```
function []=addition_of_conotoxin()
clc;
clear;
close all;

[V,t] = hodgkinHuxleyMembranePotential();
conc = cationConcentrations(V);
%membranePotentialPlot(t,V,conc);
%cationTimePlot(t,conc);
concentration_matrix = potassiumSodiumConcentration(t,V,conc);
potassiumSodiumTimePlot(t,concentration_matrix,V);
end

function [V,t] = hodgkinHuxleyMembranePotential()
    %Constants set for all Methods
    Cm=0.01; % Membrane Capcitance uF/cm^2
    dt=0.01;% Time Step ms
    tmax = 35;
    t=0:dt:tmax; %Time Array ms

    I=0.4; %External Current Applied
    ENa=55.17; % mv Na reversal potential
    EK=-72.14; % mv K reversal potential
    El=-49.42; % mv Leakage reversal potential
    gbarNa=1.2; % mS/cm^2 Na conductance
    gbarK=0.36; % mS/cm^2 K conductance
    gbarl=0.003; % mS/cm^2 Leakage conductance
    V(1)=-60; % Initial Membrane voltage
    m(1)=am(V(1))/(am(V(1))+bm(V(1))); % Initial m-value
    n(1)=an(V(1))/(an(V(1))+bn(V(1))); % Initial n-value
    h(1)=ah(V(1))/(ah(V(1))+bh(V(1))); % Initial h-value
    for i=1:length(t)-1
        %Euler method to find the next m/n/h value
        m(i+1)=m(i)+dt*((am(V(i))*(1-m(i)))-(bm(V(i))*m(i)));
        n(i+1)=n(i)+dt*((an(V(i))*(1-n(i)))-(bn(V(i))*n(i)));
        h(i+1)=h(i)+dt*((ah(V(i))*(1-h(i)))-(bh(V(i))*h(i)));
        gNa=gbarNa*m(i)^3*h(i);
        gK=gbarK*n(i)^4;
        gl=gbarl;

        INa=gNa*(V(i)-ENa);
        IK=gK*(V(i)-EK);
        Il=gl*(V(i)-El);

        %Euler method to find the next voltage value
        V(i+1)=V(i)+(dt)*((1/Cm)*(I-(INa+IK+Il)));

    end
end

function [conc] = cationConcentrations(V)
    % Finding the total concentration of cations
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```
    cellvol = .67; %E.coli volume \mum^3
    cellvol = cellvol * (1/(1e+6))^3 * (1000/1);
    %           \mum^3 * (1m/1e6\mum)^3 * (L/m^3)
    %cellcol = cellvol*1000
    %          m^3   * (L/m^3)
    cellsurfacearea = .77911; %\mum^2
    p = 1.6e-19; %charge of single +1 ion
    C = 1*(1/(1e6))*(100)^2*cellsurfacearea*(1/1e6)^2; %Capacitance per unit lengt
    %1\muF/cm^2*(1F/1e6\muF)*(100cm/m)^2*(\mum^2)*(1m/1e6\mum)^2
    nions = C.*V.*10^3/p; %Unitless
    N = 6.02e23; %Avogadro's Number
    nmols = nions/N;
    I_o = 190+20; %Initial intracellular concentration of positive ions in E. Coli
    conc = (nmols./cellvol)+I_o; %Concentration change per voltage change
end

function[] = membranePotentialPlot(t,V,conc)
    %Ploting the membrane potential and cation concentration v. time
    figure
    yyaxis left
    plot(t,V,'b')
    ylabel('Membrane Potential(mV)');
    yyaxis right
    plot(t,conc,'r')
    ylim([290,310])
    ylabel('Concentration of positive ions (mM)')
    legend('Membrane potential(mV)','Concentration')
    xlabel('Time (\mu s)');
    title('Membrane potential and Cation Concentration')
    title('Membrane potential for Hodgkin-Huxley Model')
end

function [] = cationTimePlot(t,conc)
    %Ploting the concentrations of cations v. time
    figure
    plot(t,conc,'r')
    title('Intracellular Cation Concentration Due To Change In Voltage')
    legend('Concentration of positive ions (mM)')
    xlabel('Time ( \mu s)')
    ylabel('Concentration (mM)')
end

function [concentration_matrix] = potassiumSodiumConcentration(t,V,conc)
    % Determine the concentrations of Potassium and Sodium
    %based on the total concentration of cations
    %Initial intracellular concentration of Potassium
    Kinitial = 190;% mM

    %Initial intracellular concentration of Sodium
    Nainitial = conc(1)-Kinitial;

    %Vector of initial concentrations
    initial_concentration = [Kinitial; Nainitial];
```

```
    %Initialize a matrix where first row is K concentration, second row is Na
    %concentration, each column is time step corresponding to the Euler's
    %method time step for determining membrane potential

    %Series of if-statements which determine which channel/pump is relevent
    %given the voltage and time.

