ELEC 4700 ASSIGNMENT 1

Contents

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Electron Modelling

a) The thermal veolocity is given by (T = 300K):

$V_t = sqrt(2kT/0.26m_o)$

$V_t = 1.87 * 10^5 m/s$

b) The Mean free path is:

$= 1.87 * 10^5/0.2ps$

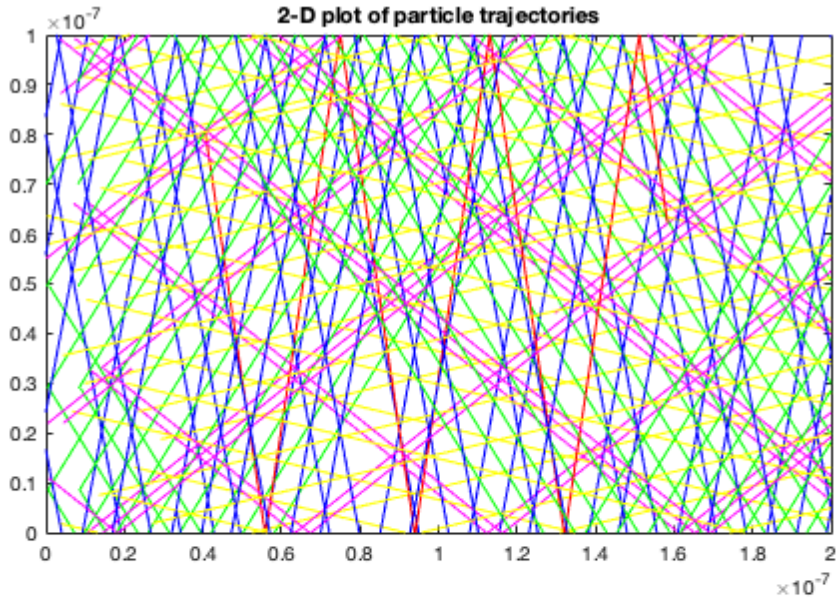
$= 3.74 * 10^(- 9)m$

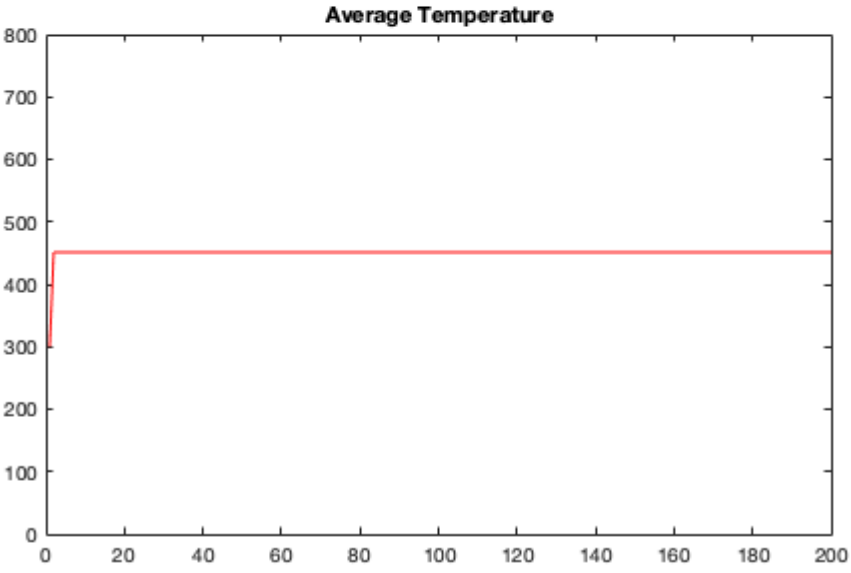
c) 2-D plot of particle trajectories

```
clearvars
clearvars -GLOBAL
close all
set(0,'DefaultFigureWindowStyle', 'docked')

%CONSTANTS AND VARIABLES

global C
global Em T
global BoundX BoundY
global Pxp Px Pyp Py Vx Vy
global Vtherm
global nElectrons
global t_mn



C.q_0 = 1.60217653e-19;             % electron charge
C.hb = 1.054571596e-34;             % Dirac constant
C.h = C.hb * 2 * pi;                    % Planck constant
C.m_0 = 9.10938215e-31;             % electron mass
C.kb = 1.3806504e-23;               % Boltzmann constant
C.eps_0 = 8.854187817e-12;          % vacuum permittivity
C.mu_0 = 1.2566370614e-6;           % vacuum permeability
C.c = 299792458;                    % speed of light
C.g = 9.80665;                      % metres (32.1740 ft) per s²
```

```
Em = 0.26 * C.m_0;                    % Mass of the Electron
BoundX = 200e-9;                     % X boundary
BoundY = 100e-9;                     % Y boundary
T = 300;                             % Semiconductor temperature

t_mn = 0.2e-11;                      % Mean time between collisions

TimeSteps = 200;                    % Number of time steps

nElectrons = 50;                    % Number of electrons

dt = 1e-13;                          % Time Step



Pxp(1: nElectrons) = rand(nElectrons, 1) * BoundX;
Pyp(1: nElectrons) = rand(nElectrons, 1) * BoundY;

Vtherm = sqrt(2 * C.kb * T/Em);

Vx(1: nElectrons) = randn(nElectrons, 1) * Vtherm;
Vy(1: nElectrons) = randn(nElectrons, 1) * Vtherm;

myColors = ['r' 'b' 'g' 'y' 'm' ];
myColorTyp = 1;

Pscat = 1 - exp(-(dt/t_mn));

a = randi(nElectrons,5,1);

TAvgp = 300;
for i=2:TimeSteps

   Px(1: nElectrons) = Pxp(1: nElectrons) + (Vx .* dt);
   Py(1: nElectrons) = Pyp(1: nElectrons) + (Vy .* dt);

   Vy((Py>BoundY) | (Py<0)) = -Vy((Py>BoundY) | (Py<0));

   for j=1:5
       subplot(2,1,1);
       plot([Pxp(a(j)) Px(a(j))], [Pyp(a(j)) Py(a(j))],myColors(j));
       xlim([0 BoundX]);
       ylim([0 BoundY]);
   end
   pause(0.1)
   hold on
   title('2-D plot of particle trajectories');

   VxAvg = mean(abs(Vx));
   VyAvg = mean(abs(Vy));

   TAvg = (((VxAvg^2)+ (VyAvg^2)) * Em)/(2 * C.kb);

   subplot(2,1,2);
   plot([i-1 i],[TAvgp TAvg],'r');
   xlim([0 TimeSteps]);
   ylim([0 800]);
   pause(0.1)
   hold on
   title('Average Temperature');
```

```
    Px(Px>BoundX) = Px(Px>BoundX)-BoundX;
    Px(Px<0) = BoundX;

    Pxp = Px;
    Pyp = Py;

    TAvgp = TAvg;

end
```

