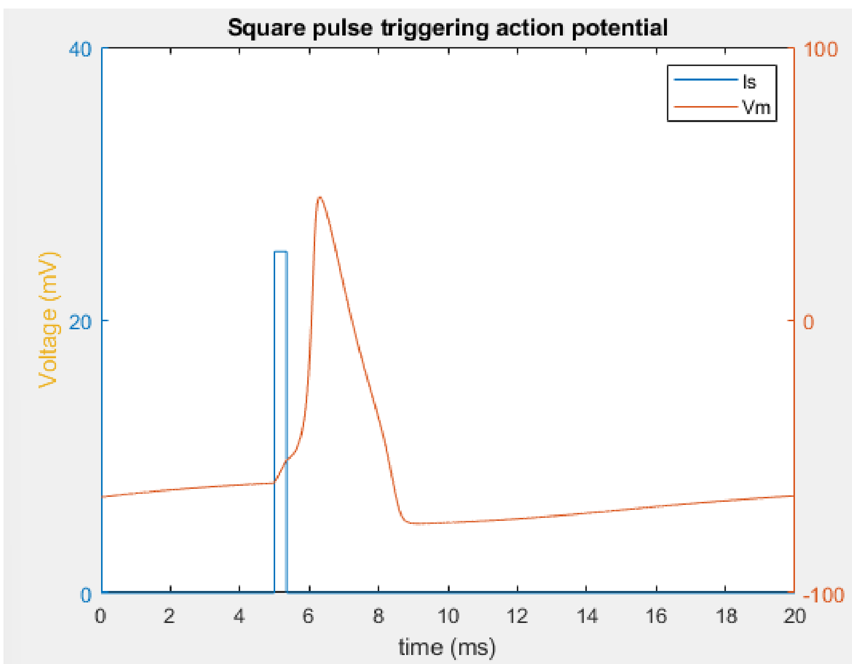
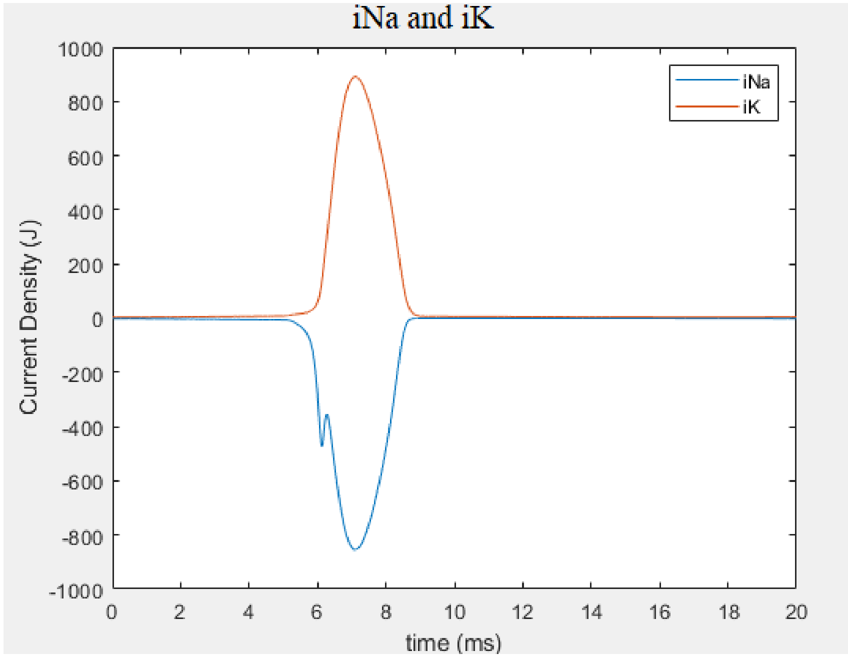
All Code (q1p1.m, hh_diff_eq.m, hhdiff2.m) are given in the last section of this report. Continuing are the answers to the problems excluding code.