    %Numerical derivative of concentration wrt time
    dC = diff(conc);
    concentration_matrix = zeros(2,length(dC));
    concentration_matrix(:,1) = initial_concentration;
    %Initialize a matrix to represent which channel is open:
    % [Na channel; Na/K pump; K channel]
    channelopen = zeros(4,length(dC));
    channelopen(1,:) = t(1:length(t)-1);
    thresholdpotential = -38.0389; %mV

    disp(['The threshold potential for the opening of sodium voltage'...,
        ' gated ion channel in E. coli is predicted to be ',...
         num2str(thresholdpotential),' milivolts']);
    for n = 2:length(conc)-1
        %Determine which pump is open based on changing concentrations
        if dC(n-1) > 0 %ie, if cation concentration is rising
            if V(n-1)> thresholdpotential %mV, the approximate threshold for Na ch
                channelopen(2,n) = 1;
                concentration_matrix(:,n) = sodium_channel(dC(n),...
                    concentration_matrix(:,n-1));
            else %If the threshold has not been meet, the change is due to
                 %the Na/K pumps
                concentration_matrix(:,n) = sodium_potassium_pump(dC(n),...
                    concentration_matrix(:,n-1));
                channelopen(3,n) = 1;
            end
        else %if the cation concentration is decreasing, it is due to a opening
             %of K chanels
            channelopen(4,n)=1;
            concentration_matrix(:,n) = potassium_channel(dC(n),...
                concentration_matrix(:,n-1));
        end
    end
end

function []= potassiumSodiumTimePlot(t,concentration_matrix,V)
    %Plot concentrations of both ions v. time
    figure
    plotyy(t(1:length(t)-1),concentration_matrix(1,:),t(1:length(t)-1),...
        concentration_matrix(2,:))
    grid minor
    ylabel('Concentration (mM)')
    xlabel('Time (\mus)')
    legend('K^{+}', 'Na^{+}')
    title('Concentrations of individual intracellular cations')
end
```

```
function [V] = goldmanhogkinkatz(t,concentration_matrix)
%Assume extracellular concentration remains fixed
    R = 8.3144598;
    T = 310;
    F = 96485;
    Kin = concentration_matrix(1,:);
    Kout = 10.455;
    Nain = concentration_matrix(2,:);
    Naout = 481.75;
    p_k = 1;
    p_na = 0.05;

    numerator = Kout*p_k+Naout*p_na;
    denominator = (Kin*p_k+Nain*p_na);
    for n = 1:length(t)-1
        V(n) = -R*T/F * log(numerator/denominator(n));
    end

    figure
    plot(t(1:length(t)-1),V)
end

function [out] = potassium_channel(dC,Cin)
    out = Cin + dC*[1;0];
end

function [out] = sodium_channel(dC,Cin)
    out = Cin + dC*[0;1];
end

function [out] = sodium_potassium_pump(dC,Cin)
    out = Cin + dC*[3;-2];
end

function [a] = am(v) %Alpha for Variable m
    a = 0.1*(v+35)/(1-exp(-(v+35)/10));
end

function [b] = bm(v) %Beta for variable m
    b = 4.0*exp(-0.0556*(v+60));
end

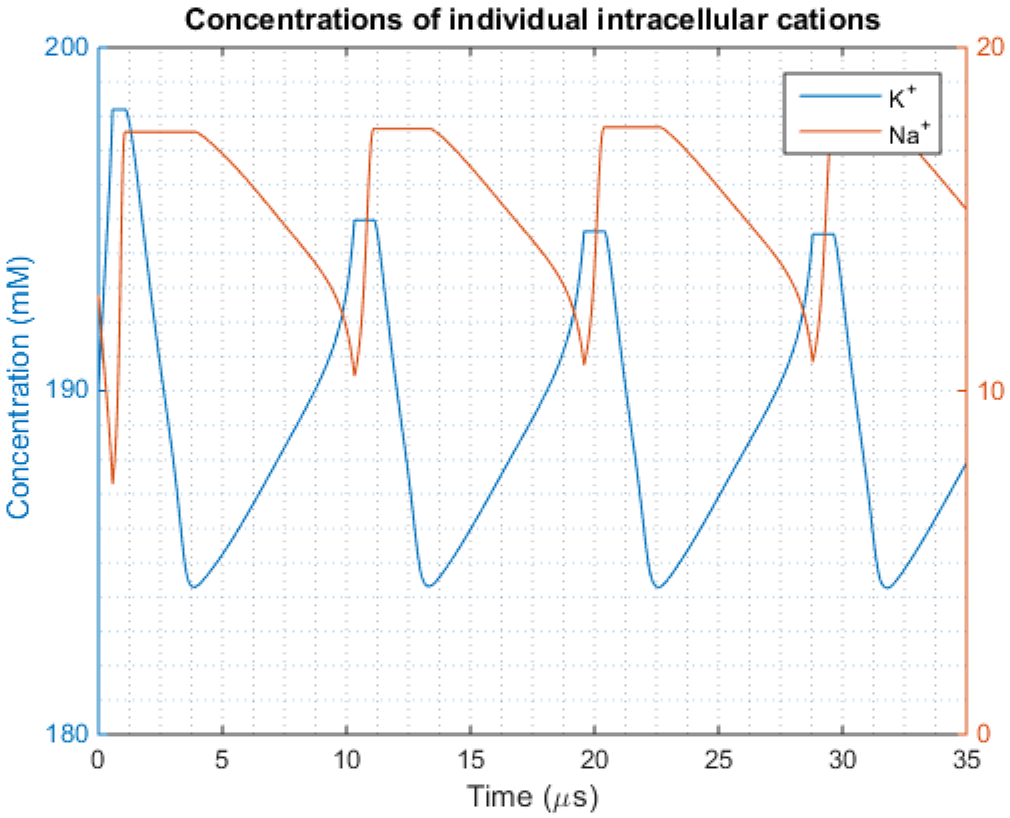
function [a] = an(v) %Alpha for variable n
    a = .01*(v+50)/(1-exp(-(v+50)/10));
end

function [b] = bn(v) %Beta for variable n
    b = 0.125*exp(-(v+60)/80);
end

function [a] = ah(v) %Alpha value forr variable h
    a = 0.07*exp(-0.05*(v+60));
end
```

```
function [b] = bh(v) % beta value for variable h
    b = 1/(1+exp(-(0.1)*(v+30)));
end
```

The threshold potential for the opening of sodium voltage gated ion channel in E.



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