ELEC 4700 Assignment 3

Table of Contents

Q1 - Modify Assignment 1 Monte-Carlo to include Electric feild 1
Addition of constant electric field of 0.1V 2
Q1 Main Loop 2
Function for Electric Field (No change from Assignment 2) 6
Q2 - Add electric field for Lab 2 bottle neck program 7
Q2 Main Loop 10
Q3 - Add electric field for Lab 2 bottle neck with density map 12
Q3 Main Loop 15

Monte_Carlo + Finite Difference Method - Jinseng Vanderkloot 101031534 - Due: March 20, 2022

Q1 - Modify Assignment 1 Monte-Carlo to include Electric feild

```
clc;
clear all;
close all;

m0 = 9.10938215e-31;            % electron mass
mn = 0.26*m0;                   % Effective mass
Temp = 300;                     % Inital Temp (K)
kb = 1.3806504e-23;             % Boltzmann constant
tmn = 0.2e-12;                  % Mean time between collision
e = 1.602e-19;                  % Charge of an Electron (Assignment 3 for
 force)

%Thermal Velocity (Question 1.A)
vt=sqrt((2*kb*Temp)/mn);        % Sim in 2D so (2*kb*Temp), 3D is (3*kb*Temp)

% Plotting Area
wArea = 200e-9;
lArea = 100e-9;

numElec = 30000;                 %Number of simulated Electrons
numEPlot = 20;                  %Number of plotted Electrons
dt = (lArea*wArea)/2;             %Typically 1/100 of region size
stepsTot = 150;                 %Total amount of steps (1000 was a long
 simulation)
tTot= stepsTot*dt;              %Total Simulation time
x = zeros(1,numElec);           %Inital X matrix
y = zeros(1,numElec);           %Inital y matrix
vx = zeros(1,numElec);          %Inital velocity x matrix
vy = zeros(1,numElec);          %Inital velocity y matrix
vtot = zeros(1,numElec);        %Inital velocity matrix
VEnew = zeros(1,numElec);       %add x vector with field force velocity
colors = rand(numElec,3);       %Color assignment for each electron
```

```
%Probability of Scatter
scatOn = 1;                     %Turn Scatter on (1) or off(0)
Pscatter = 1-exp(-dt/tmn);      %Scatter Equation
tScatter = zeros(1,numElec);    %track scatter for each particle


%S1 Electron Random Assignments
for cnt = 1:numElec
    x(cnt)=rand()*wArea;
    y(cnt)=rand()*lArea;
    angle = (2*pi*rand());
    vx(cnt)=vt*cos(angle);   % velocity * random direction
    vy(cnt)=vt*sin(angle);   % velocity * random direction
%     vtot(cnt)= sqrt (vx(cnt)^2)+(vy(cnt)^2);
end
```

Addition of constant electric field of 0.1V

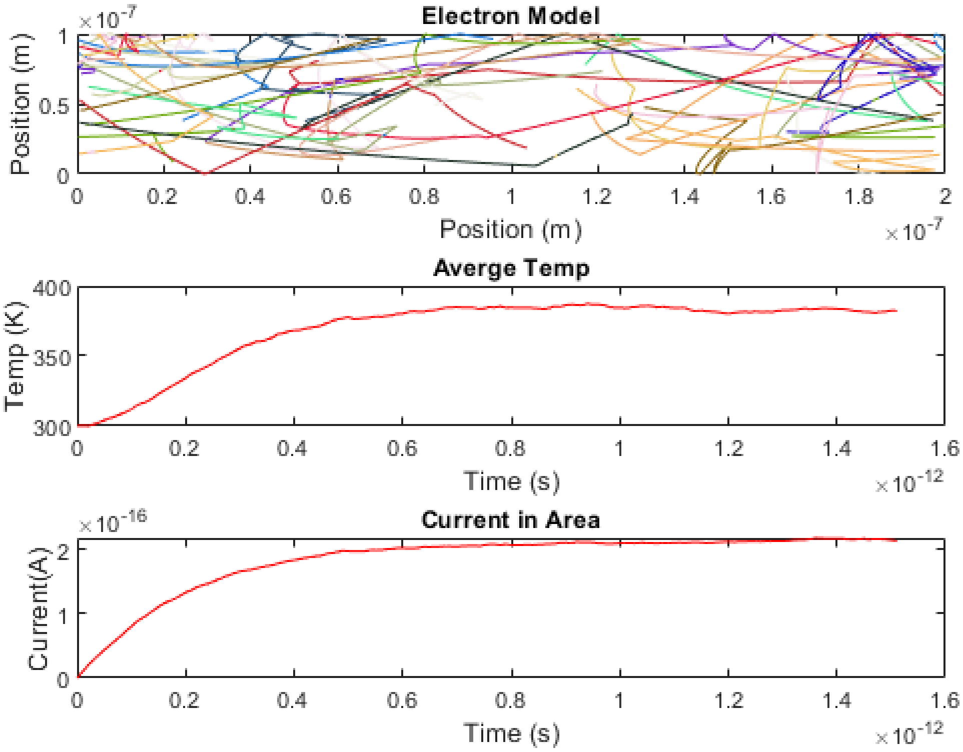
```
VAreaX = 0.1; %0.1V across x direction
VAreaY = 0; %added for possibility of Y field force
Ex = VAreaX/wArea;  % electric field along the x-axis
Ey = VAreaY/lArea;  % electric field along the y-axis
aX = (e * Ex)/mn ; % Acceleration in x due to Field
aY = (e * Ey)/mn ; % Acceleration in y due to Field
vxForce= (aX)*dt; % Velocity in x due to Field
vyForce= (aY)*dt; % Velocity in y due to Field

%The value of Ex = 50000(V/m) for 0.1V acorss the area, The force applied
%to each particle is 8e-14 N

%The acceleration due to the field in the x direction is a =
%3.381973859521560e+17 m/s^2
```

