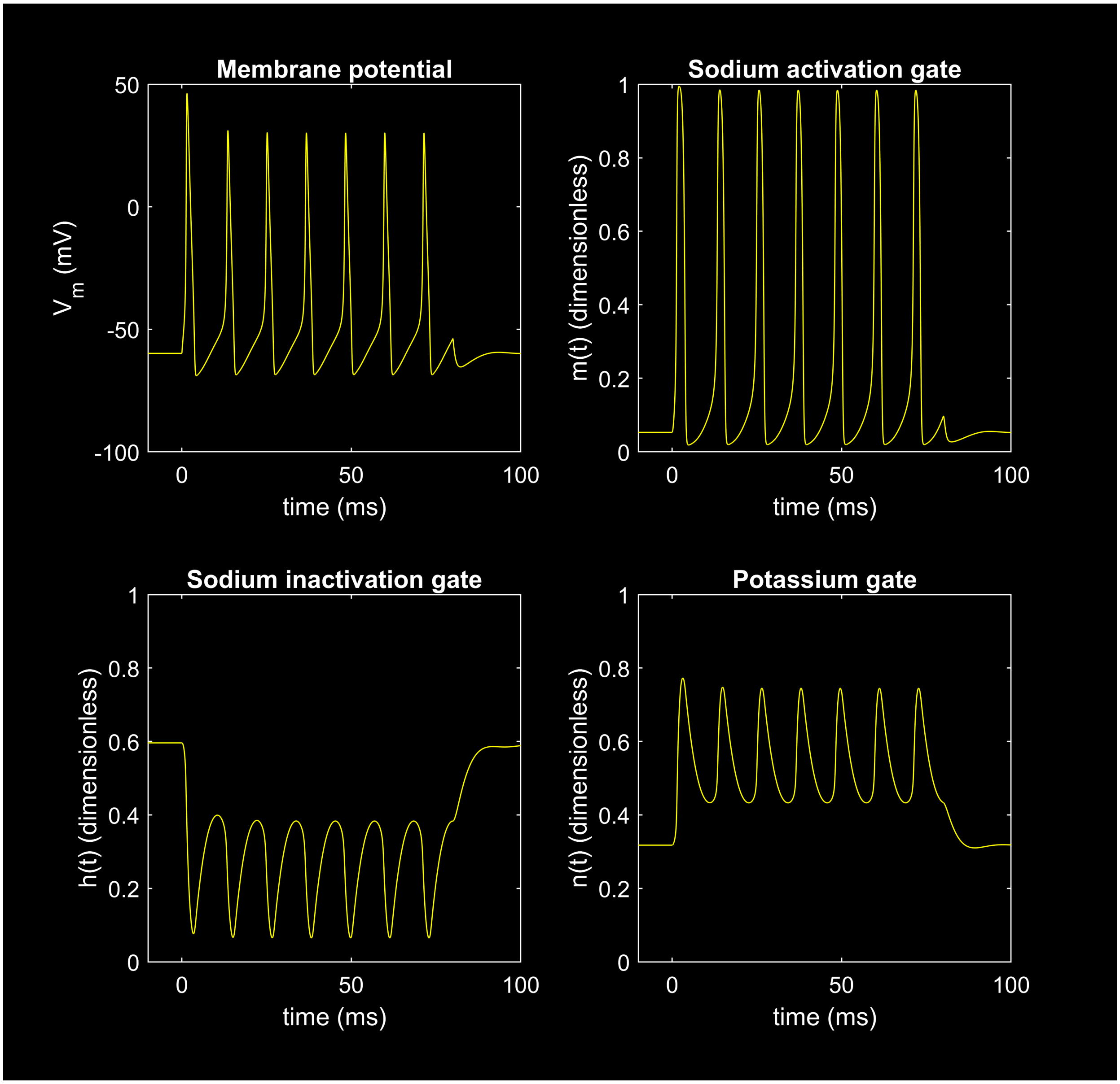
AP's per second: 10

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



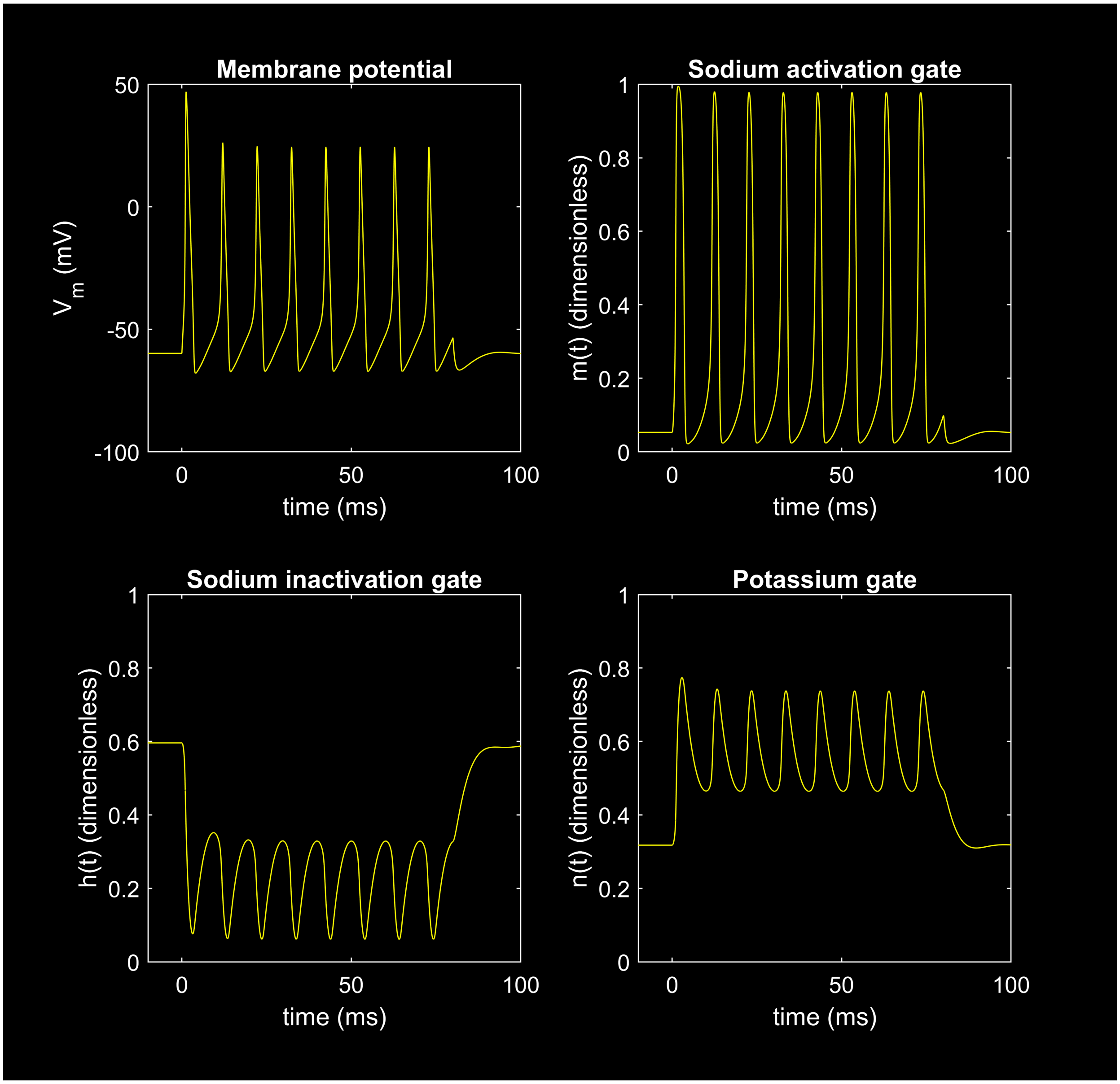
AP's per second: 60

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



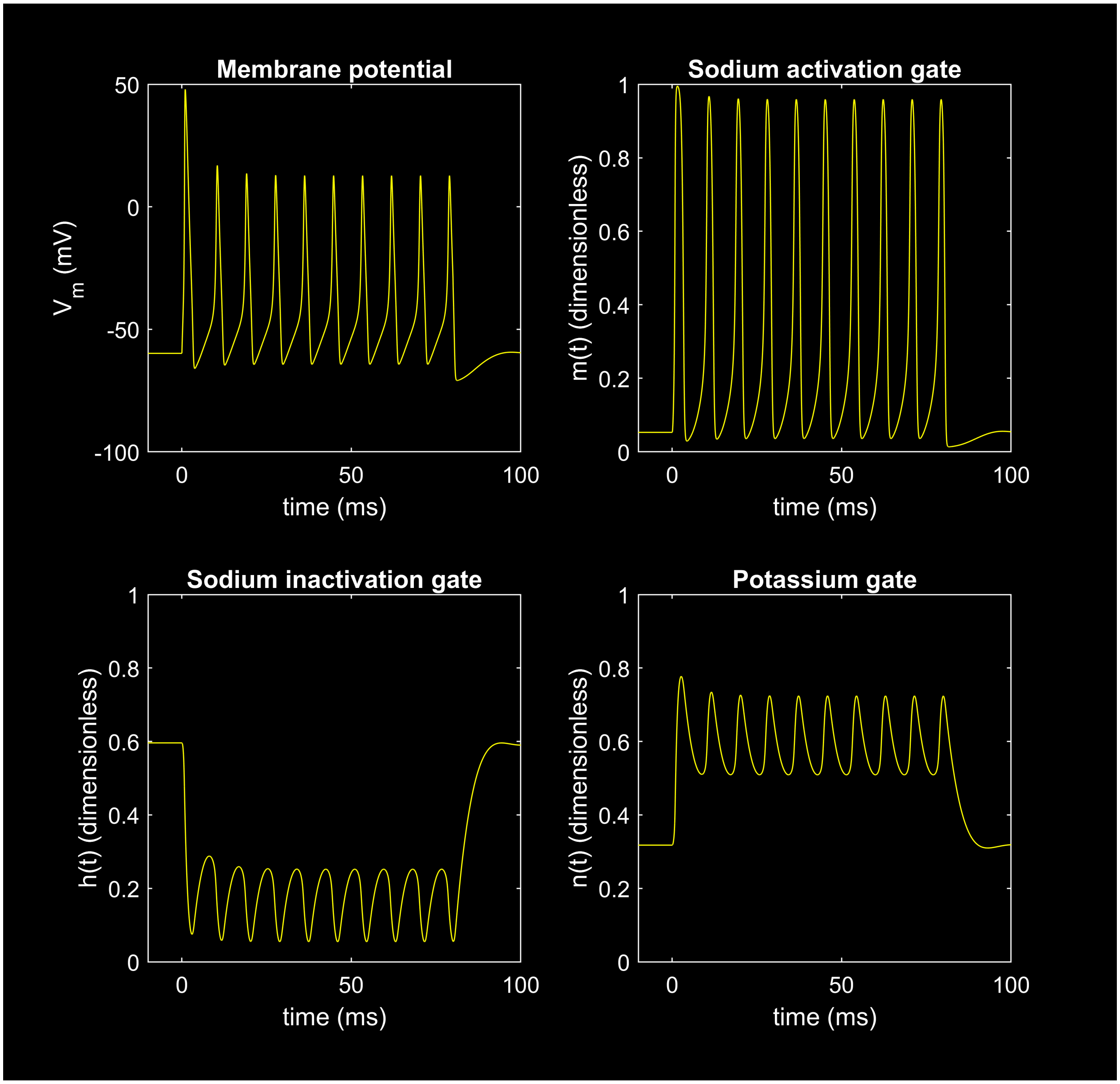
AP's per second: 70

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



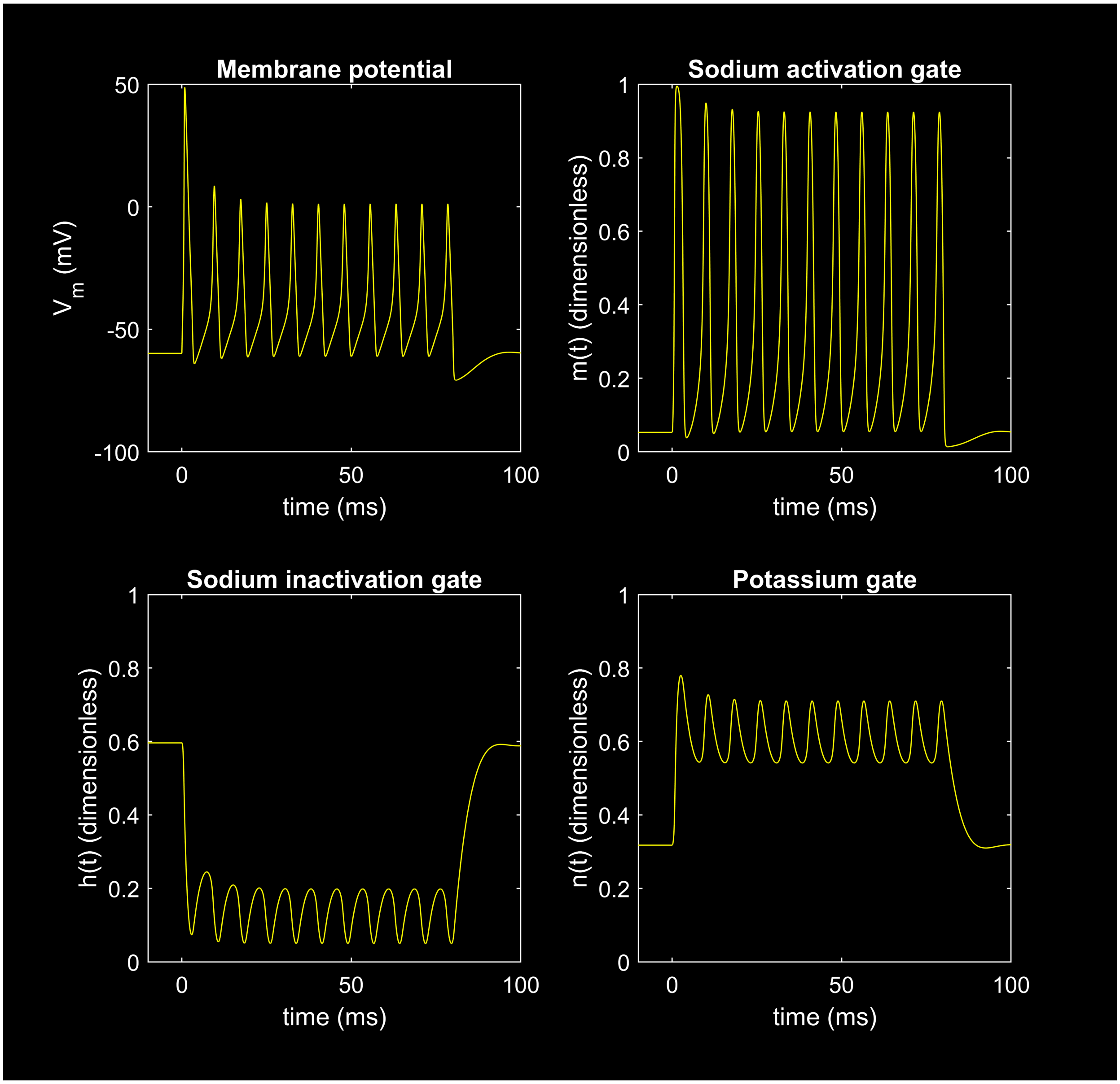
AP's per second: 80

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



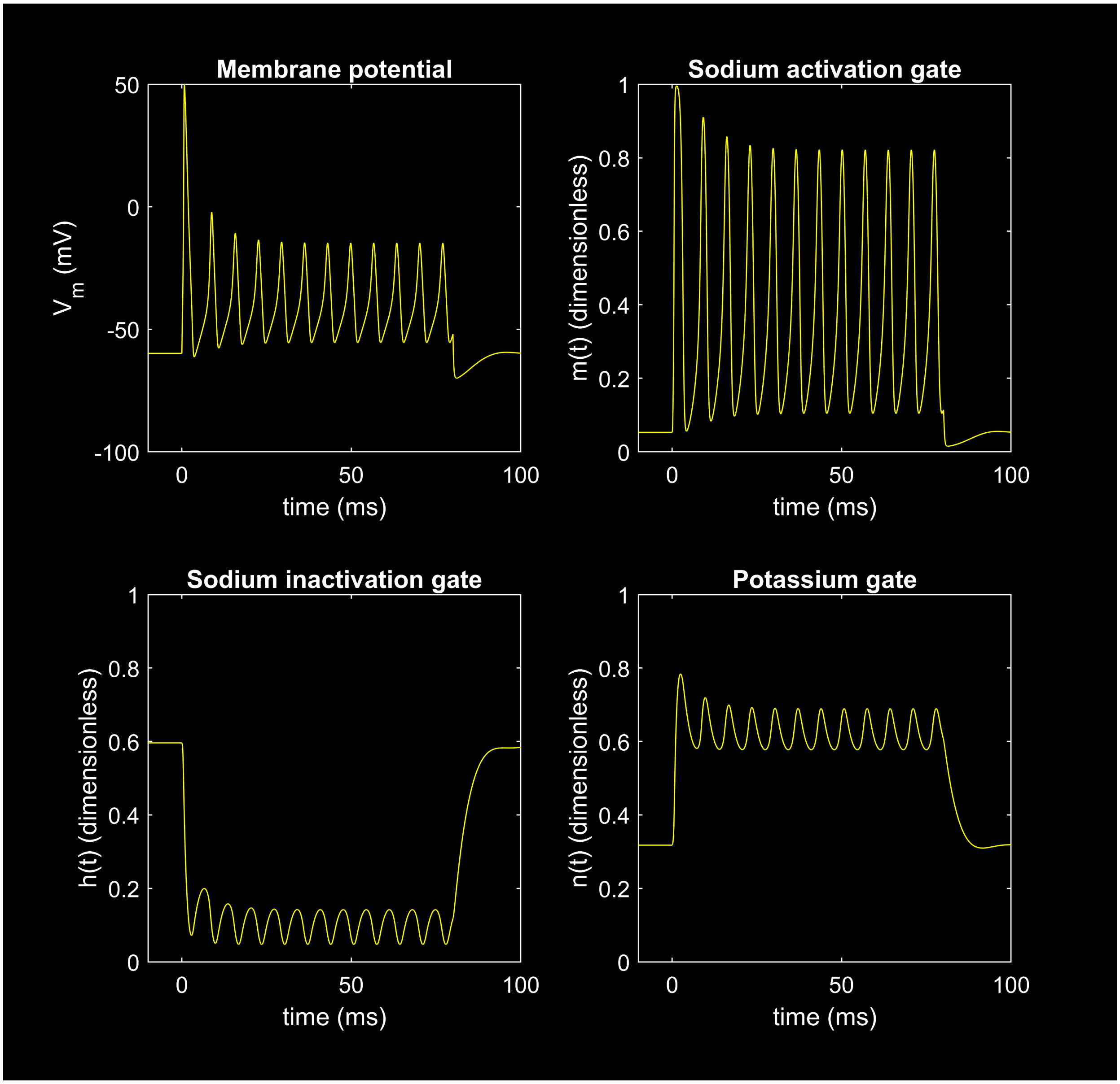
AP's per second: 100