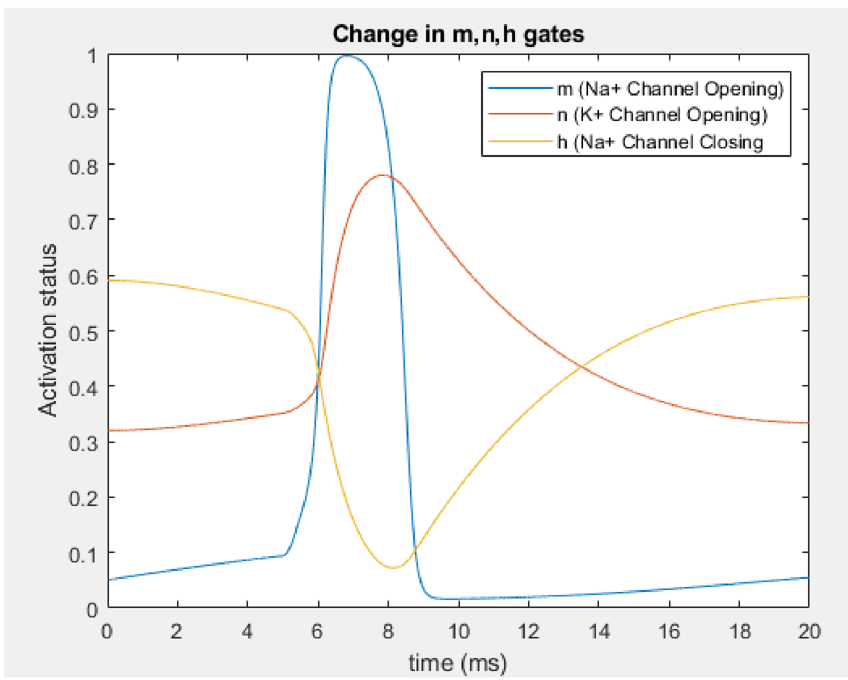
Problem 1&2

Three graphs below show the result from the problem 1 and 2.

1. Square Pulse Triggering Action Potential
2. 'Change in iNa and iK'
3. Change in m,n,h gates

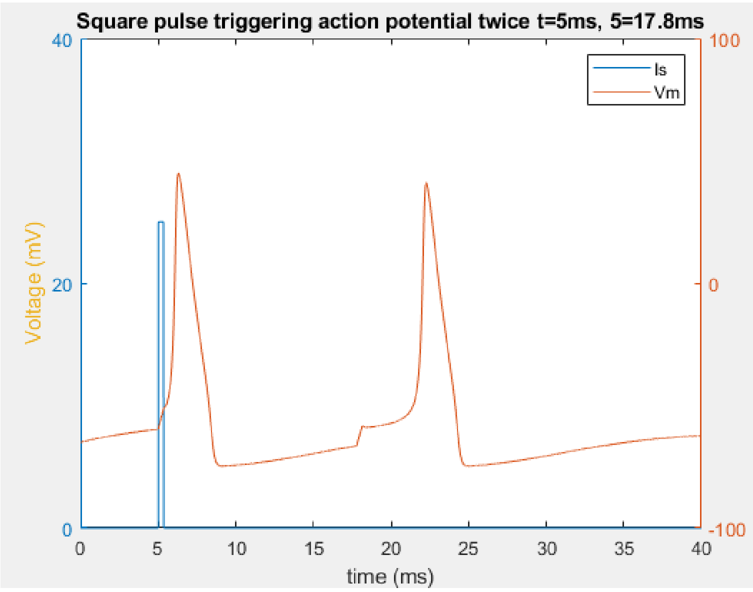



iNa and iK
iNa
iK
Current Density (J)
time (ms)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
0
2
4
6
8
10
12
14
16
18
20