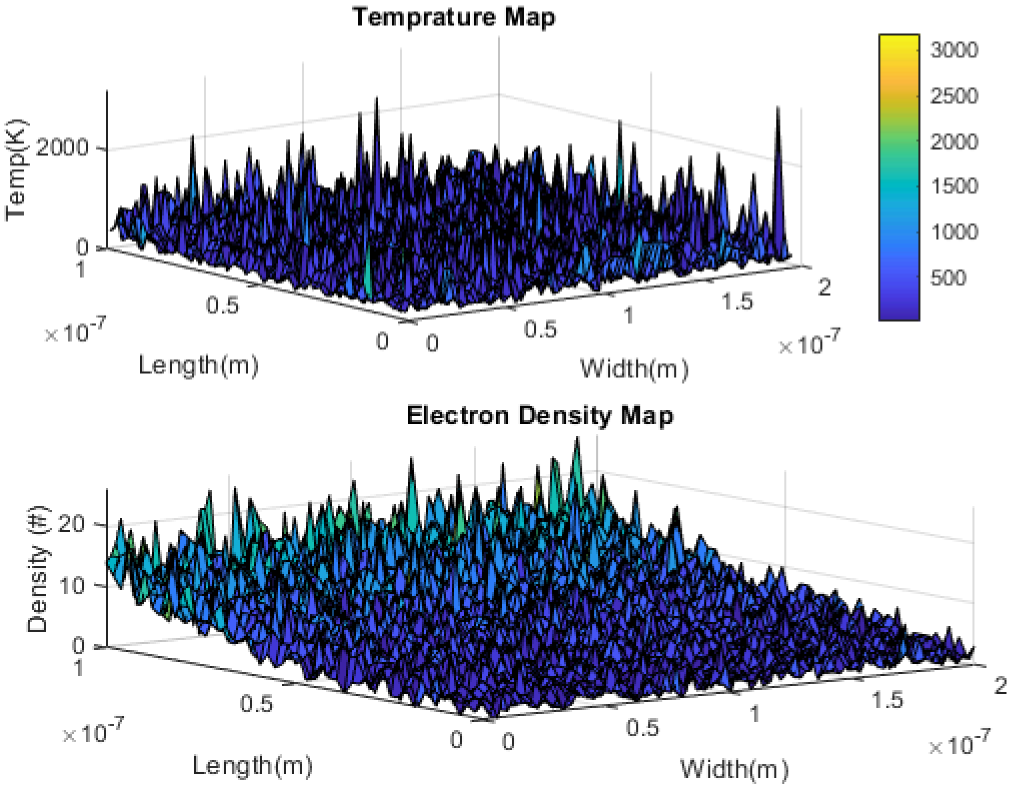
Q1 Main Loop

```
t=0;
intCNT = 2;
eTemp(1) = Temp;
while t < tTot
    t = t + dt;

    %Store old position
    oldx = x;
    oldy = y;

    %Update to new position with velocity including Field Force
    vx(1:numElec) = vx + vxForce;
    vy(1:numElec) = vy + vxForce;
    x(1:numElec) = x(1:numElec) + (vx(1:numElec).*dt);
    y(1:numElec) = y(1:numElec) + (vy(1:numElec).*dt);

    vtot(1:numElec)= sqrt((vx(1:numElec).^2)+(vy(1:numElec).^2));
```

```
   %Apply boundary conditions
   for check = 1:numElec
        if scatOn==1
           if Pscatter > rand()
               vx(check)=(vt/sqrt(2))*randn();
               vy(check)=(vt/sqrt(2))*randn();
               tScatter(check)= 0; %If collision, time goes to 0
           else
               tScatter(check)= tScatter(check) + dt; %track time increaing
while no collision
           end
       end

       %If bottom contact, bounce off in opposite direction
       if (y(check)<=0)
           y(check) = 0;
           vy(check) = -vy(check);
       end
       %If top contact, bounce off in opposite directio
       if (y(check)>=lArea)
           y(check) = lArea;
           vy(check) = -vy(check);
       end
       %if left side of box, come out right side
       if(x(check)<=0)
          x(check) = x(check) + wArea;
       end
       %if right side of box, come out left side
       if(x(check)>=wArea)
         x(check) = x(check) - wArea;
       end
   end

   %Plot Boundary and map some electrons
   for Eplot = 1:numEPlot
       subplot (3,1,1)
       %if the electron went out of sides and back on other side, do not
       %draw line
       if abs(oldx(Eplot)-x(Eplot))<(wArea/2)
           p = plot([oldx(Eplot),x(Eplot)],[oldy(Eplot),y(Eplot)]);
       end
       p.Color=colors(Eplot,:);
       axis([0,wArea,0,lArea]);
       title('Electron Model'), xlabel('Position (m)', 'FontSize', 10),
ylabel('Position (m)', 'FontSize', 10);

       hold on;
   end
   pause(0.01);

   %Average Temprature
   subplot (3,1,2)
   Time(:,intCNT) = t;
```

```
    allT = ((vtot(:).^2).*mn)./(2*kb);
    eTemp(:,intCNT) = mean(allT);

    plot(Time,eTemp,"r");
    title('Averge Temp'),xlabel('Time (s)', 'FontSize', 10), ylabel('Temp
 (K)', 'FontSize', 10);
    hold on;

    %Current over time with Field
    Ix(:,intCNT)= e*1000000000000*mean(vx)* wArea * lArea; %Current = e * n *
 vd * Area (Particle density is 10e15 cm^-2)
    %not sure about value but the relationship of the current is shown in
    %the plot
    subplot (3,1,3)
    plot(Time,Ix,"r");
    title('Current in Area'),xlabel('Time (s)', 'FontSize', 10),
 ylabel('Current(A)', 'FontSize', 10);
    hold on;

    intCNT = intCNT +1;
end
figure(2)
%Electron Temprature Map (Use Surf now to get 3D plot over the area)
    allT = ((vtot(:).^2).*mn)./(2*kb);
    xv = linspace(min(x), max(x),100);
    yv = linspace(min(y), max(y),50);
    [X,Y] = meshgrid(xv,yv);
    ETM=griddata(x,y,allT,X,Y);
    subplot(2,1,1);
    surf(X,Y,ETM),colorbar,title("Temprature Map")
    xlabel('Width(m)', 'FontSize', 10), ylabel('Length(m)', 'FontSize',
 10),zlabel('Temp(K)', 'FontSize', 10);
    axis([0, wArea, 0 lArea]);

%Electron Density Map (Use Surf now to get 3D plot over the area)
    eMapX=linspace(0, wArea, 101); %increase by 1 for surf
    eMapY=linspace(0, lArea, 51); %increase by 1 for surf
    EDM=histcounts2(y,x,eMapY,eMapX);
    subplot(2,1,2)
    surf(X,Y,EDM),title('Electron Density Map');
     xlabel('Width(m)', 'FontSize', 10), ylabel('Length(m)', 'FontSize',
 10),zlabel('Density (#)', 'FontSize', 10);


    %The current increases since until equilibrium because there is a force
    %not actin gon the particles so they move from left to reight creating
    %current flow. The larger the current density, the larger the current>
    %The larger the feidl strenth, the larger the current.
```