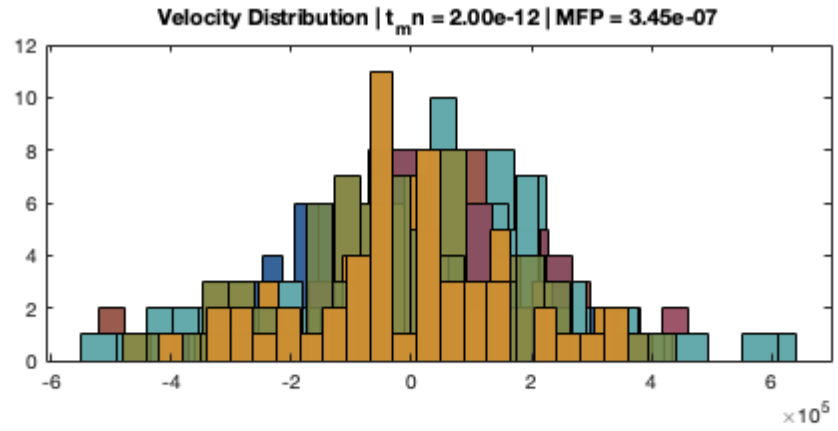


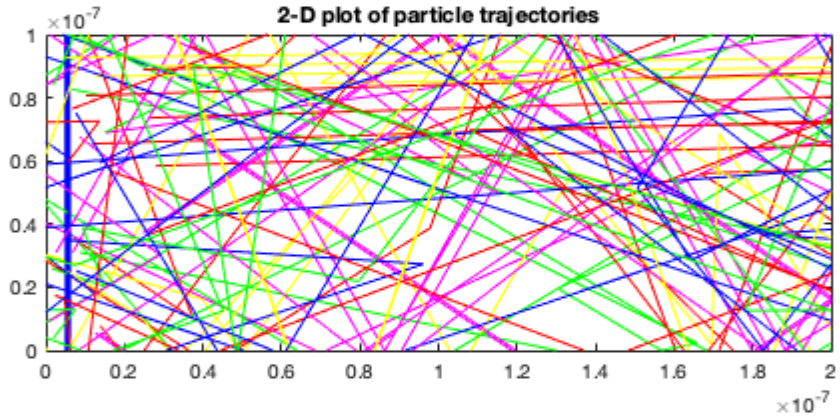


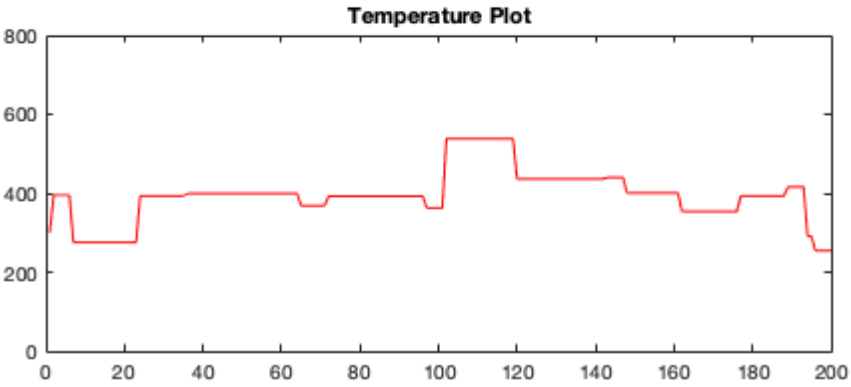
Collisions with Mean Free Path (MFP)

```
clearvars
clearvars -GLOBAL
close all
set(0,'DefaultFigureWindowStyle', 'docked')

%CONSTANTS AND VARIABLES

C.q_0 = 1.60217653e-19;              % electron charge
C.hb = 1.054571596e-34;              % Dirac constant
C.h = C.hb * 2 * pi;                    % Planck constant
C.m_0 = 9.10938215e-31;              % electron mass
C.kb = 1.3806504e-23;                % Boltzmann constant
C.eps_0 = 8.854187817e-12;           % vacuum permittivity
C.mu_0 = 1.2566370614e-6;            % vacuum permeability
C.c = 299792458;                     % speed of light
C.g = 9.80665;                       % metres (32.1740 ft) per s²

Em = 0.26 * C.m_0;                     % Mass of the Electron
BoundX = 200e-9;                     % X boundary
BoundY = 100e-9;                     % Y boundary
T = 300;                             % Semiconductor temperature

t_mn = 0.2e-11;                      % Mean time between collisions

TimeSteps = 200;                    % Number of time steps

nElectrons = 50;                    % Number of electrons

dt = 1e-13;                           % Time Step



Pxp(1: nElectrons) = rand(nElectrons, 1) * BoundX;
Pyp(1: nElectrons) = rand(nElectrons, 1) * BoundY;

Vtherm = sqrt(2 * C.kb * T/Em);

Vx(1: nElectrons) = randn(nElectrons, 1) * Vtherm;