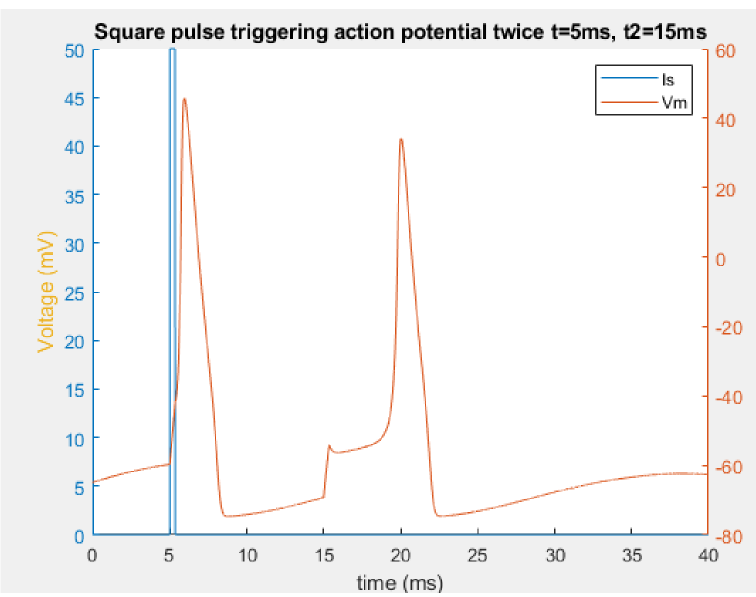

Change in m,n,h gates
m (Na+ Channel Opening)
n (K+ Channel Opening)
h (Na+ Channel Closing
Activation status
time (ms)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
20

Problem 3

3a) When the second stimulation was given at t2=17.8ms (i.e. 12.8 ms away from the first pulse), the actional potential showed to occur.

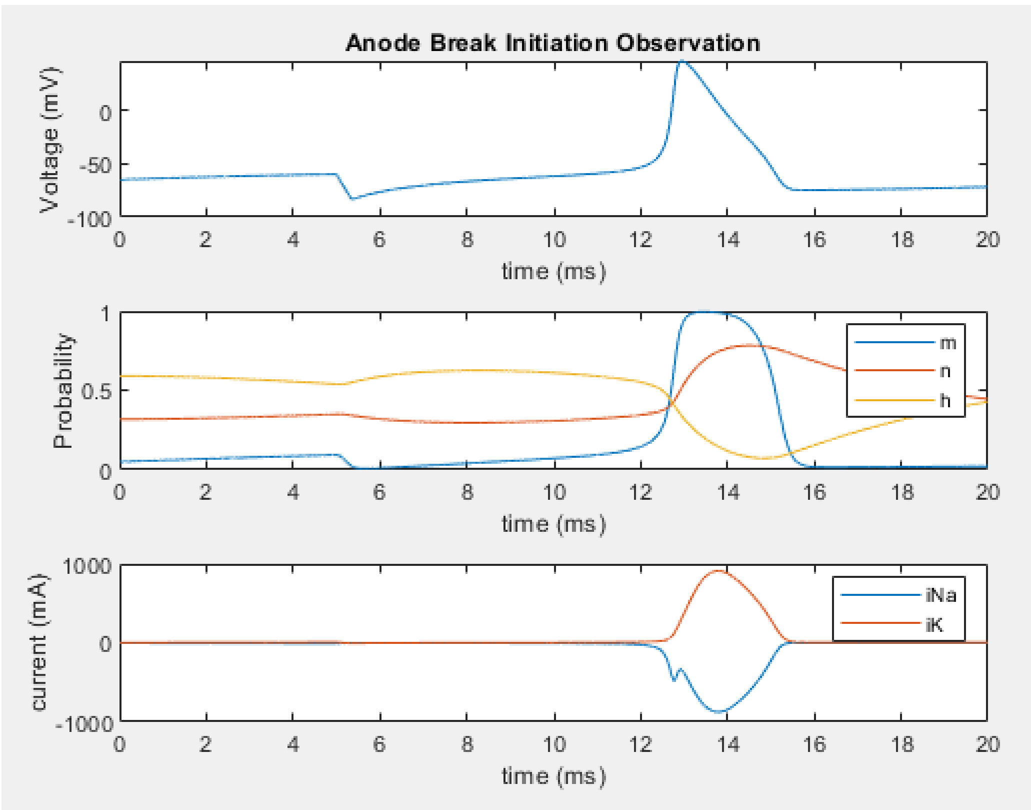


3b) When the second pulse magnitude of pulse was doubled, t2 = 15ms (i.e. 10ms away from the first pulse) showed to derive an actional potential reaction. This tells us that amplifying the square pulse input signal shortens the delay for the neural circuit to show response.