Electron Model
×10^-7
1
0.5
0
Position (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Position (m)
×10^-7
Averge Temp
400
350
300
Temp (K)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Time (s)
×10^-12
Current in Area
×10^-16
2
1
0
Current(A)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Time (s)
×10^-12


Temprature Map
Temp(K)
2000
0
1
0.5
0
×10^-7
Length(m)
0
0.5
1
1.5
2
Width(m)
×10^-7
3000
2500
2000
1500
1000
500
Electron Density Map
Density (#)
20
10
0
1
0.5
0
×10^-7
Length(m)
0
0.5
1
1.5
2
Width(m)
×10^-7

Function for Electric Field (No change from Assignment 2)

function [V] = A2_Function(nx, ny, xBox, yBox,boxCond,x0,x1) %Inputs: %Area x dimension, Area y dimension, box x dimension in middle of area, %Box y dimension from bottom to high and from top down, box conductivity, %x0 = volatge at left side, x1 = volatge at right side.

global Carea %NEEDS TO BE GLOBAL

% Add bottleneck Carea = ones(nx,ny); %set conduction area to 1 % In area, place boxes with new conduction (faster than for loop) Carea(nx/2 - xBox/2:nx/2 + yBox/2,1:yBox) = boxCond; %Bottom Box Carea(nx/2 - xBox/2:nx/2 + yBox/2,ny-yBox:ny) = boxCond; %Top Box

G = sparse(nx*ny,ny*nx); F = zeros(nx*ny,1);

for i = 1:nx for j = 1:ny n = j + (i-1) * ny; % middle nxm = j + (i-2) * ny; % right nxp = j + i * ny; % left nym = j-1 + (i-1) * ny; % top nyp = j+1 + (i-1) * ny; % down if i == 1 %Left Boundary V=Vo G(n,n) = 1; F(n,1) = x0; elseif i == nx %Right Boundary V=Vo G(n,n) = 1; F(n,1) = x1; elseif j == 1 %Bottom Boundary (Free) bxm = (Carea(i,j) + Carea(i-1,j)) / 2; bxp = (Carea(i,j) + Carea(i+1,j)) / 2; byp = (Carea(i,j) + Carea(i,j+1)) / 2;

```
           G(n,n) = -(bxm + bxp + byp);
           G(n,nxm) = bxm;
           G(n,nxp) = bxp;
           G(n,nyp) = byp;
       elseif j == ny %Top Boundary (Free)
           bxm = (Carea(i,j) + Carea(i-1,j)) / 2;
           bxp = (Carea(i,j) + Carea(i+1,j)) / 2;
           bym = (Carea(i,j) + Carea(i,j-1)) / 2;

           G(n,n) = -(bxm + bxp + bym);
           G(n,nxm) = bxm;
           G(n,nxp) = bxp;
           G(n,nym) = bym;
       else %Middle
           bxm = (Carea(i,j) + Carea(i-1,j)) / 2;
           bxp = (Carea(i,j) + Carea(i+1,j)) / 2;
           byp = (Carea(i,j) + Carea(i,j+1)) / 2;
           bym = (Carea(i,j) + Carea(i,j-1)) / 2;

           G(n,n) = -(bxm + bxp + bym + byp);
           G(n,nxm) = bxm;
           G(n,nxp) = bxp;
           G(n,nym) = bym;
           G(n,nyp) = byp;
       end
   end
end
```

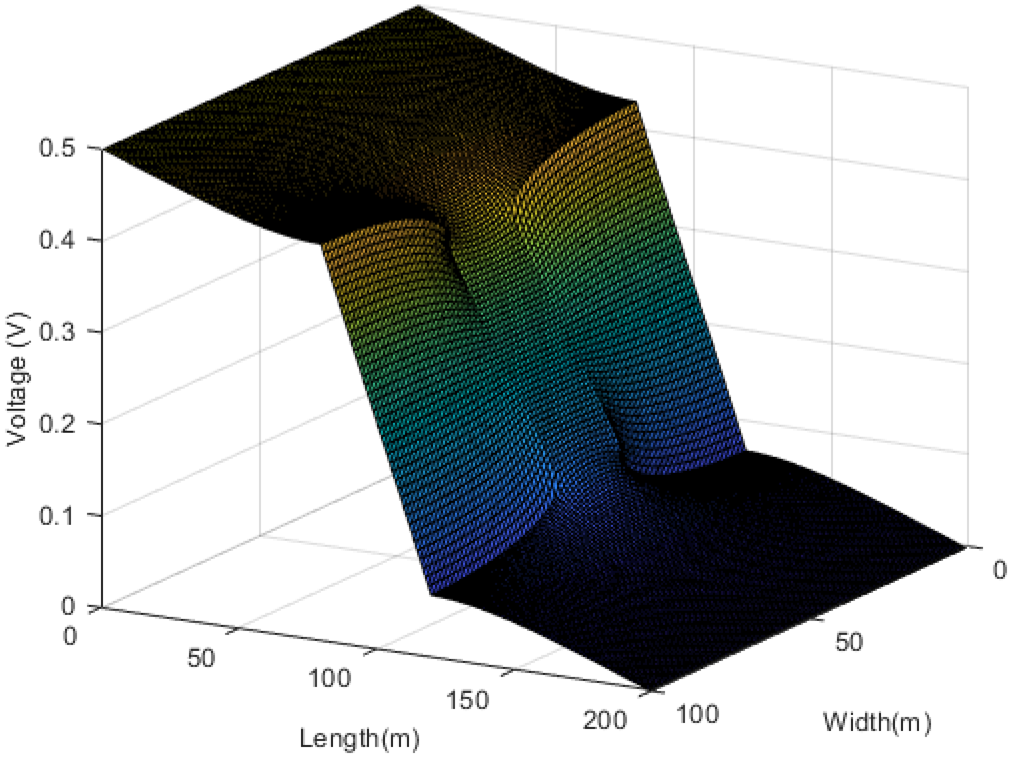
V = G\F;