Vy(1: nElectrons) = randn(nElectrons, 1) * Vtherm;

myColors = ['r' 'b' 'g' 'y' 'm' ];
myColorTyp = 1;

Pscat = 1 - exp(-(dt/t_mn));

a = randi(nElectrons,5,1);

TAvgp = 300;

for i=2:TimeSteps

   if(Pscat > rand())
      Vx(1: nElectrons) = randn(nElectrons, 1) * Vtherm;
      Vy(1: nElectrons) = randn(nElectrons, 1) * Vtherm;
   end

   Px(1: nElectrons) = Pxp(1: nElectrons) + (Vx .* dt);
   Py(1: nElectrons) = Pyp(1: nElectrons) + (Vy .* dt);
```

```
    Vy((Py>BoundY) | (Py<0)) = -Vy((Py>BoundY) | (Py<0));

    for j=1:5
        subplot(3,1,2);
        plot([Pxp(a(j)) Px(a(j))], [Pyp(a(j)) Py(a(j))],myColors(j));
        xlim([0 BoundX]);
        ylim([0 BoundY]);
    end
    pause(0.1)
    hold on
    title('2-D plot of particle trajectories');

    VxAvg = mean(abs(Vx));
    VyAvg = mean(abs(Vy));

    TAvg = (((VxAvg^2)+ (VyAvg^2)) * Em)/(2 * C.kb);

    VAvg = sqrt(((VxAvg^2)+ (VyAvg^2)));

    subplot(3,1,3);
    plot([i-1 i],[TAvgp TAvg],'r');
    xlim([0 TimeSteps]);
    ylim([0 800]);
    pause(0.1)
    hold on
    title('Temperature Plot');

    Px(Px>BoundX) = Px(Px>BoundX)-BoundX;
    Px(Px<0) = BoundX;

    Pxp = Px;
    Pyp = Py;

    t_mnCalc = -dt/log(1 - Pscat);
    MFP = VAvg * t_mnCalc;
    TAvgp = TAvg;
    subplot(3,1,1);
    histogram(Vx,20);
    hold on
    title( sprintf('Velocity Distribution | t_mn = %0.2e | MFP = %0.2e', t_mnCalc, MFP));
end
%
%
```