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



AP's per second: 110

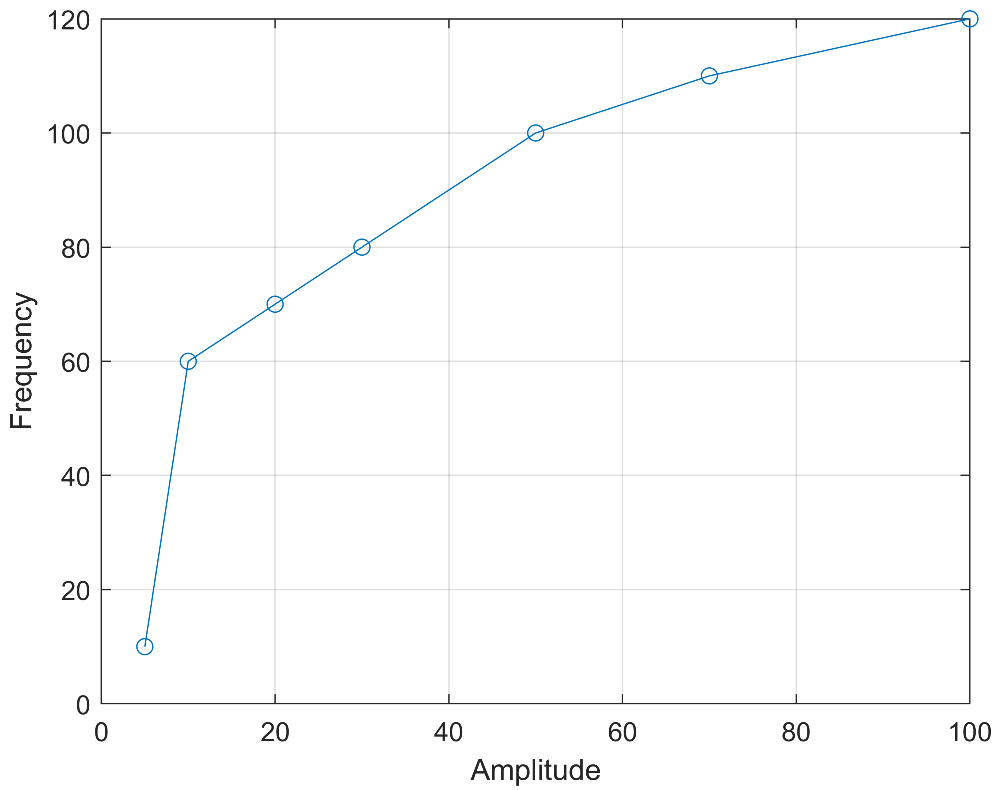
```
amp1 = 100;
width1 = 80;
delay2 = 0;
amp2 = 0;
width2 = 0;
hhmplot(0,100,0);
```



AP's per second: 120

```
Amplitudes = [5, 10, 20, 30, 50, 70, 100];
Frequencies = [10, 60, 70, 80, 100, 110, 120];

figure;
plot(Amplitudes, Frequencies, 'o-');
xlabel('Amplitude')
ylabel('Frequency')
grid on
```

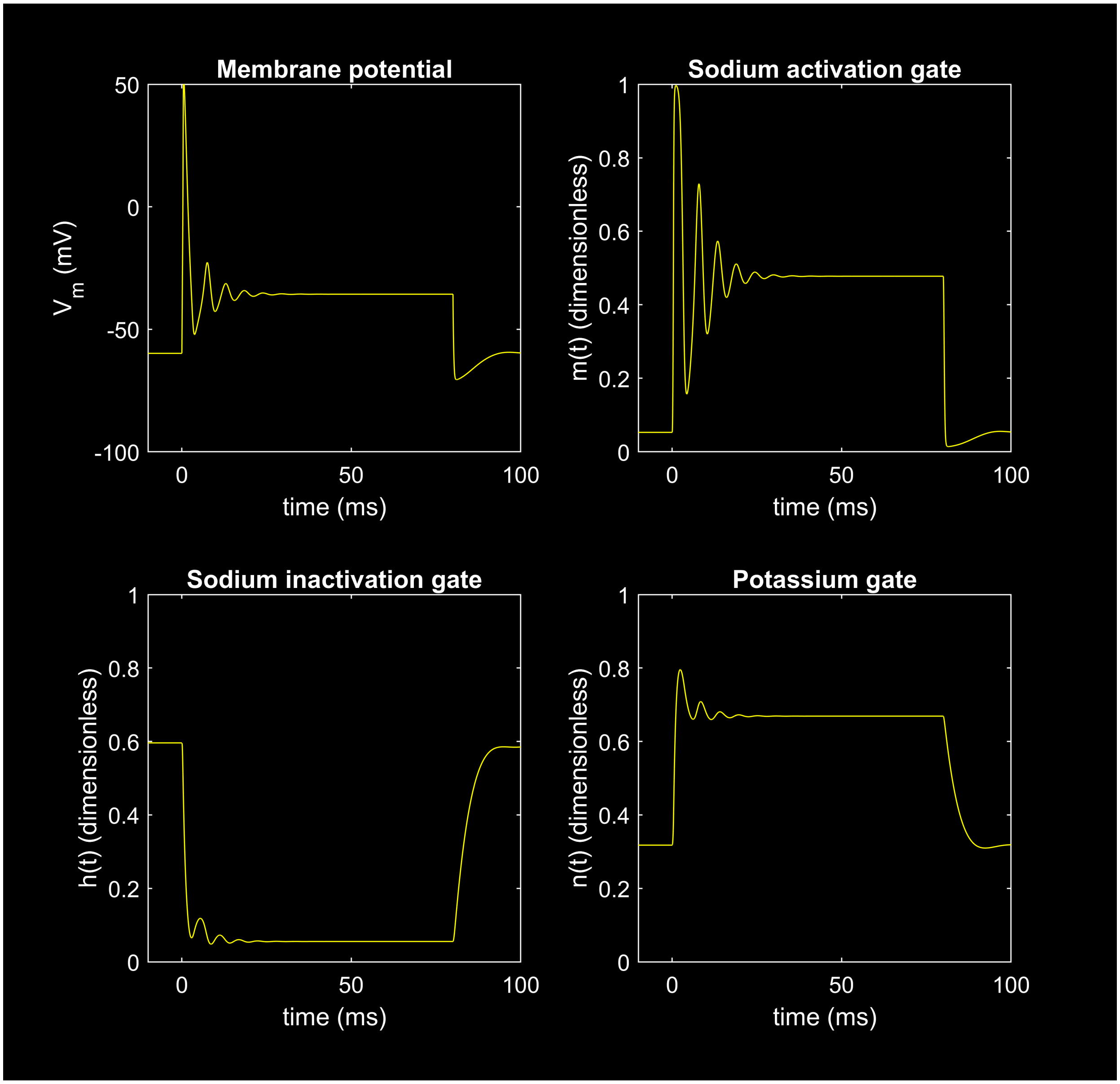


The action potential amplitude decreases with the increasing amplitude of the stimulus.