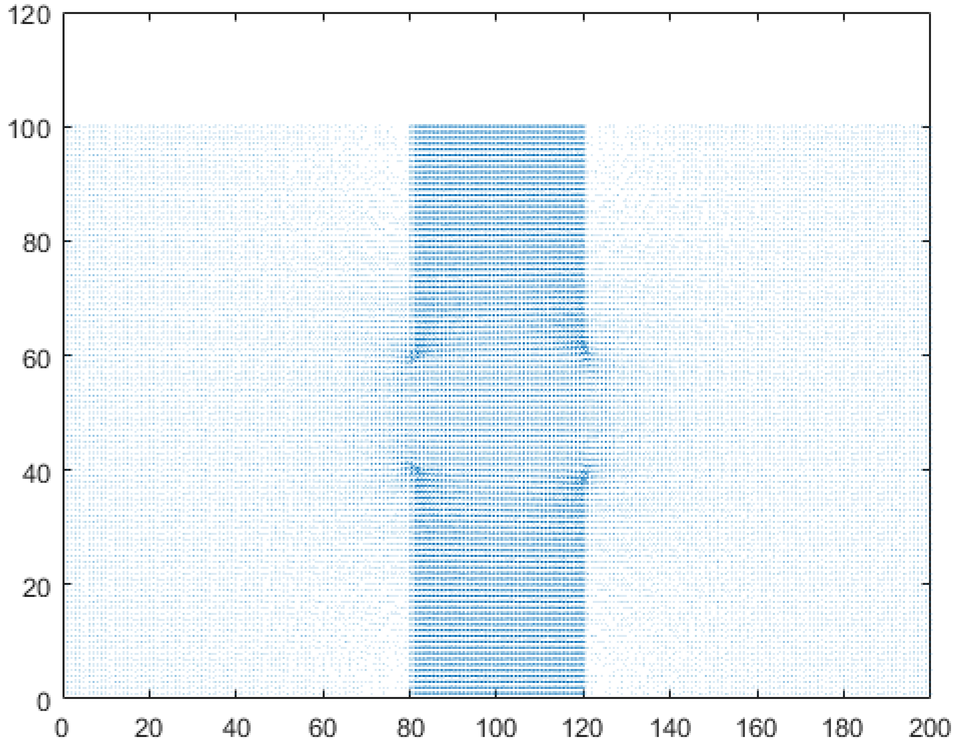
end

Q2 - Add electric field for Lab 2 bottle neck program

```
clc
clear all
close all

%Initial
m0 = 9.10938215e-31;            % electron mass
mn = 0.26*m0;                   % Effective mass
Temp = 300;                     % Inital Temp (K)
kb = 1.3806504e-23;             % Boltzmann constant
tmn = 0.2e-12;                  % Mean time between collision
q = 1.602e-19;                  % Charge of an Electron (Assignment 3 for
 force)

% Region Area
wArea = 200e-9;
lArea = 100e-9;

%Thermal Velocity (Question 1.A)
vt=sqrt((2*kb*Temp)/mn);        % Sim in 2D so (2*kb*Temp), 3D is (3*kb*Temp)

%Electron motion
numElec = 1000;                  %Number of simulated Electrons.
numEPlot = 30;                  %Number of plotted Electrons
dt = (lArea*wArea)/2;           %Typically 1/100 of region size
stepsTot = 200;                 %Total amount of steps (1000 took to long)
tTot= stepsTot*dt;              %Total Simulation time
x = zeros(1,numElec);           %Inital X matrix
y = zeros(1,numElec);           %Inital y matrix
vx = zeros(1,numElec);          %Inital velocity x matrix
vy = zeros(1,numElec);          %Inital velocity y matrix
vtot = zeros(1,numElec);        %Inital velocity matrix
xfield = zeros(1,numElec);      %Inital Position in E field x
yfield = zeros(1,numElec);      %Inital Position in E field y
vxForce = zeros(1,numElec);      %Inital Force due to position in E field x
vyForce = zeros(1,numElec);      %Inital Force due to position in E field y

%Probability of Scatter
scatOn = 1;                     %Turn Scatter on (1) or off(0)
Pscatter = 1-exp(-dt/tmn);      %Scatter Equation
tScatter = zeros(1,numElec);

%Bottle Neck Boundary reduced to prevent bleeding
% X limit (no particle between X1 and X2 - Cosider Y limits)
boxX1=80e-9;
boxX2=120e-9;
% Y Limit (no particles between 0 and Y1 and Y2 to Y limit)
boxY1 = 40e-9;
boxY2 = 60e-9;
```

```
%Electric Field added
x0 = 0.5; %voltage at right side of area increased to 0.5V to see huge effect
x1 = 0; %Voltage at left side of area
nx = wArea*1e9; % # of colums (changes to have same ratio as A1 area 2/1)
ny = lArea*1e9; % # of rows
xBox = 40; %Width of box (changes to same box ratio as A1 area l= 40 and w=40)
yBox = 40; %Hight of box
boxCond = 0.01;
V=A2_Function(nx, ny, xBox, yBox, boxCond, x0, x1);
Vmap = reshape(V, [ny, nx]);
[Ex,Ey] = gradient(-Vmap);

figure('name', 'Voltage Surface Plot')
surf(Vmap'),view(120,20);
 xlabel('Width(m)', 'FontSize', 10), ylabel('Length(m)', 'FontSize',
 10),zlabel('Voltage (V)', 'FontSize', 10);

figure('name', 'Electric Field Vector Plot');
 xlabel('Width(m)', 'FontSize', 10), ylabel('Length(m)', 'FontSize', 10);;
quiver(Ex,Ey);


%Electron Graph
for cnt = 1:numElec
    x(cnt)=rand()*wArea;
    y(cnt)=rand()*lArea;
    %If the electrons are place in the box, re-roll position
    while (x(cnt)>=boxX1 && x(cnt)<=boxX2 && (y(cnt)<=boxY1 ||
 y(cnt)>=boxY2))) %Relocate them if in boundary
        x(cnt)=rand()*wArea;
        y(cnt)=rand()*lArea;
    end
    vx(cnt)=(vt/sqrt(2))*randn();  % velocity * Gaussian dist
    vy(cnt)=(vt/sqrt(2))*randn();  % velocity * Gaussian dist
    vtot(cnt)= sqrt (vx(cnt)^2)+(vy(cnt)^2);
    colors= rand(numElec,3);
end

%Boundary Energy/Velocity loss coefficient (reduction in velocity =
%reduction in temprature)
vloss = 0.95;
```