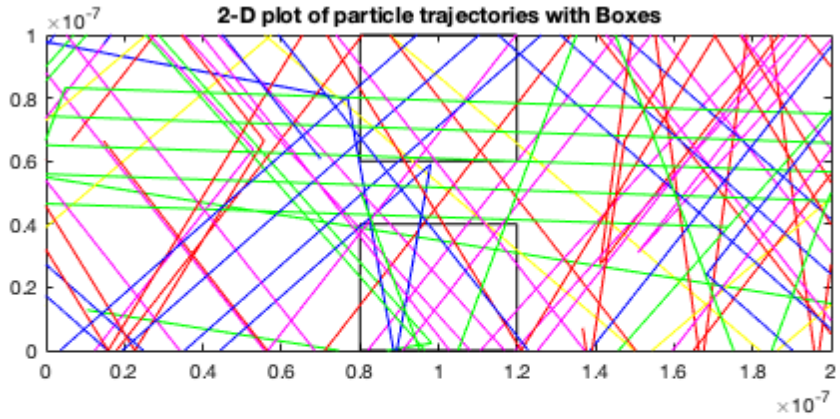
Enhancements

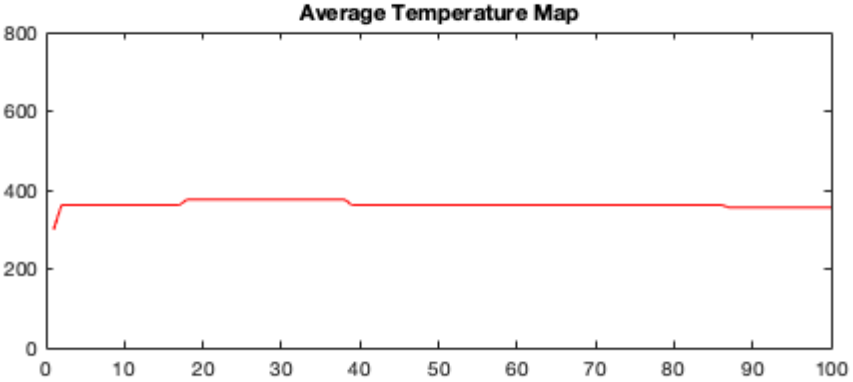
```
clearvars
clearvars -GLOBAL
close all
set(0,'DefaultFigureWindowStyle', 'docked')
C.q_0 = 1.60217653e-19;              % electron charge
C.hb = 1.054571596e-34;              % Dirac constant
C.h = C.hb * 2 * pi;                     % Planck constant
C.m_0 = 9.10938215e-31;              % electron mass
C.kb = 1.3806504e-23;                % Boltzmann constant
C.eps_0 = 8.854187817e-12;           % vacuum permittivity
C.mu_0 = 1.2566370614e-6;            % vacuum permeability
```