Here, the frequency increases with the increasing stimulus.

Question 6

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



Instead of an action potential there is a constant voltage present.

Action Potential Amplitude:

- The h factor (representing sodium channel inactivation) responds to depolarization. As the membrane becomes more depolarized, the h factor decreases, allowing more sodium channels to be in the active state.
- With more active sodium channels, a larger influx of sodium ions occurs during the upstroke phase of the action potential, resulting in a higher peak amplitude.

At high stimulus amplitudes, the depolarization of the membrane becomes so extreme that the h factor approaches or reaches values close to 1 (indicating minimal inactivation). As a result, a significant number of sodium channels remain in the inactivated state, hindering the influx of sodium ions and reducing the amplitude of the action potential.

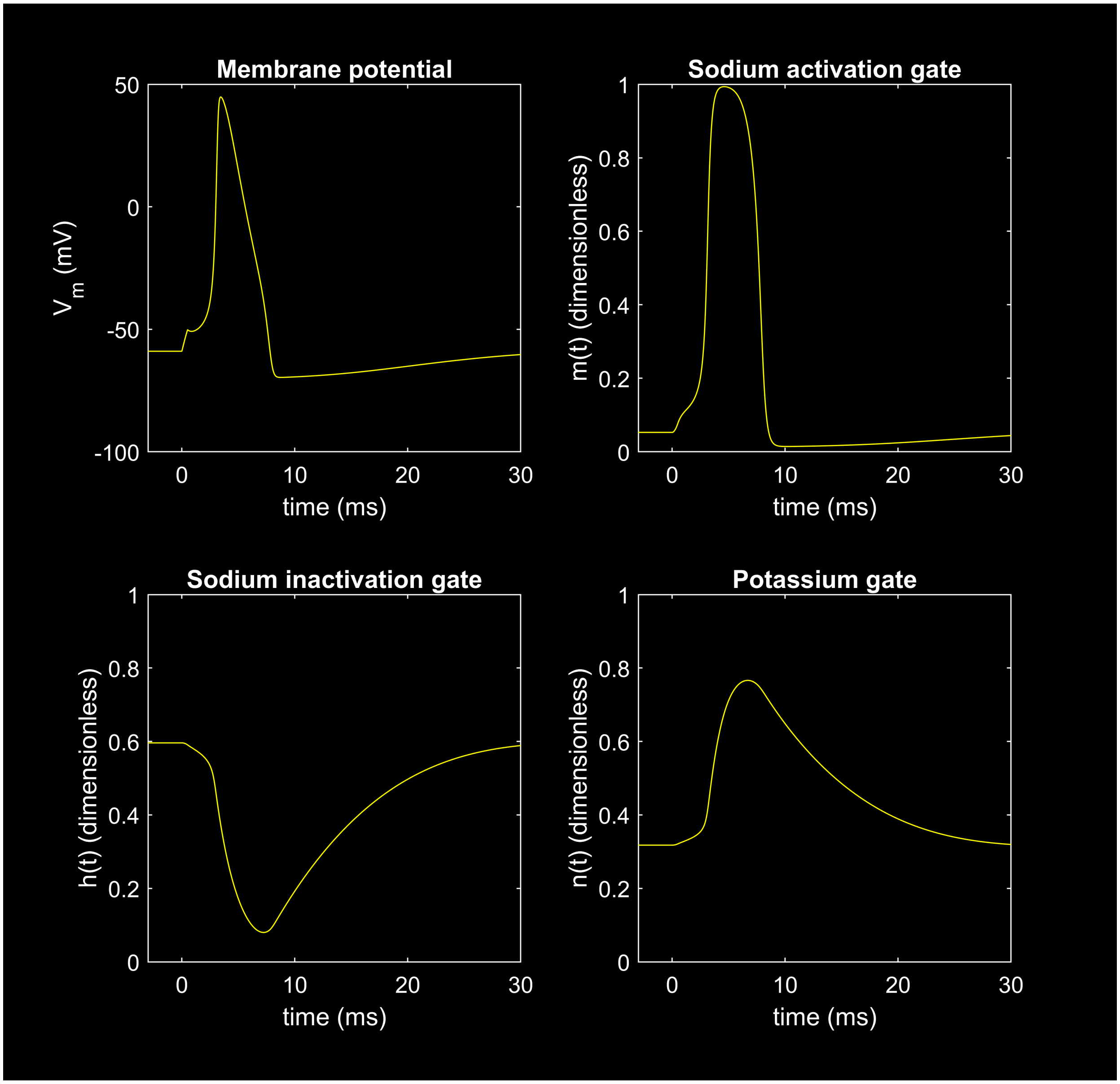
1. Depolarization Block:

- The n factor (representing potassium channel activation) is also influenced by membrane depolarization. As the membrane potential increases, the n factor increases, indicating a greater activation of potassium channels.
- The activation of potassium channels leads to an efflux of potassium ions, repolarizing the membrane and contributing to the repolarization phase of the action potential.

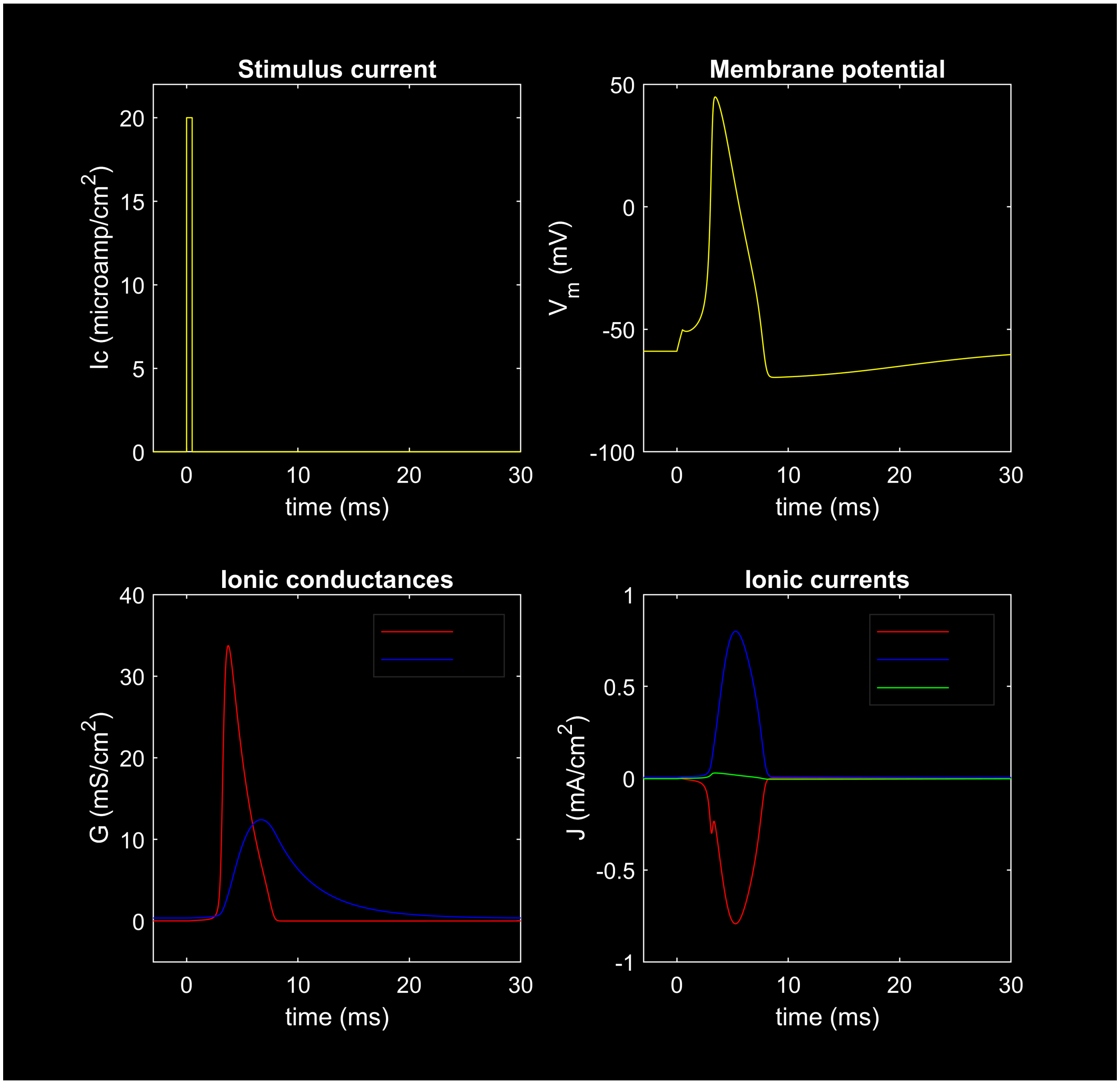
At very high stimulus amplitudes, the depolarization of the membrane can be so intense that it triggers a persistent and prolonged activation of potassium channels (n factor). This results in an excessive efflux of potassium ions, causing rapid and sustained repolarization. As a consequence, the membrane potential remains in a hyperpolarized state, making it difficult to reach the threshold required to generate subsequent action potentials. This block in action potential generation is known as depolarization block.

Question 7

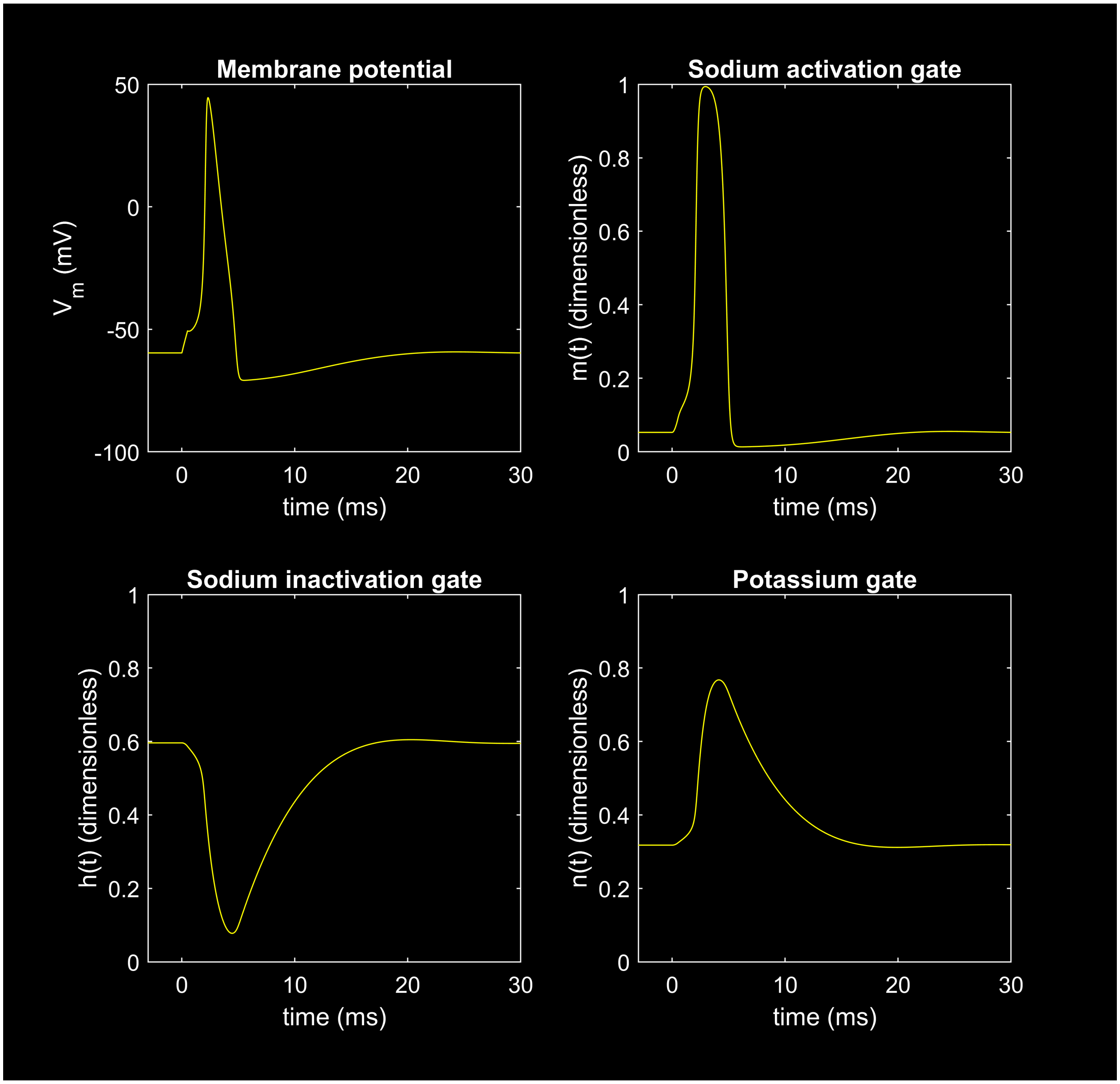
```
vclamp = 0;
amp1 = 20;
width1 = 0.5;
tempc = 0;
hhmplot(0,30,0);
```