Voltage (V)
0.5
0.4
0.3
0.2
0.1
0
Length(m)
0
50
100
150
200
Width(m)
0
50
100

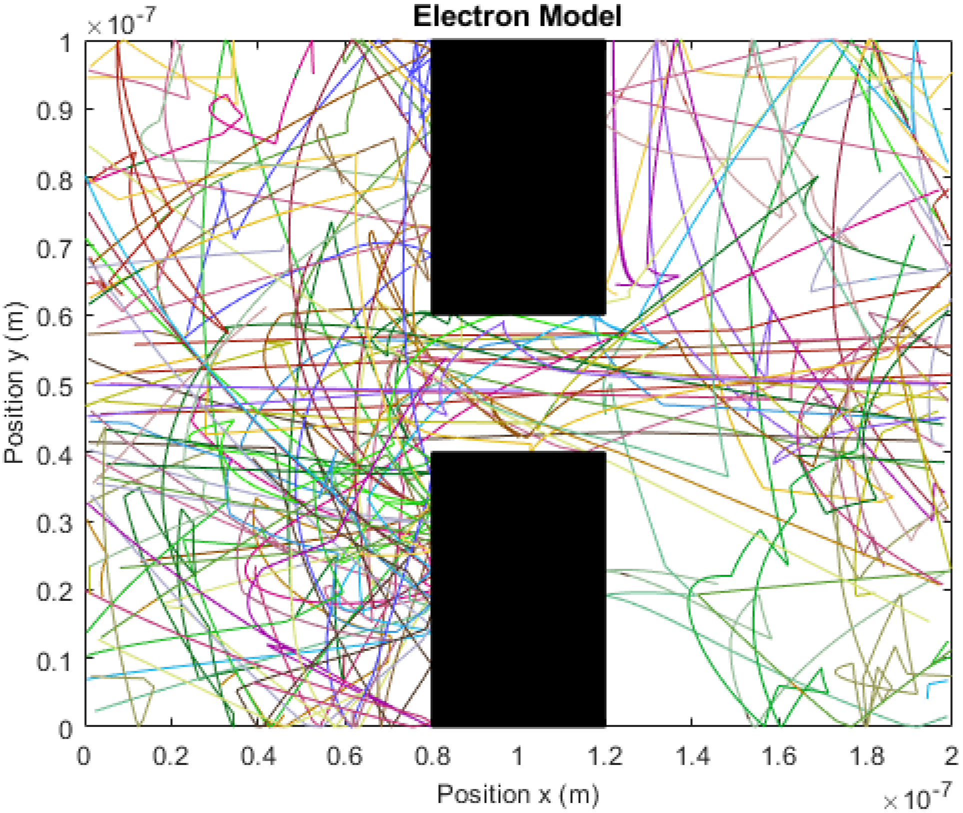

120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
200

Q2 Main Loop

```
t=0;
while t < tTot
    t = t + dt;

    %Store old position
    oldx = x;
    oldy = y;

    %Update to new position
    x(1:numElec) = x(1:numElec) + (vx(1:numElec).*dt);
    y(1:numElec) = y(1:numElec) + (vy(1:numElec).*dt);

    vtot(1:numElec)= sqrt ((vx(1:numElec).^2)+(vy(1:numElec).^2));

    for check = 1:numElec
        %Scatter
        if scatOn==1
            if Pscatter > rand()
                vx(check)=(vt/sqrt(2))*randn();
                vy(check)=(vt/sqrt(2))*randn();
                tScatter(check)= 0; %If collision, time goes to 0
            else
                tScatter(check)= tScatter(check) + dt; %track time increaing
 while no collision
            end
        end

        % Bring X and Y of particle location to values able to be tracked
        % in electric field mesh to apply field forces
        xfield(check) = round(x(check)*1e9);
        yfield(check) = round(y(check)*1e9);

        %Make sure field effects still apply to particles which go across
        %area
        if xfield(check)>200
            xfield(check) = 200;
        end
        if xfield(check)<1
            xfield(check) = 1;
        end
        if yfield(check)>100
            yfield(check) = 100;
        end
        if yfield(check)<1
            yfield(check) = 1;
        end
        %Apply field force to particles
        vxForce(check)= ((q *Ex(yfield(check),xfield(check))/(wArea/nx))/
mn)*dt; % V=(q*E)/mass F=q*E
        vyForce(check)= ((q *Ey(yfield(check),xfield(check))/(lArea/ny))/
mn)*dt; % V=(q*E)/mass F=q*E
```

```
       vx(check) = vx(check)+ vxForce(check);
       vy(check) = vy(check)+ vyForce(check);

       %Apply Boundary Conditions
       %If bottom contact, bounce off in opposite direction
       if (y(check)<=0)
           y(check) = 0;
           vy(check) = -vy(check);
       end
       %If top contact, bounce off in opposite directio
       if (y(check)>=lArea)
           y(check) = lArea;
           vy(check) = -vy(check);
       end
       %If left side of box, come out right side
       if(x(check)<=0)
          x(check) = x(check) + wArea;
       end
       %If right side of box, come out left side
       if(x(check)>=wArea)
          x(check) = x(check) - wArea;
       end

       %Apply bottle neck conditions
       %If contact on left walls of boundary (not in Gap)
       if (oldx(check)<boxX1 && x(check)>=boxX1 && (y(check)<= boxY1 ||
y(check)>= boxY2) && oldx(check)>((1/5)*wArea) && oldx(check)<((4/5)*wArea))
           x(check)=boxX1;
           vx(check) = -(vx(check)*vloss);
       end
       %If contact on right walls of boundary (not in Gap)
       if (oldx(check)>boxX2 && x(check)<=boxX2 && (y(check)<= boxY1 ||
y(check)>= boxY2) && oldx(check)>((1/5)*wArea)&& oldx(check)<((4/5)*wArea))
           x(check)=boxX2;
           vx(check) = -(vx(check)*vloss);
       end
       %If contact with bottom boundary in gap
       if (x(check)>boxX1 && x(check)< boxX2 && oldy(check)>boxY1 &&
y(check)<= boxY1)
           y(check)= boxY1;
           vy(check) = -(vy(check)*vloss);
       end
       %If contact with top boundary in gap
       if (x(check)>boxX1 && x(check)< boxX2 && oldy(check)<boxY2 &&
y(check)>=boxY2)
           y(check)=boxY2;
           vy(check) = -(vy(check)*vloss);
       end
   end

   %Plot Boundary and map some electrons
   for Eplot = 1:numEPlot
       figure(3)
       %if the electron went out of sides and back on other side, do not
```

```
        %draw line
        if abs(oldx(Eplot)-x(Eplot))<(wArea/2)
            p = plot([oldx(Eplot),x(Eplot)],[oldy(Eplot),y(Eplot)]);
        end

        rectangle('Position',[boxX1 0 (boxX2-boxX1) boxY1],'FaceColor',[0 0
 0])
        rectangle('Position',[boxX1 boxY2 (boxX2-boxX1) (lArea-
boxY2)],'FaceColor',[0 0 0])
        p.Color=colors(Eplot,:);
        axis([0,wArea,0,lArea]);
        title('Electron Model'), xlabel('Position x (m)', 'FontSize', 10),
 ylabel('Position y (m)', 'FontSize', 10);
        pause(0.1);
        hold on;
    end
end
```