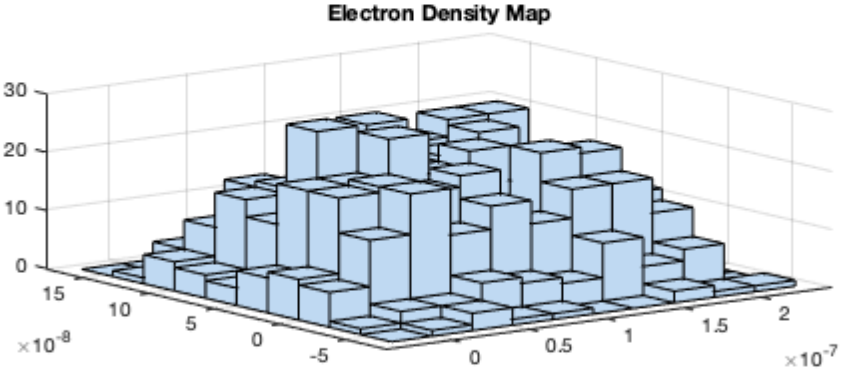
```
C.c = 299792458;                    % speed of light
C.g = 9.80665;                      % metres (32.1740 ft) per s²


Em = 0.26 * C.m_0;                    % Mass of the Electron
BoundX = 200e-9;                    % X boundary
BoundY = 100e-9;                    % Y boundary
T = 300;                            % Semiconductor temperature

t_mn = 0.2e-11;                     % Mean time between collisions

TimeSteps = 100;                   % Number of time steps

nElectrons = 1000;                    % Number of electrons

dt = 1e-13;                         % Time Step

% BOX 1 Boundaries

Box1Bnd1x = 0.8e-7;
Box1Bnd1y = 1e-7;
Box1Bnd2x = 1.2e-7;
Box1Bnd2y = 1e-7;
Box1Bnd3x = 1.2e-7;
Box1Bnd3y = 0.6e-7;
Box1Bnd4x = 0.8e-7;
Box1Bnd4y = 0.6e-7;

% BOX 2 Boundaries

Box2Bnd1x = 0.8e-7;
Box2Bnd1y = 0.4e-7;
Box2Bnd2x = 1.2e-7;
Box2Bnd2y = 0.4e-7;
Box2Bnd3x = 1.2e-7;
Box2Bnd3y = 0;
Box2Bnd4x = 0.8e-7;
Box2Bnd4y = 0;

subplot(3,1,1);
myBoxes(Box1Bnd1x, Box1Bnd1y, Box1Bnd2x, Box1Bnd2y, Box1Bnd3x, Box1Bnd3y, Box1Bnd4x, Box1Bnd4y);
myBoxes(Box2Bnd1x, Box2Bnd1y, Box2Bnd2x, Box2Bnd2y, Box2Bnd3x, Box2Bnd3y, Box2Bnd4x, Box2Bnd4y);
hold on

%INITITAL POSITIONS

%Check if electrons are within Box 1 and Box 2

x = randi(nElectrons,1);
Pxp(1: x) = ((Box2Bnd4x - 0).*rand(x, 1))* BoundX;
Pxp(x+1: nElectrons) = ((BoundX - Box2Bnd3x).*rand(nElectrons - x, 1) + Box2Bnd3x )* BoundX;


Pyp(1: nElectrons) = rand(nElectrons, 1) * BoundY;

Vtherm = sqrt(2 * C.kb * T/Em);

Vx(1: nElectrons) = randn(nElectrons, 1) * Vtherm;
Vy(1: nElectrons) = randn(nElectrons, 1) * Vtherm;
```

```
Px(1: nElectrons) = Pxp(1: nElectrons) + (Vx .* dt);
Py(1: nElectrons) = Pyp(1: nElectrons) + (Vy .* dt);

myColors = ['r' 'b' 'g' 'y' 'm' ];
myColorTyp = 1;

Pscat = 1 - exp(-(dt/t_mn));

a = randi(nElectrons,5,1);

TAvgp = 300;

for i=2:TimeSteps

   if(Pscat > rand())
      Vx(1: nElectrons) = randn(nElectrons, 1) * Vtherm;
      Vy(1: nElectrons) = randn(nElectrons, 1) * Vtherm;
   end

   Vy((Py>BoundY) | (Py<0)) = -Vy((Py>BoundY) | (Py<0));




   for j=1:5
       subplot(3,1,1);

       plot([Pxp(a(j)) Px(a(j))], [Pyp(a(j)) Py(a(j))],myColors(j));
       xlim([0 BoundX]);
       ylim([0 BoundY]);
   end
   pause(0.1)
   hold on
   title('2-D plot of particle trajectories with Boxes');

   VxAvg = mean(abs(Vx));
   VyAvg = mean(abs(Vy));

   TAvg = (((VxAvg^2)+ (VyAvg^2)) * Em)/(2 * C.kb);

   subplot(3,1,2);
   plot([i-1 i],[TAvgp TAvg],'r');
   xlim([0 TimeSteps]);
   ylim([0 800]);
   pause(0.1)
   hold on
   title('Average Temperature Map');

   Px(Px>BoundX) = Px(Px>BoundX)-BoundX;
   Px(Px<0) = BoundX;

   Pxp = Px;
   Pyp = Py;

   TAvgp = TAvg;

   Px(1: nElectrons) = Pxp(1: nElectrons) + (Vx .* dt);
   Py(1: nElectrons) = Pyp(1: nElectrons) + (Vy .* dt);
```

```
end

subplot(3,1,3);
hist3([Px.',Py.']);
title('Electron Density Map');
```







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