Membrane potential
Vm (mV)
time (ms)
Sodium activation gate
m(t) (dimensionless)
time (ms)
Sodium inactivation gate
h(t) (dimensionless)
time (ms)
Potassium gate
n(t) (dimensionless)
time (ms)

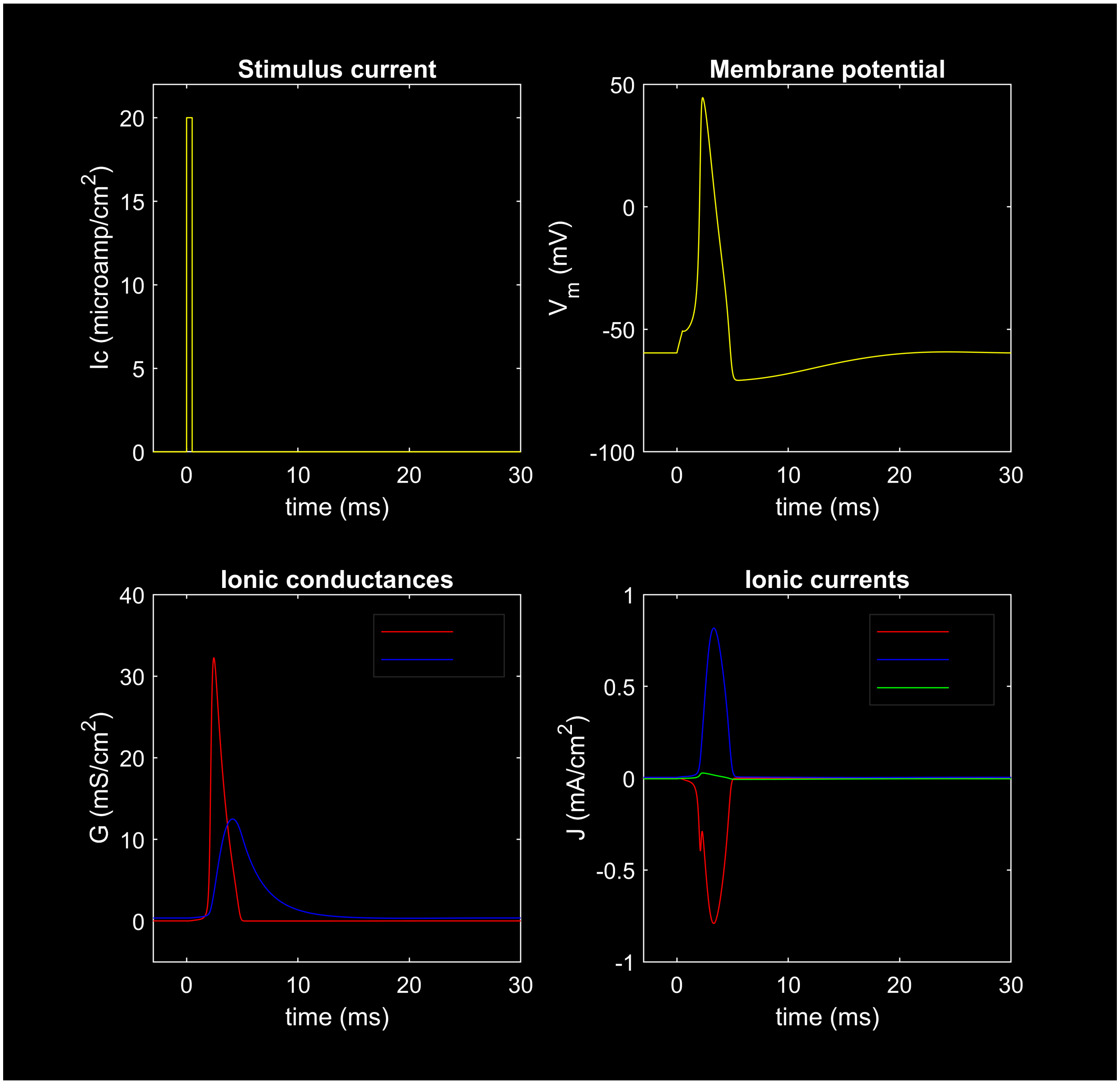
```
hhsplot(0,30);
```



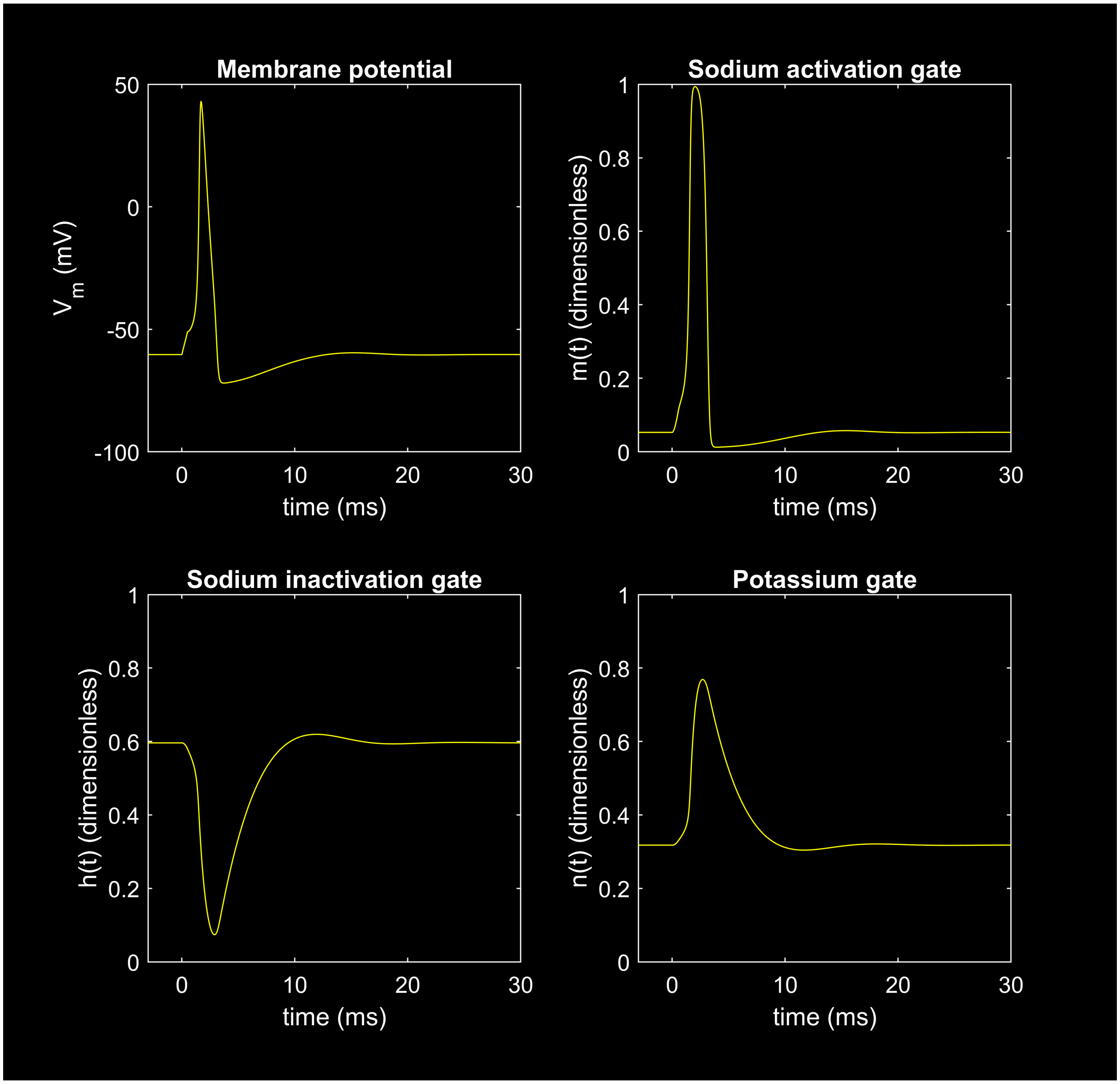

```
vclamp = 0;
amp1 = 20;
width1 = 0.5;
tempc = 5;
hhmplot(0,30,0);
```


Membrane potential
V_m (mV)
time (ms)
Sodium activation gate
m(t) (dimensionless)
time (ms)
Sodium inactivation gate
h(t) (dimensionless)
time (ms)
Potassium gate
n(t) (dimensionless)
time (ms)

```
hhsplot(0,30);
```

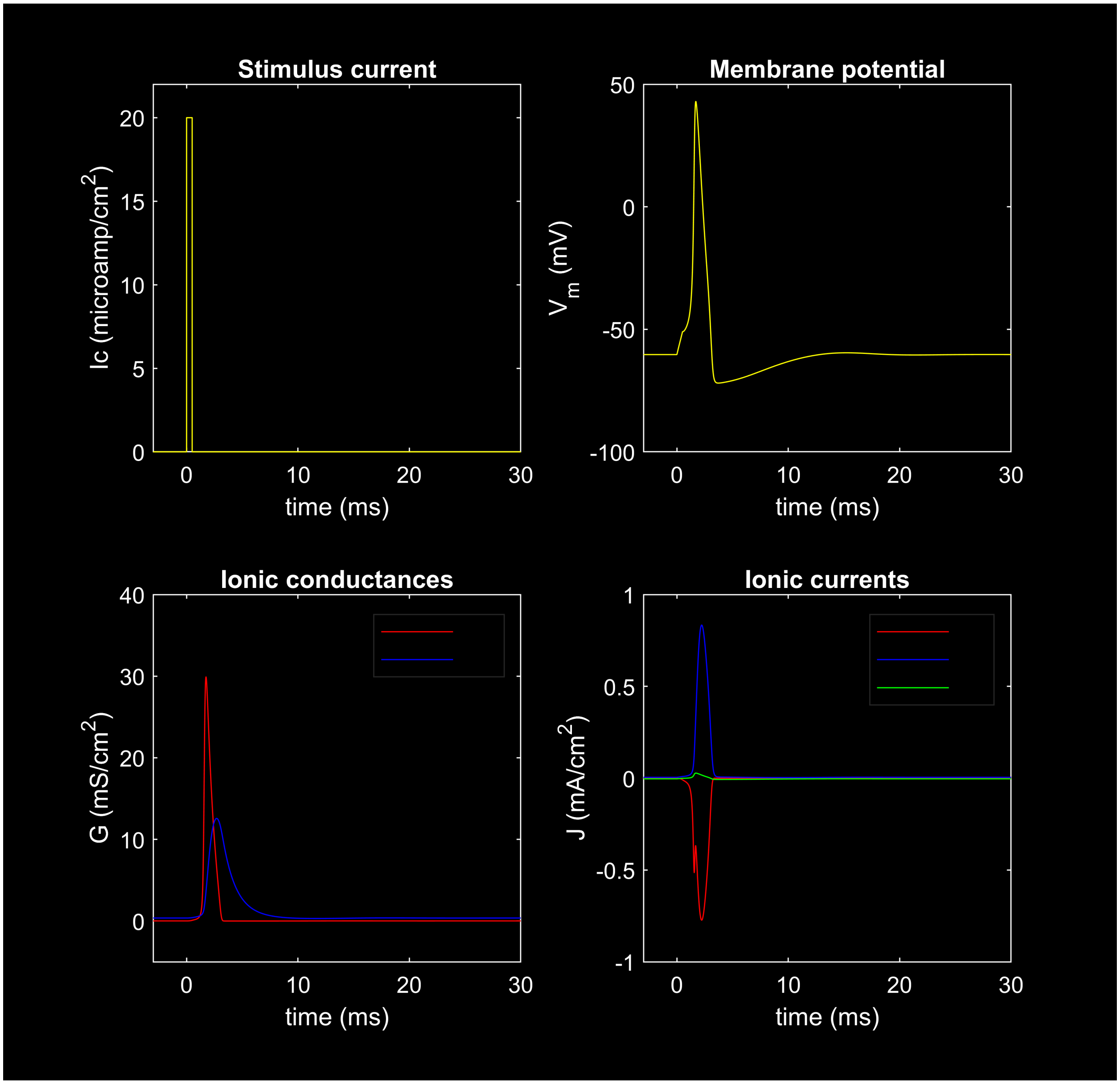



```
vclamp = 0;
amp1 = 20;
width1 = 0.5;
tempc = 10;
hhmplot(0,30,0);
```