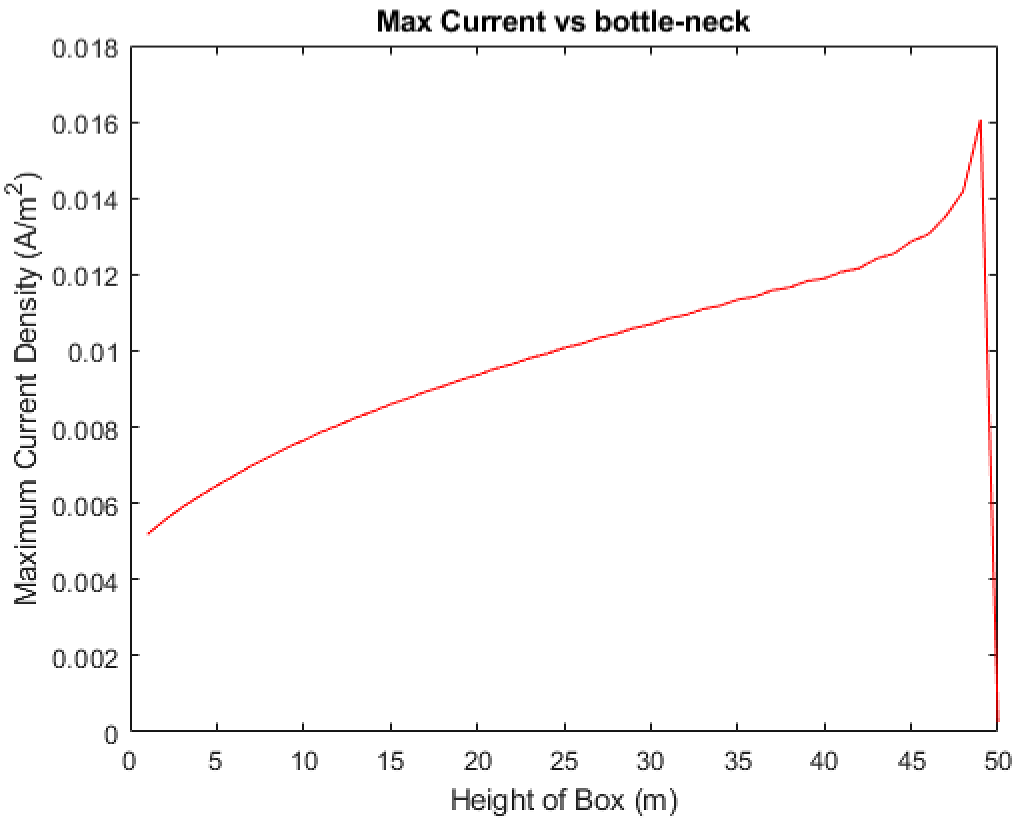


Q3 - Add electric field for Lab 2 bottle neck with density map

```
clc
clear all
close all
warning ('off')
```

```
%Initial
m0 = 9.10938215e-31;            % electron mass
mn = 0.26*m0;                   % Effective mass
Temp = 300;                     % Inital Temp (K)
kb = 1.3806504e-23;             % Boltzmann constant
tmn = 0.2e-12;                  % Mean time between collision
q = 1.602e-19;                  % Charge of an Electron (Assignment 3 for
 force)

% Region Area
wArea = 200e-9;
lArea = 100e-9;

%Thermal Velocity (Question 1.A)
vt=sqrt((2*kb*Temp)/mn);        % Sim in 2D so (2*kb*Temp), 3D is (3*kb*Temp)

%Electron motion
numElec =30000;                  %Number of simulated Electrons
numEPlot = 20;                  %Number of plotted Electrons
dt = (lArea*wArea)/2;           %Typically 1/100 of region size
stepsTot = 400;                 %Total amount of steps (1000 was a long
 simulation)
tTot= stepsTot*dt;              %Total Simulation time
x = zeros(1,numElec);           %Inital X matrix
y = zeros(1,numElec);           %Inital y matrix
vx = zeros(1,numElec);          %Inital velocity x matrix
vy = zeros(1,numElec);          %Inital velocity y matrix
vtot = zeros(1,numElec);        %Inital velocity matrix
xfield = zeros(1,numElec);      %Inital Position in E field x
yfield = zeros(1,numElec);      %Inital Position in E field y
vxForce = zeros(1,numElec);      %Inital Force due to position in E field x
vyForce = zeros(1,numElec);      %Inital Force due to position in E field y

%Probability of Scatter
scatOn = 1;                     %Turn Scatter on (1) or off(0)
Pscatter = 1-exp(-dt/tmn);      %Scatter Equation
tScatter = zeros(1,numElec);

%Bottle Neck Boundary reduced to prevent bleeding
% X limit (no particle between X1 and X2 - Cosider Y limits)
boxX1=80e-9;
boxX2=120e-9;