Problem 4

The original square pulse was tripled, then multiplied by -1 to derive an anode break initiation.



All Codes

Code: main.m

```
clc;
clear;
close all;
% MAIN PROGRAM P1, P2, P3, P4

%Initial parameters
y0(1,1) = -65; % Initial Membrane Voltage
y0(2,1) = 0.05; %m
y0(3,1) = 0.32; %n
y0(4,1) = 0.59; %h

dt=[0,20];  % time of integration in ms
%dt=[0,40];  uncomment this part for problem 3

Temp = 20;
Gas = 8.31;
Faraday = 96485.33;
Kelvin = 273 + Temp;

gNa = 120; %mS/cm^2
gK = 36; %mS/cm^2
gL = 0.3; %ms/cm^2
exNa = 490; %mmol/L
exK = 20;
inNa = 50;
inK = 400;
lNp = -50; %mV
mC = 1; %uF/cm^2

%Na, K Nernst Potential
nNa = (Gas * Kelvin) / Faraday * 1000 * log(exNa / inNa);
nK = (Gas * Kelvin) / Faraday * 1000 * log(exK / inK);

%setup
is = 5;
id = 0.35;
im = 25;
%im = 50; %uncomment for 3b



options=odeset('RelTol',1e-4,'AbsTol',[1e-8, 1e-8, 1e-8, 1e-8],'MaxStep',0.01);
[t,y]=ode45('hh_diff_eq',dt,y0,options);
```

```
iK = ((y(:,3).^4) .* (y(:,1)-nK)) .* gK ;
iNa = ((y(:,2).^3) .* y(:,4) .* (y(:,1)-nNa)) .* gNa ;

I=zeros(1,length(t));
for t0=1:length(t)
    if t(t0)>is && t(t0)<(is+id)
        I(t0)=im;
    end
end

V=y(:,1);
m=y(:,2);
n=y(:,3);
h=y(:,4);

iNa = (m.^3 .* h .* (V-nNa)) .* gNa ;
iK = (n.^4 .* (V-nK)) .* gK;


figure(1);
[ax,p1] = plotyy(t,I,t,y(:,1))
title('Square pulse triggering action potential')
xlabel('time (ms)')
ylabel('Voltage (mV)', 'Color', '#EDB120')
legend('Is', 'Vm')

figure(2);
plot(t,iNa,t,iK)
ylabel('Current Density (J)')
xlabel('time (ms)')
title('Change in iNa and iK')
legend('iNa','iK')


figure(3);
plot(t,y(:,2))
hold all
plot(t,y(:,3))
plot(t,y(:,4))
title('Change in m,n,h gates')
legend('m (Na+ Channel Opening)','n (K+ Channel Opening)','h (Na+ Channel Closing')
xlabel('time (ms)')
ylabel('Activation status')

% Problem 3a
figure(4);
[ax,p1] = plotyy(t,I,t,y(:,1))
title('Square pulse triggering action potential twice t=5ms, t2=17.8ms')
xlabel('time (ms)')
ylabel('Voltage (mV)', 'Color', '#EDB120')
legend('Is', 'Vm')
% Problem 3b
figure(5);
[ax,p1] = plotyy(t,I,t,y(:,1))
```

```
title('Square pulse triggering action potential twice t=5ms, t2=15ms')
xlabel('time (ms)')
ylabel('Voltage (mV)', 'Color', '#EDB120')
legend('Is', 'Vm')




% Problem 4
clc;
clear all; close all;

gNa = 120; %mS/cm^2
gK = 36; %mS/cm^2
nNa = 57.59;
nK = -75.59;
y0(1,1) = -65; % Initial Membrane Voltage
y0(2,1) = 0.05; %m
y0(3,1) = 0.32; %n
y0(4,1) = 0.59; %h


dt = [0,20];
options = odeset('RelTol',1e-4,'AbsTol',[1e-8,1e-8,1e-8,1e-8],'MaxStep',0.01);
[t,y] = ode45('hhdiff2',dt,y0,options);
V=y(:,1);
m=y(:,2);
n=y(:,3);
h=y(:,4);
iNa = (m.^3 .* h .* (V-nNa)) .* gNa ;
iK = (n.^4 .* (V-nK)) .* gK;


figure
subplot(3,1,1);
plot(t,y(:,1));
xlabel('time (ms)');
ylabel('Voltage (mV)');
title('Anode Break Initiation Observation')

subplot(3,1,2);
plot(t,m);
hold all
xlabel('time (ms)');
ylabel('Probability');
plot(t,n);
xlabel('time (ms)');
ylabel('Probability');
plot(t,h);
xlabel('time (ms)');
ylabel('Probability');
legend('m','n','h');

subplot(3,1,3);
plot(t,iNa);
```

```
hold all
xlabel('time (ms)');
ylabel('current (mA)');
plot(t, iK);
legend('iNa','iK');
```