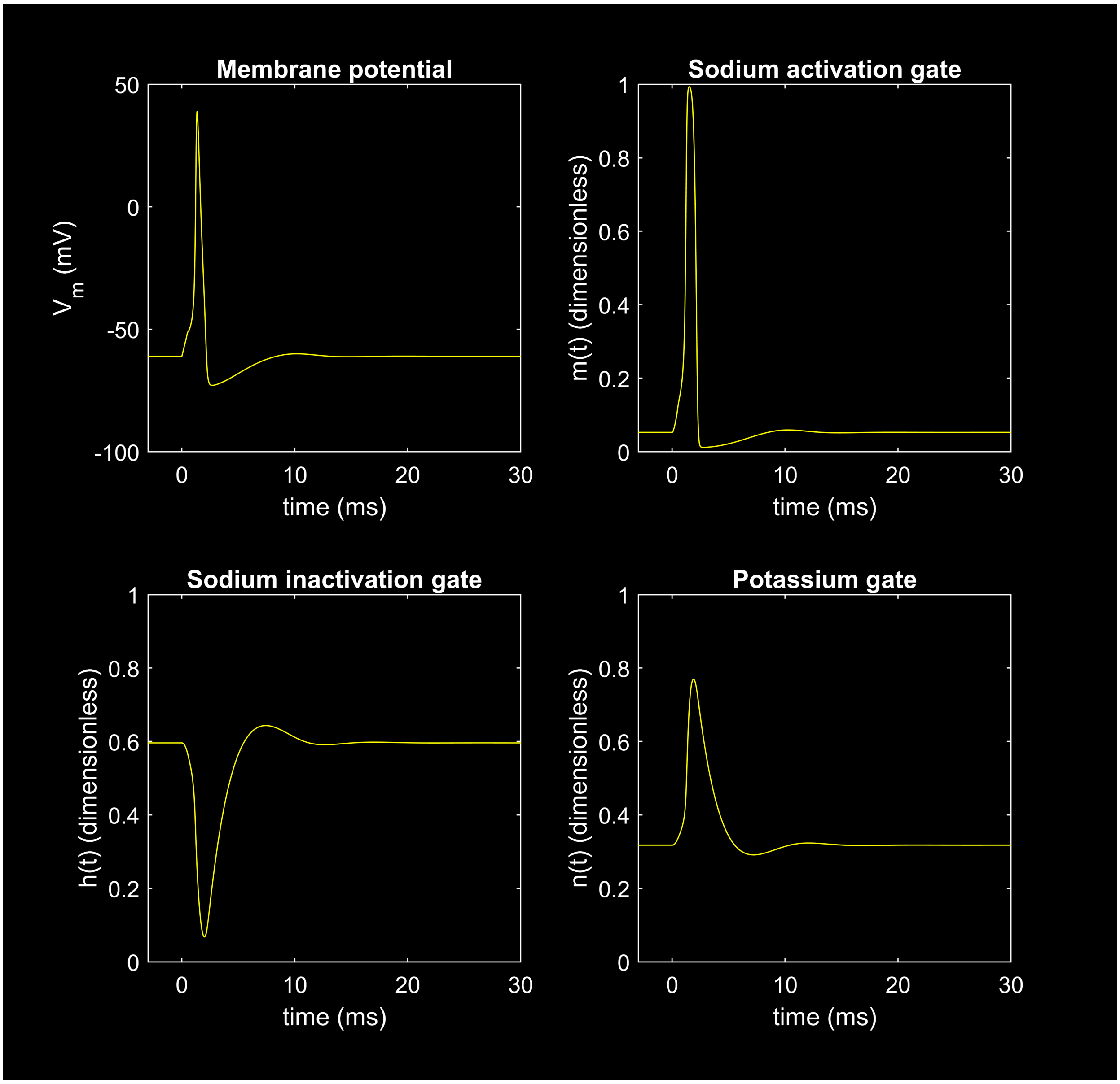


Membrane potential
50
0
-50
-100
V_m (mV)
0
10
20
30
time (ms)
Sodium activation gate
1
0.8
0.6
0.4
0.2
0
m(t) (dimensionless)
0
10
20
30
time (ms)
Sodium inactivation gate
1
0.8
0.6
0.4
0.2
0
h(t) (dimensionless)
0
10
20
30
time (ms)
Potassium gate
1
0.8
0.6
0.4
0.2
0
n(t) (dimensionless)
0
10
20
30
time (ms)

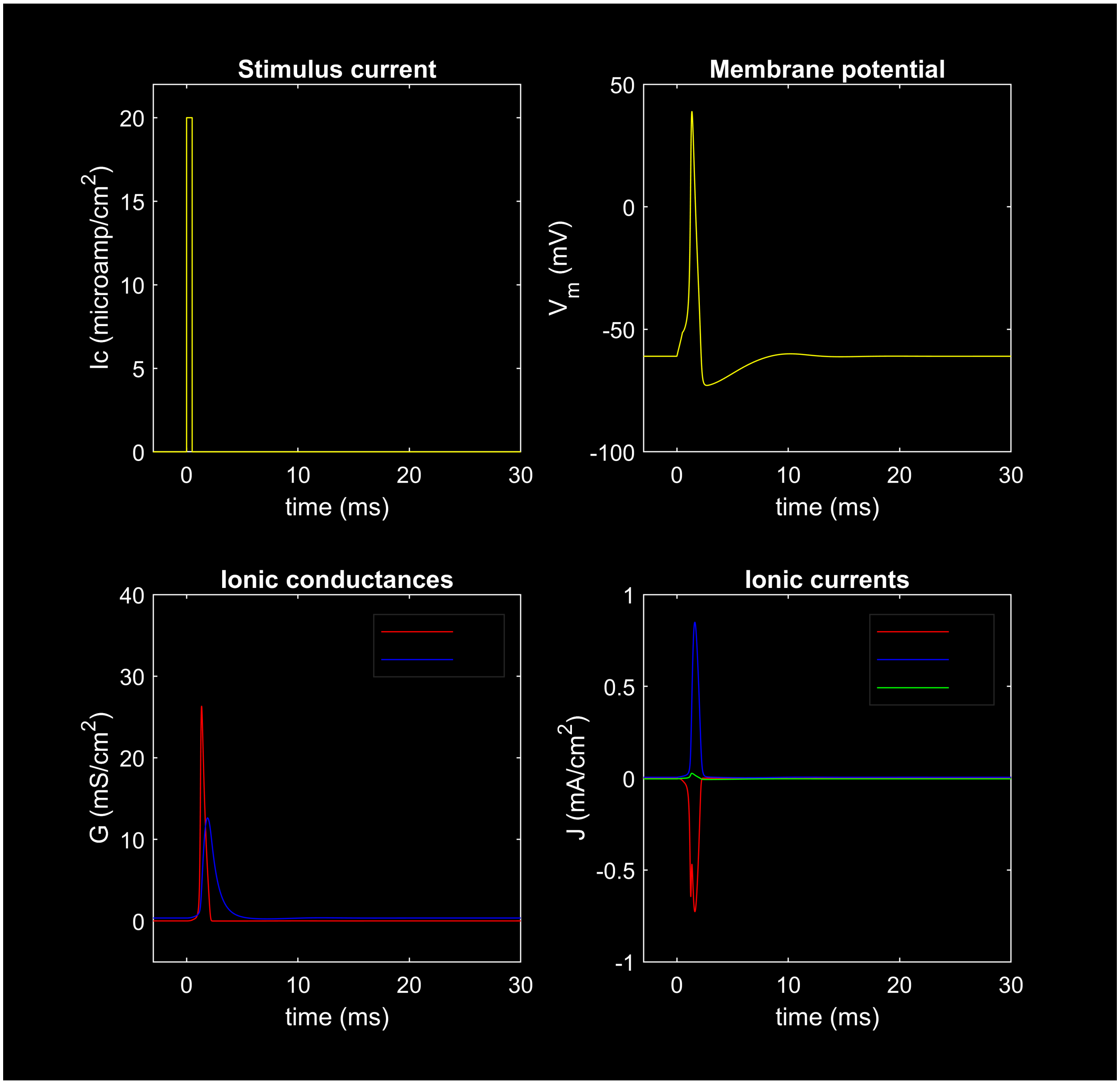

```
hhsplot(0,30);
```



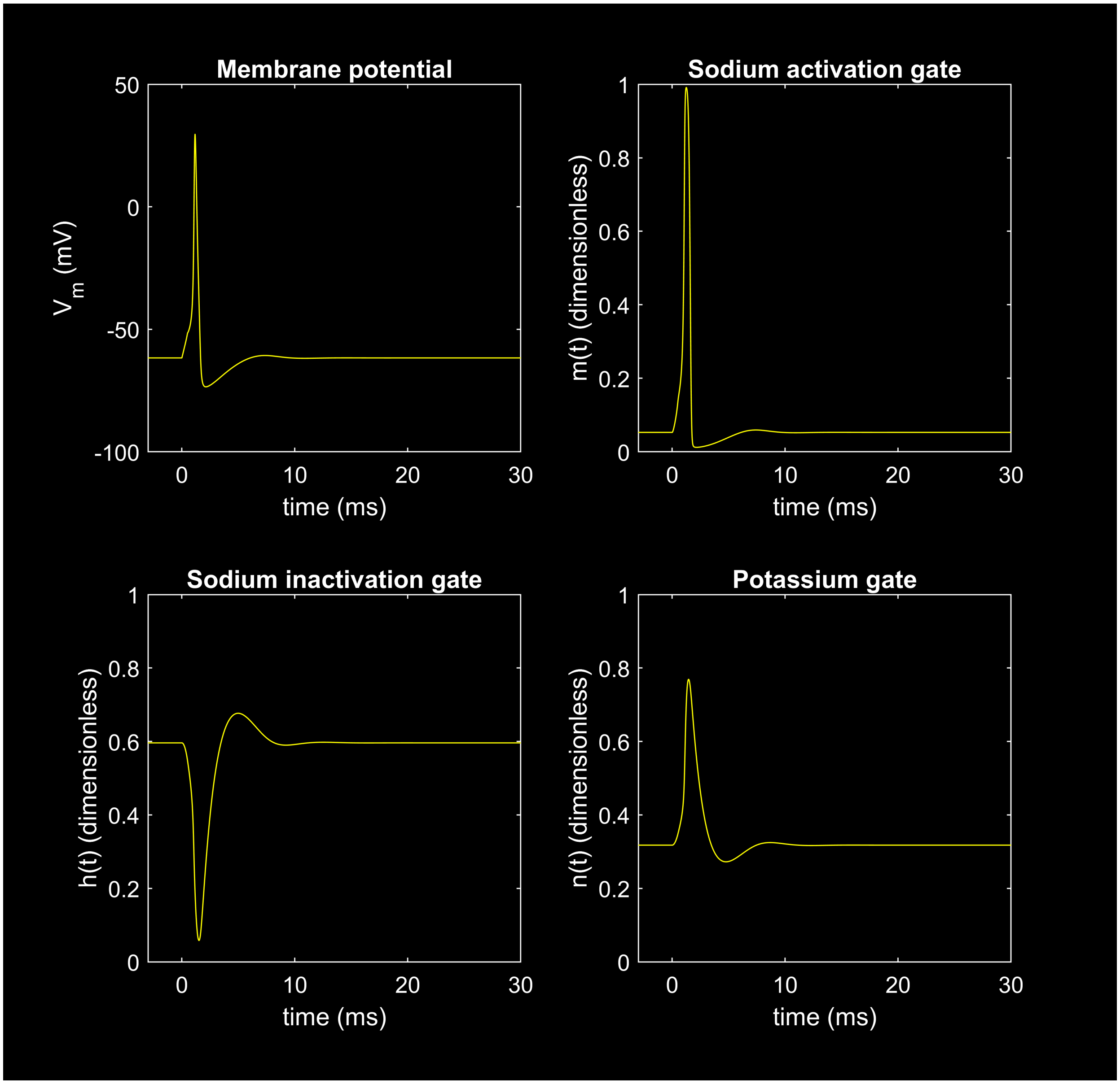

```
vclamp = 0;
amp1 = 20;
width1 = 0.5;
tempc = 15;
hhmplot(0,30,0);
```