% Y Limit (no particles between 0 and Y1 and Y2 to Y limit)
boxY1 = 40e-9;
boxY2 = 60e-9;

%Electric Field
x0 = 0.8; %voltage at right side of area increased to 0.8V to see huge effect
x1 = 0; %Voltage at left side of area
nx = wArea*1e9; % # of colums (changes to have same ratio as A1 area 2/1)
ny = lArea*1e9; % # of rows
xBox = 40; %Width of box (changes to same box ratio as A1 area l= 40 and w=40)
yBox = 1:1:50; %Hight of box for bottleneck
```

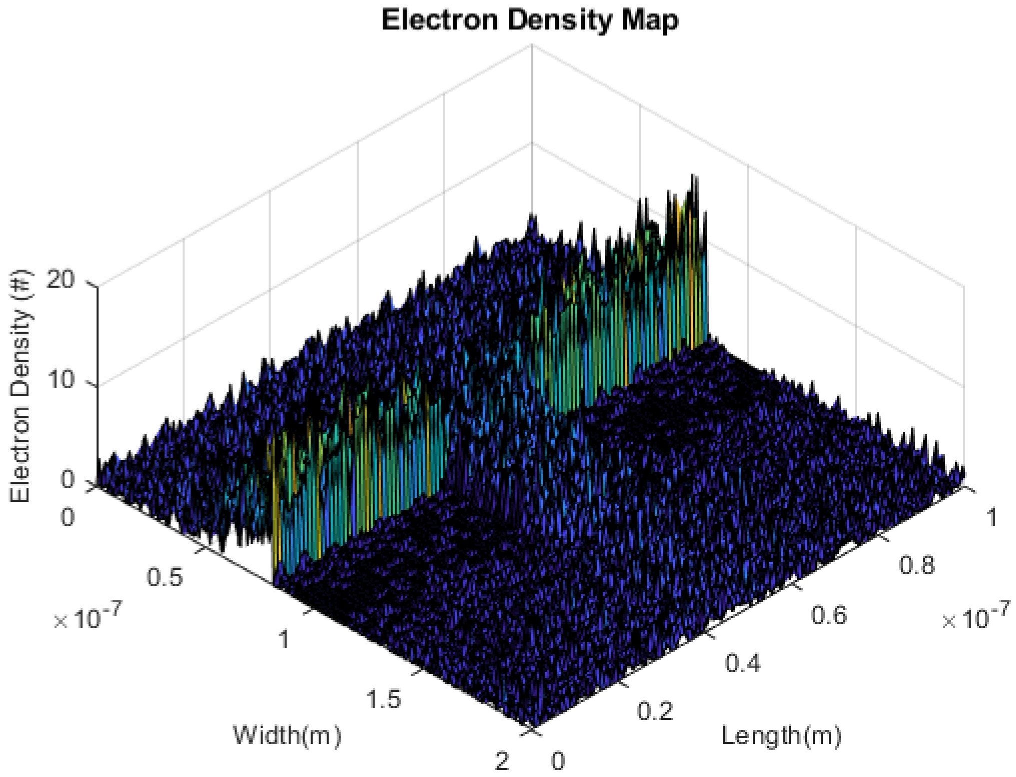
```
boxCond = 0.01;
V=A2_Function(nx, ny, xBox, yBox, boxCond, x0, x1);
Vmap = reshape(V, [ny, nx]);
[Ex,Ey] = gradient(-Vmap);

% figure('name', 'Voltage Surface Plot')
% surf(Vmap'),view(120,20);
%
% figure('name', 'Electric Field Vector Plot');
% quiver(Ex,Ey);

cur = zeros(50,1);
global Carea %Must declare global for both in and out of function

for a = 1:50
    V=A2_Function(nx, ny, xBox, a, boxCond, x0, x1);
    Vmap = reshape(V, [ny, nx]);
    J = Carea'.*gradient(-Vmap);
    cur(a,1) = max(J,[],"all");
end

figure('name', 'Max Current vs bottle-neck');
plot(yBox,cur, 'r');
xlabel('Height of Box (m)');
ylabel('Maximum Current Density (A/m^2)');
title('Max Current vs bottle-neck');

%Reset yBox value after bottle-neck plot
yBox = 40;

%Electron Graph
for cnt = 1:numElec
    x(cnt)=rand()*wArea;
    y(cnt)=rand()*lArea;
    %If the electrons are place in the box, re-roll position
    while (x(cnt)>=boxX1 && x(cnt)<=boxX2 && (y(cnt)<=boxY1 ||
 y(cnt>=boxY2))) %Relocate them if in boundary
        x(cnt)=rand()*wArea;
        y(cnt)=rand()*lArea;
    end
    vx(cnt)=(vt/sqrt(2))*randn();  % velocity * Gaussian dist
    vy(cnt)=(vt/sqrt(2))*randn();  % velocity * Gaussian dist
    vtot(cnt)= sqrt (vx(cnt)^2)+(vy(cnt)^2);
    colors= rand(numElec,3);
end

%Boundary Energy/Velocity loss coefficient (reduction in velocity =
%reduction in temprature)
vloss = 0.95;
```