Code: hh_diff_eq.m

```
function [dydt] = hh_diff_eq(t,y)

is = 5;
id = 0.35;
im = 25;
%im = 50; %uncomment for problem 3b


if (t>is) && (t<id+is)
    I=im;
%elseif (t>17.8) && (t<17.8+id) %uncomment for problem3a
    %I = im;
%elseif (t>15) && (t<15+id) %uncomment for problem3b
    %I = im;
else
    I = 0;
end

V=y(1,1);
m=y(2,1);
n=y(3,1);
h=y(4,1);
vRest=-65;
vMem=V-vRest;

gNa = 120; %mS/cm^2
gK = 36; %mS/cm^2
gL = 0.3; %ms/cm^2

exNa = 490; %mmol/L
exK = 20;
inNa = 50;
inK = 400;

mC = 1; %uF/cm^2
lNp = -50; %mV
nNa = 57.59;
nK = -75.59;


a_n=.01*(10-vMem)./(exp((10-vMem)/10)-1);
b_n=.125*exp(-vMem/80);

a_m=.1*(25-vMem)./(exp((25-vMem)/10)-1);
b_m=4*exp(-vMem/18);

a_h=0.07*exp(-vMem/20);
b_h=1/(exp((30-vMem)/10)+1);


%ode V, n, m, h
dydt(1,1)= ((I-gNa*m^3*h*(V-nNa))-(gK*n^4*(V-nK))-(gL*(V-lNp)))/mC ;
```

```
dydt(2,1)= (a_m*(1-m)-b_m*m);
dydt(3,1)= (a_n*(1-n)-b_n*n);
dydt(4,1)= (a_h*(1-h)-b_h*h);

end
```

Code: hhdiff2.m

```
function [dydt] = hhdiff2(t,y)

is = 5;
id = 0.35;
im = -25*3;

if (t>is) && (t<id+is)
    I=im;
else
    I = 0;
end

V=y(1,1);
m=y(2,1);
n=y(3,1);
h=y(4,1);
vRest=-65;

vMem=V-vRest;

gNa = 120; %mS/cm^2
gK = 36; %mS/cm^2
gL = 0.3; %ms/cm^2

mC = 1; %uF/cm^2
lNp = -50; %mV
nNa = 57.59;
nK = -75.59;


a_n=.01*(10-vMem)./(exp((10-vMem)/10)-1);
b_n=.125*exp(-vMem/80);

a_m=.1*(25-vMem)./(exp((25-vMem)/10)-1);
b_m=4*exp(-vMem/18);

a_h=0.07*exp(-vMem/20);
b_h=1/(exp((30-vMem)/10)+1);


%ode V, n, m, h
dydt(1,1)= ((I-gNa*m^3*h*(V-nNa))-(gK*n^4*(V-nK))-(gL*(V-lNp)))/mC ;
dydt(2,1)= (a_m*(1-m)-b_m*m);
dydt(3,1)= (a_n*(1-n)-b_n*n);
dydt(4,1)= (a_h*(1-h)-b_h*h);

end
```