Membrane potential
V_m (mV)
50
0
-50
-100
0
10
20
30
time (ms)
Sodium activation gate
m(t) (dimensionless)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
time (ms)
Sodium inactivation gate
h(t) (dimensionless)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
time (ms)
Potassium gate
n(t) (dimensionless)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
time (ms)

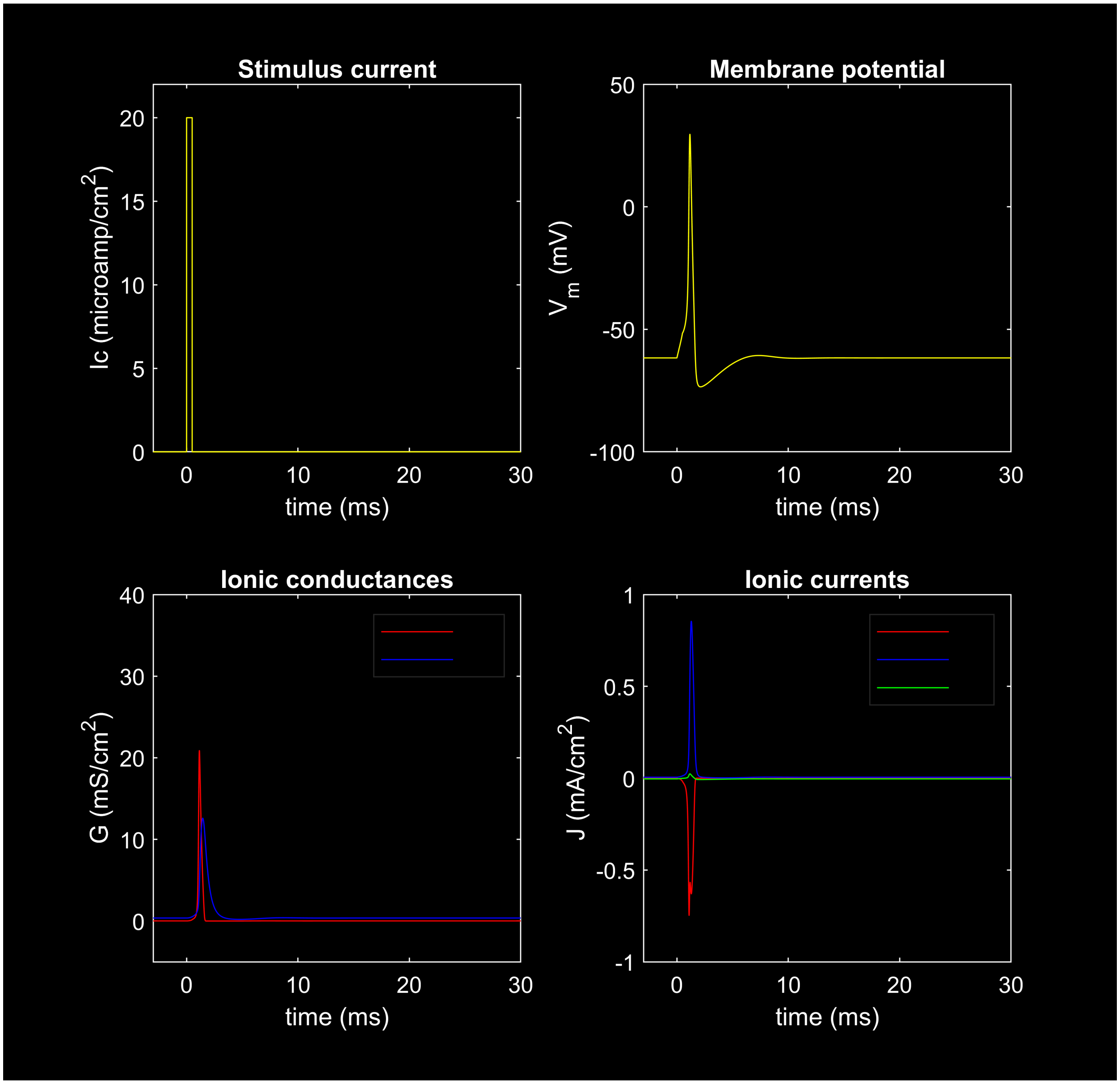
```
hhsplot(0,30);
```



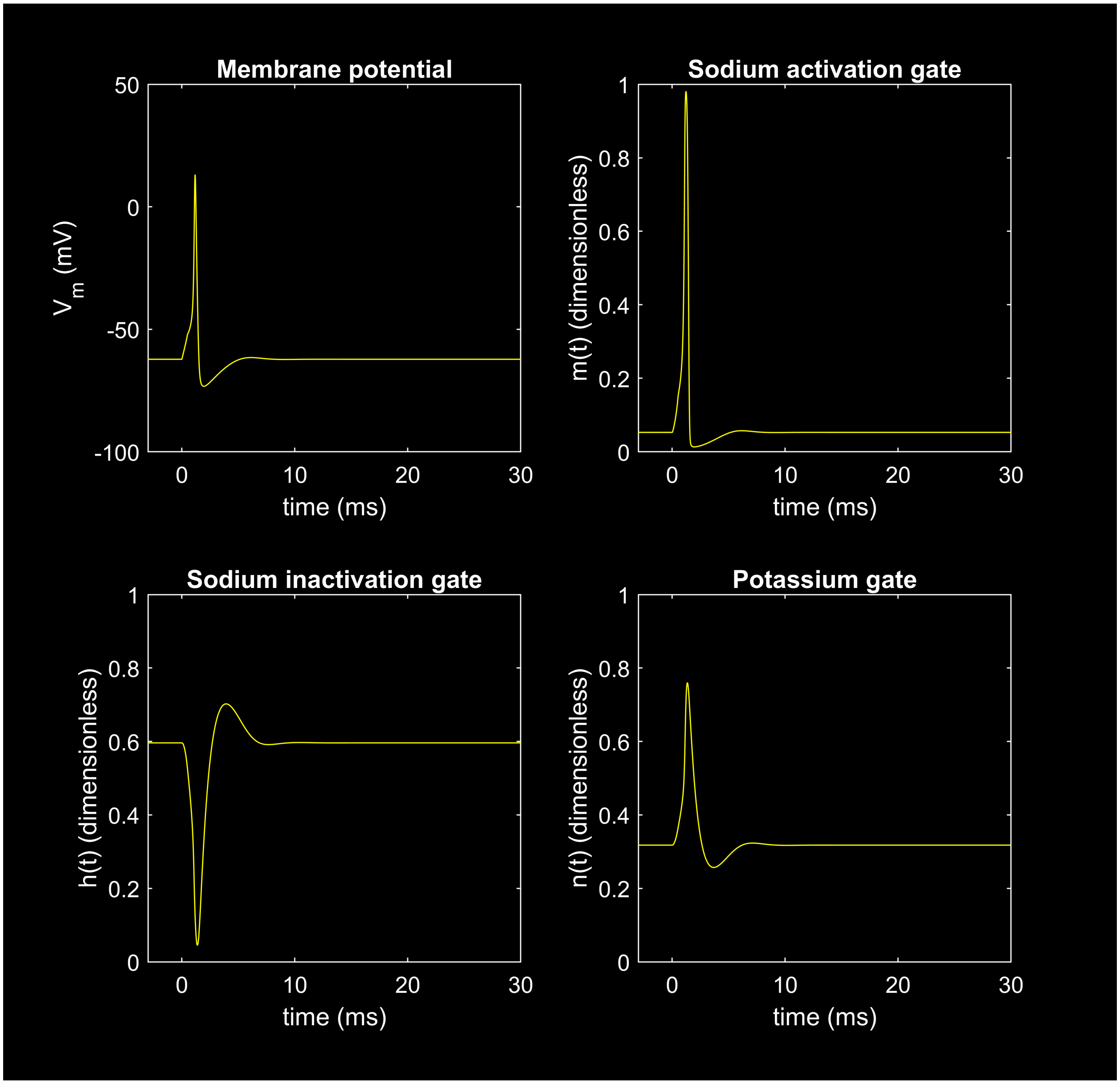

```
vclamp = 0;
amp1 = 20;
width1 = 0.5;
tempc = 20;
hhmplot(0,30,0);
```


Membrane potential
Sodium activation gate
Sodium inactivation gate
Potassium gate
V_m (mV)
m(t) (dimensionless)
h(t) (dimensionless)
n(t) (dimensionless)
time (ms)