Q3 Main Loop

```
t=0;
while t < tTot
    t = t + dt;

    %Store old position
    oldx = x;
    oldy = y;

    %Update to new position
    x(1:numElec) = x(1:numElec) + (vx(1:numElec).*dt);
    y(1:numElec) = y(1:numElec) + (vy(1:numElec).*dt);

    vtot(1:numElec)= sqrt ((vx(1:numElec).^2)+(vy(1:numElec).^2));

    for check = 1:numElec
        %Scatter
        if scatOn==1
            if Pscatter > rand()
                vx(check)=(vt/sqrt(2))*randn();
                vy(check)=(vt/sqrt(2))*randn();
                tScatter(check)= 0; %If collision, time goes to 0
            else
```

```
                tScatter(check)= tScatter(check) + dt; %track time increaing
 while no collision
            end
        end

        % Bring X and Y of particle location to values able to be tracked
        % in electric field mesh to apply field forces
        xfield(check) = round(x(check)*1e9);
        yfield(check) = round(y(check)*1e9);

        %Make sure field effects still apply to particles which go across
        %area
        if xfield(check)>200
            xfield(check) = 200;
        end
        if xfield(check)<1
            xfield(check) = 1;
        end
        if yfield(check)>100
            yfield(check) = 100;
        end
        if yfield(check)<1
            yfield(check) = 1;
        end
        %Apply field force to particles
        vxForce(check)= ((q *Ex(yfield(check),xfield(check))/(wArea/nx))/
mn)*dt; % V=(q*E)/mass F=q*E
        vyForce(check)= ((q *Ey(yfield(check),xfield(check))/(lArea/ny))/
mn)*dt; % V=(q*E)/mass F=q*E
        vx(check) = vx(check)+ vxForce(check);
        vy(check) = vy(check)+ vyForce(check);

        %Apply Boundary Conditions
        %If bottom contact, bounce off in opposite direction
        if (y(check)<=0)
            y(check) = 0;
            vy(check) = -vy(check);
        end
        %If top contact, bounce off in opposite directio
        if (y(check)>=lArea)
            y(check) = lArea;
            vy(check) = -vy(check);
        end
        %If left side of box, come out right side
        if(x(check)<=0)
           x(check) = x(check) + wArea;
        end
        %If right side of box, come out left side
        if(x(check)>=wArea)
           x(check) = x(check) - wArea;
        end

        %Apply bottle neck conditions
        %If contact on left walls of boundary (not in Gap)
        if (oldx(check)<boxX1 && x(check)>=boxX1 && (y(check)<= boxY1 ||
 y(check)>= boxY2) && oldx(check)>((1/5)*wArea) && oldx(check)<((4/5)*wArea))
            x(check)=boxX1;
            vx(check) = -(vx(check)*vloss);
        end
        %If contact on right walls of boundary (not in Gap)
        if (oldx(check)>boxX2 && x(check)<=boxX2 && (y(check)<= boxY1 ||
 y(check)>= boxY2) && oldx(check)>((1/5)*wArea)&& oldx(check)<((4/5)*wArea))
            x(check)=boxX2;
            vx(check) = -(vx(check)*vloss);
        end
        %If contact with bottom boundary in gap
        if (x(check)>boxX1 && x(check)< boxX2 && oldy(check)>boxY1 &&
 y(check)<= boxY1)
            y(check)= boxY1;
            vy(check) = -(vy(check)*vloss);
        end
        %If contact with top boundary in gap
        if (x(check)>boxX1 && x(check)< boxX2 && oldy(check)<boxY2 &&
 y(check)>=boxY2)
            y(check)=boxY2;
            vy(check) = -(vy(check)*vloss);
        end
    end
end

figure(2)
xv = linspace(min(x), max(x),200);
yv = linspace(min(y), max(y),100);
[X,Y] = meshgrid(xv,yv);
eMapX=linspace(0, wArea, 201); %increase by 1 for surf
eMapY=linspace(0, lArea, 101); %increase by 1 for surf
EDM=histcounts2(y,x,eMapY,eMapX);
surf(X,Y,EDM)
xlabel('Width(m)', 'FontSize', 10), ylabel('Length(m)', 'FontSize',
 10),zlabel('Electron Density (#)', 'FontSize', 10),
 view(45,60),title('Electron Density Map');

%Improving the simulation accuracy would be including a more realistic
%bottleneck shape and structure. A perfect rectangle is not a realistic doping
 shape.
% Including Quantum tunneling was introduced for devices. Better model
%for electron hitting eachother than a random scatter constant, two
%electron hitting eachother moving forward would still both move forward.
```



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