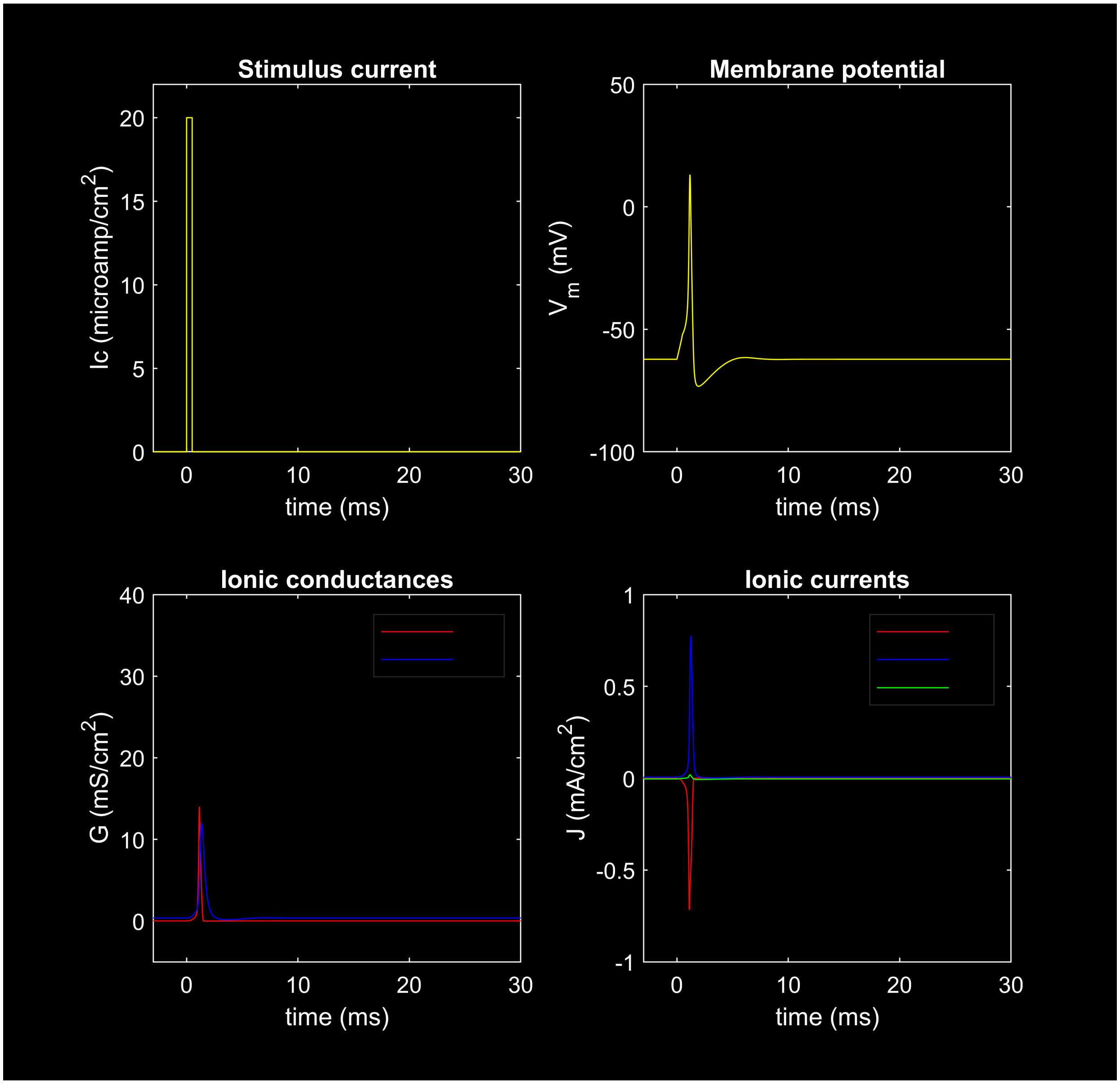
```
hhsplot(0,30);
```



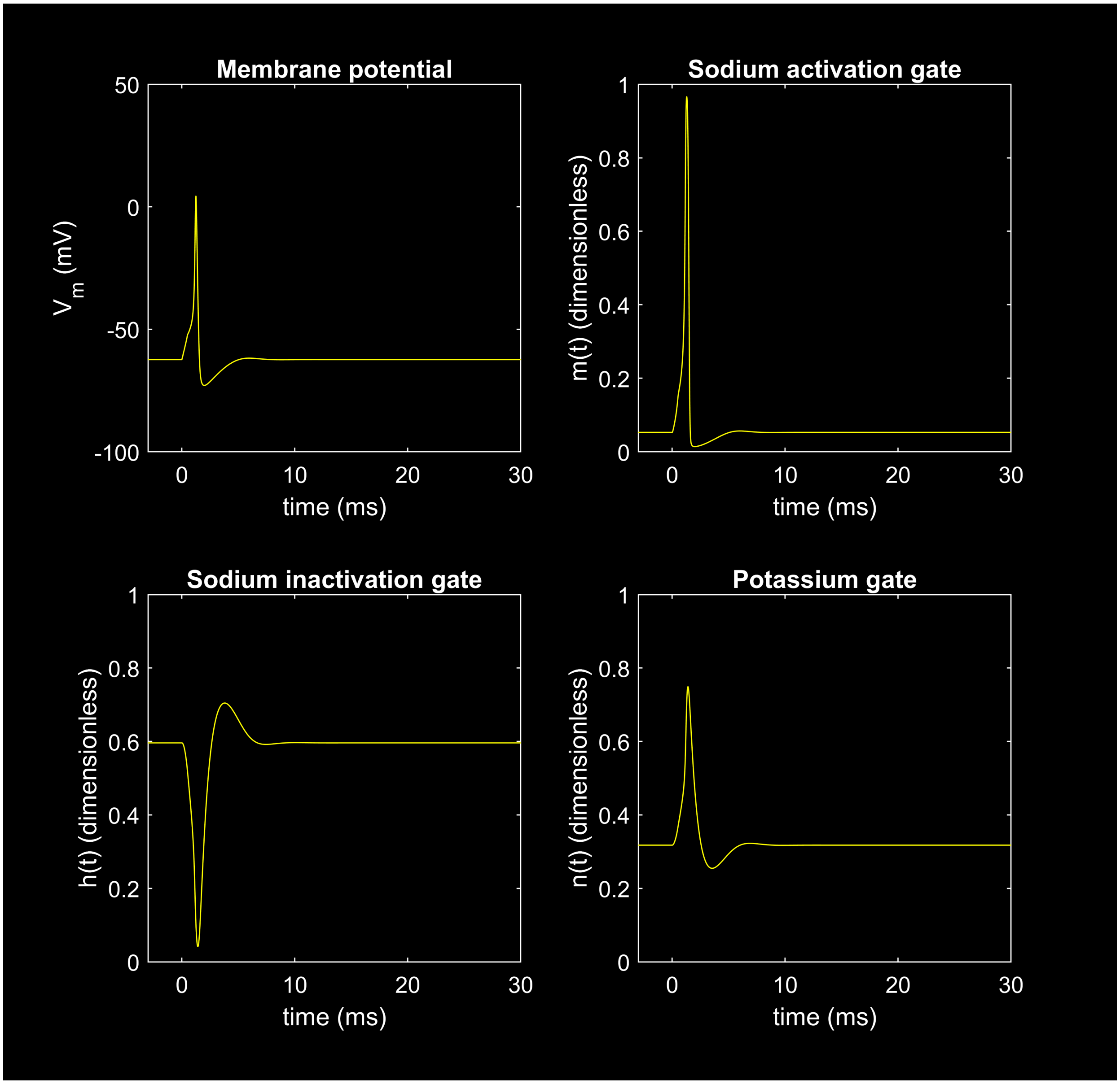

```
vclamp = 0;
amp1 = 20;
width1 = 0.5;
tempc = 24;
hhmplot(0,30,0);
```


Membrane potential
V_m (mV)
50
0
-50
-100
0
10
20
30
time (ms)
Sodium activation gate
m(t) (dimensionless)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
time (ms)
Sodium inactivation gate
h(t) (dimensionless)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
time (ms)
Potassium gate
n(t) (dimensionless)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
time (ms)

```
hhsplot(0,30);
```

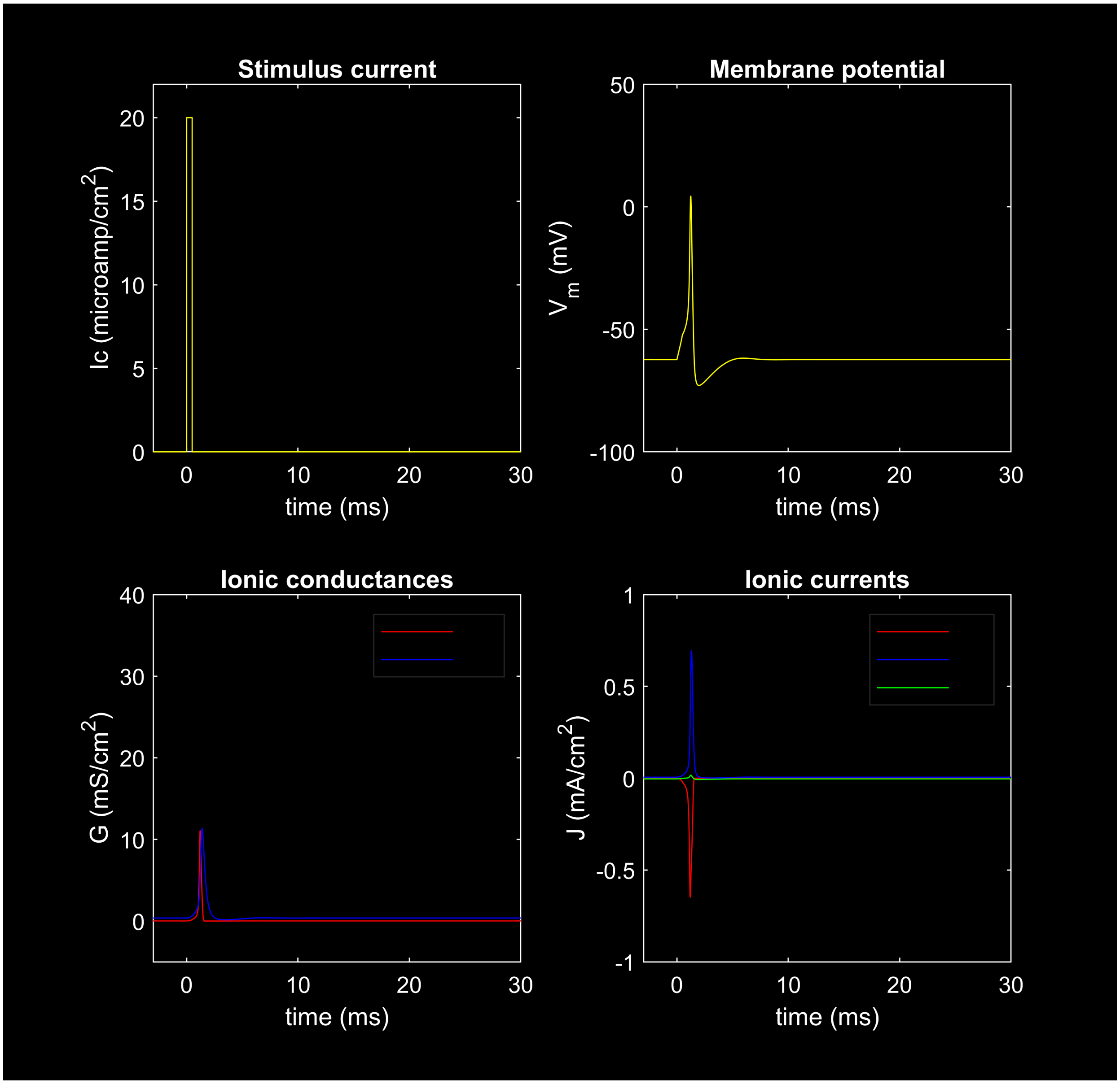



```
vclamp = 0;
amp1 = 20;
width1 = 0.5;
tempc = 25;
hhmplot(0,30,0);
```

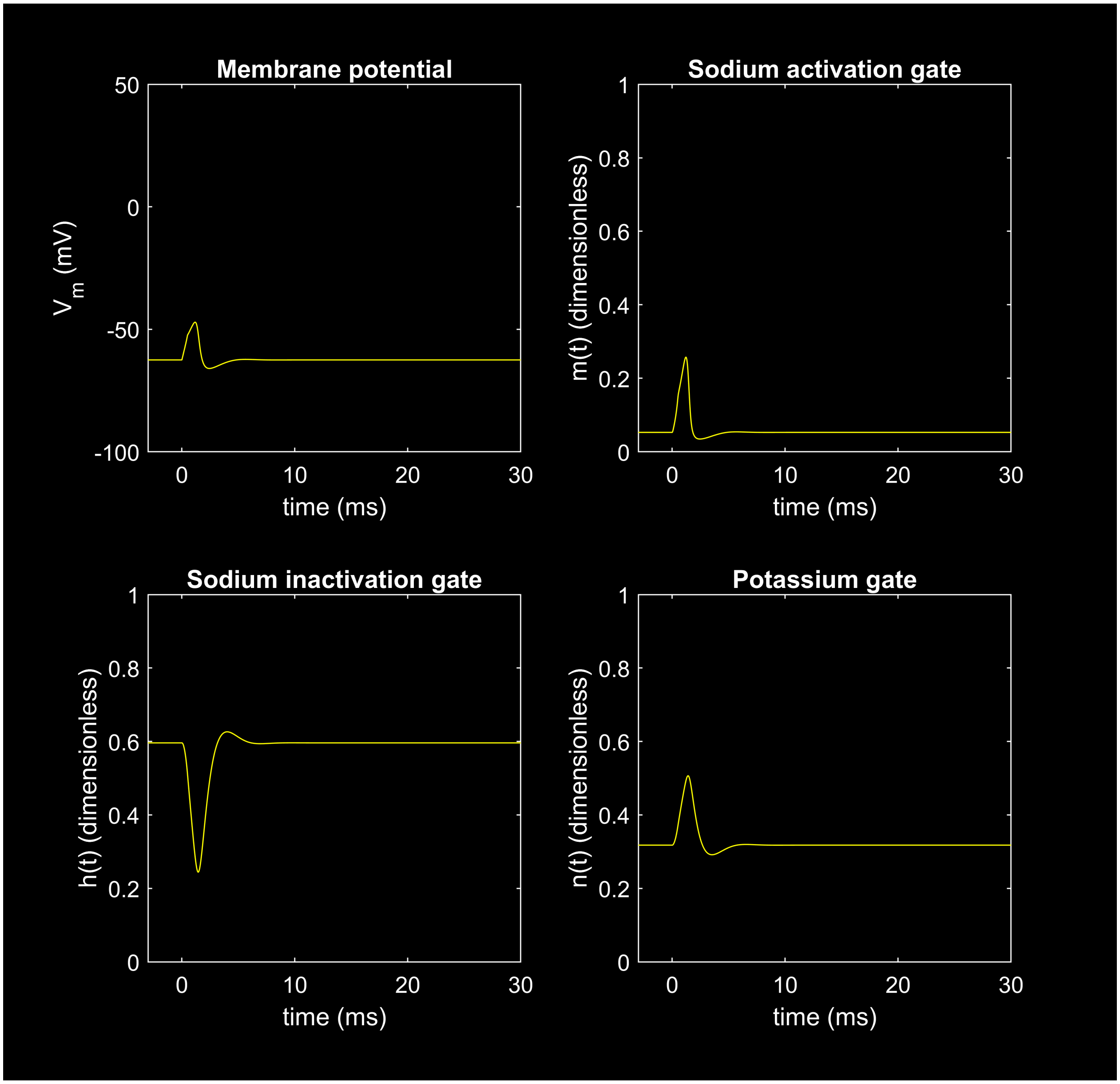


Membrane potential
V_m (mV)
50
0
-50
-100
0
10
20
30
time (ms)
Sodium activation gate
m(t) (dimensionless)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
time (ms)
Sodium inactivation gate
h(t) (dimensionless)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
time (ms)
Potassium gate
n(t) (dimensionless)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
time (ms)

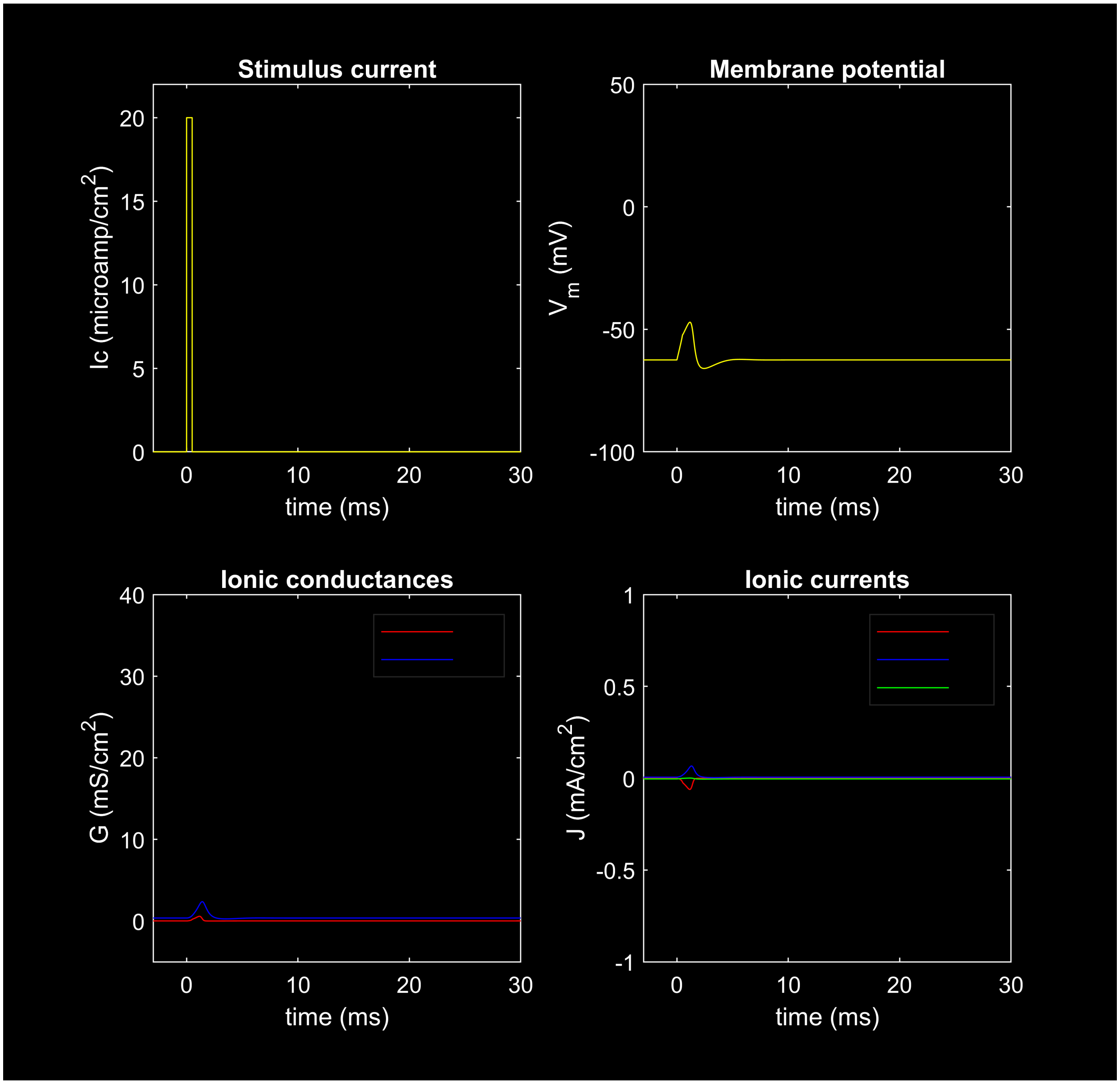

```
hhsplot(0,30);
```



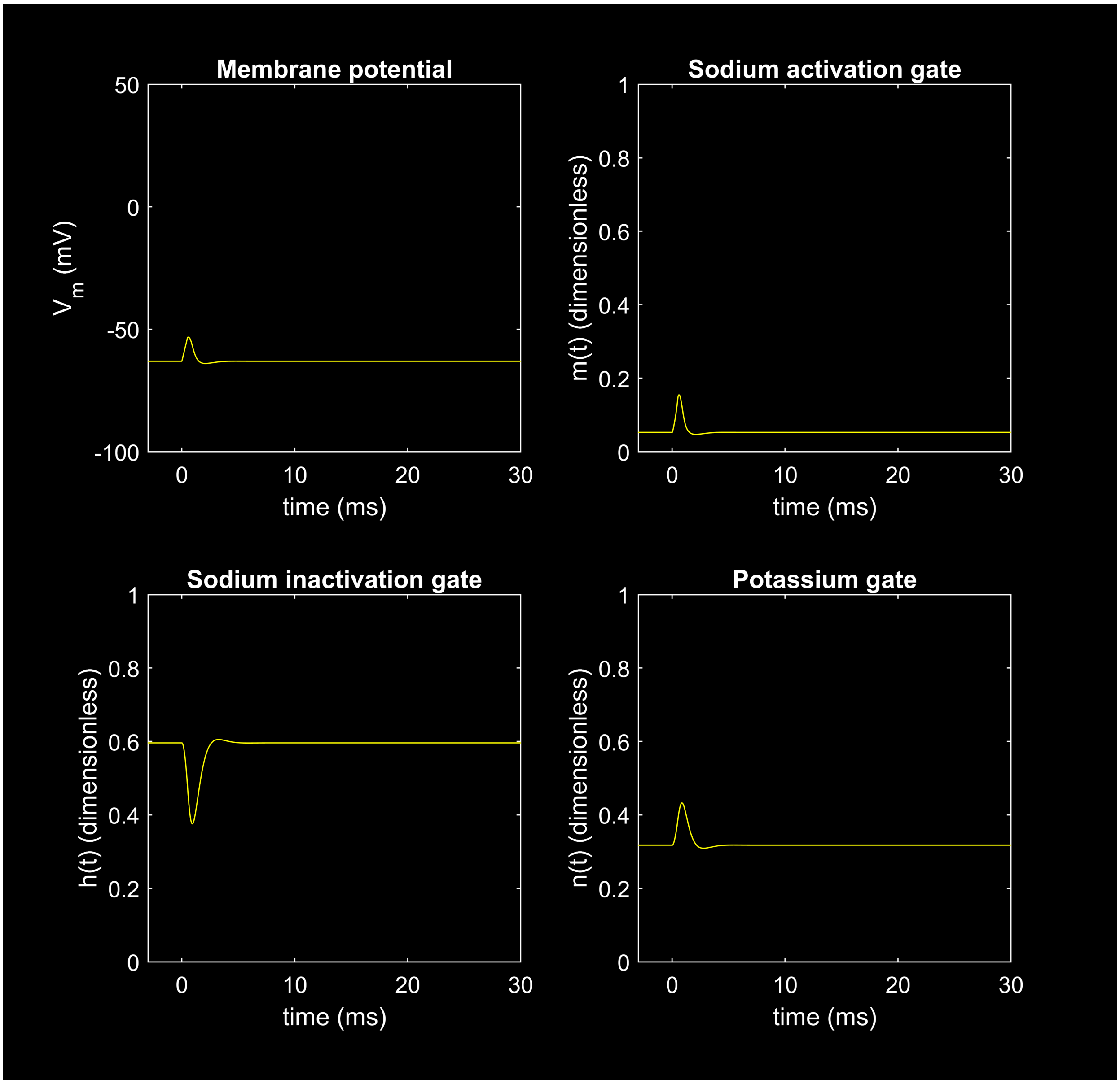

```
vclamp = 0;
amp1 = 20;
width1 = 0.5;
tempc = 26;
hhmplot(0,30,0);
```


Membrane potential
Sodium activation gate
Sodium inactivation gate
Potassium gate
V m (mV)
m(t) (dimensionless)
h(t) (dimensionless)
n(t) (dimensionless)
time (ms)
50
0
-50
-100
1
0.8
0.6
0.4
0.2
10
20
30

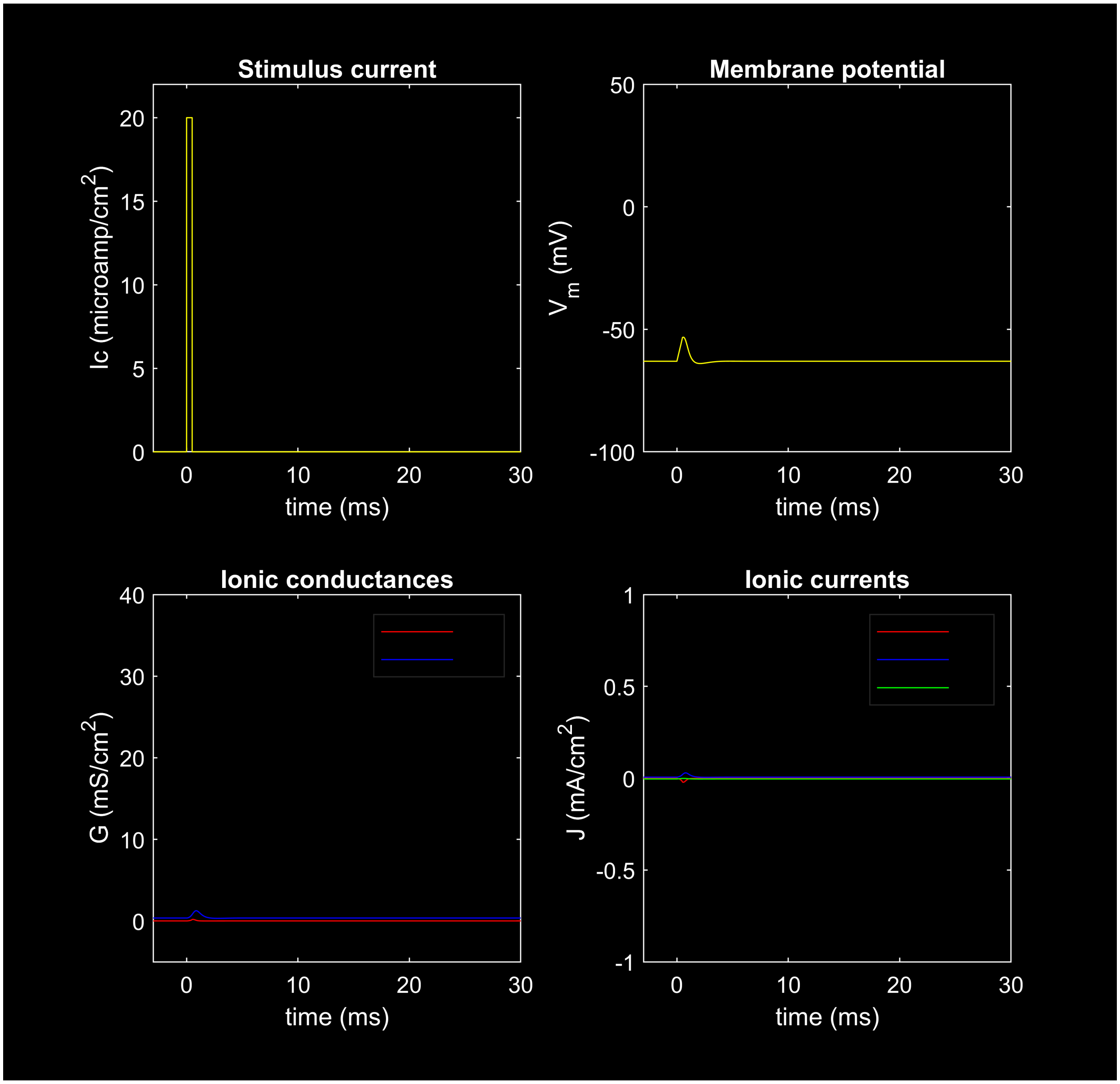
```
hhsplot(0,30);
```




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


Membrane potential
Sodium activation gate
Sodium inactivation gate
Potassium gate
V m (mV)
m(t) (dimensionless)
h(t) (dimensionless)
n(t) (dimensionless)
time (ms)
50
0
-50
-100
1
0.8
0.6
0.4
0.2
0
10
20
30

```
hhsplot(0,30);
```



1. Duration: As temperature increases, the action potential duration tends to decrease. Higher temperatures enhance ion channel kinetics, leading to faster activation and inactivation processes. This results in shorter action potential durations.

2. Amplitude: The amplitude decreases with the temperature. It is because rate of inactivation of Na channels increases, leading to lower Na channels to contribute the depolarization.

Also, Ionic channel conductance, and ionic currents has also been reduced.