Engineering Electromagnetics - Experiment 2

Name: 樊青远 | Student ID: 11812418

Apr 2020

Contents

A Introduction

From the introduction material, we found that there're two ways to calculate the electric field and potential distribution of line charges.

The first method is the integration method, which integrate the elctric field on the line charge from the head to the end on every point in the coordinates. The expression of the integration equation could be written as:

$$V = k\int_{-1}^{1}\frac{\rho dx}{R}$$

$$V = k\int_{-1}^{1}\frac{\rho dx}{(x-X_0)^2+Y_0^2)}$$

$$= k\rho dx \cdot ln\left|(x-X_0+\sqrt{(x-X_0)^2+Y_0^2})\right|_{-1}^{1}$$

$$= \mathbf{k}\rho\ln\left(\frac{1-X_0+\sqrt{(1-X_0)^2+Y_0^2}}{-1-X_0+\sqrt{(-1-X_0)^2+Y_0^2}}\right)$$

There also has another calculation method called the "infinitesimal method", which devide the line charge into multiple segments, then sum the electric field generate by every segments, respectively for all the points in the coordinates.

B Solving with Integration Method

B.1 Define the parameters and calculate the potential

B.1.1 Matlab Code

```
clear;% clear all variables in memory
clc;% Clear the contents of the command window
%% define
k=9e9; % set electrostatic constant
xm=3;% Set the range of the field in x direction
ym=3;% Set the range of the field in y direction
segments=100; %set the segment
EF_density=10e-9;
L_length=2;
tiles=100;
Q=(L_length/segments)*EF_density;

x=linspace(-xm,xm,tiles);% evenly divide the x axis into 100 segments
y=linspace(-ym,ym,tiles);% evenly divide the y axis into 100 segments
[X,Y]=meshgrid(x,y);  % To form the coordinates of each point in the field.
sumV=zeros(tiles,tiles);
xcl = linspace(-xm,xm,tiles);
ycl = linspace(-xm,xm,tiles);
for xc = 1:tiles
    for yc = 1:tiles
% calculate the electric potential point by point
    sumV(yc,xc) = k*EF_density*log((1-x(xc)+sqrt((1-x(xc)).^2+y(yc).^2))./(-1-x(xc)+sqrt((-1-x(xc)).^2+ycl(yc).^2)));
```

```
        end
    end
```

B.2 Electric Potential Distribution

B.2.1 Matlab Code

```
%% part1

figure1 = figure;%define figure
surf(X,Y,sumV);
shading interp; %disable the grid
colormap default; %set the colour map
hold on;
title({'the plot of electric potential distribution of the line ...
charges in the vacuum';'(integration method) 樊青远 11812418'}, 'fontsize',12);
pbaspect([1 1 1]);
xlabel('X axis(unit: m)','fontsize',12);% label the x axis
ylabel('Y axis(unit: m)','fontsize',12);% label the y axis
zlabel('Electric Potential (unit: V/m)','fontsize',12); %label the z axis
colorbar;
saveas(figure1,'../fig/A1.jpg');
```

B.2.2 Figure

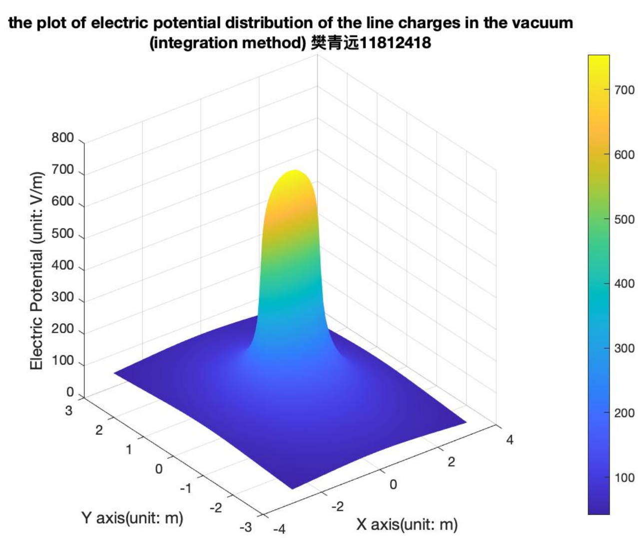

Figure 1: Electric potential distribution

B.3 Isopotential Line

B.3.1 Matlab Code

```
%% part2

Tmax=max(max(sumV)); %find the maximum potential value
Tmin=min(min(sumV)); %find the maximum potential value
Vmin=20; % set the minimum potential value for a family of equipotential lines
Vmax=600; % set the maxmium potential value for a family of equipotential lines
Veq=linspace(Vmin,Vmax,20); % set the potential for 10 equipotential lines
figure1 = figure;%define figure
contour(X,Y,sumV,Veq);  % plot 10 equipotential lines
grid on;  % form a grid  % hold the plot
hold on;
plot(0,0,'o', 'MarkerSize',12) % plot a charge at the origin
title({'Isopotential Line of the Line Charge Electric Field in Vacuum (integration method) (Unit: V)';'樊青远 11812418'}
pbaspect([1 1 1]);
xlabel('X axis(unit: m)','fontsize',12);% label the x axis
ylabel('Y axis(unit: m)','fontsize',12);% label the y axis
colorbar;
hold off;
saveas(figure1,'../fig/A2.jpg');
```

B.3.2 Figure

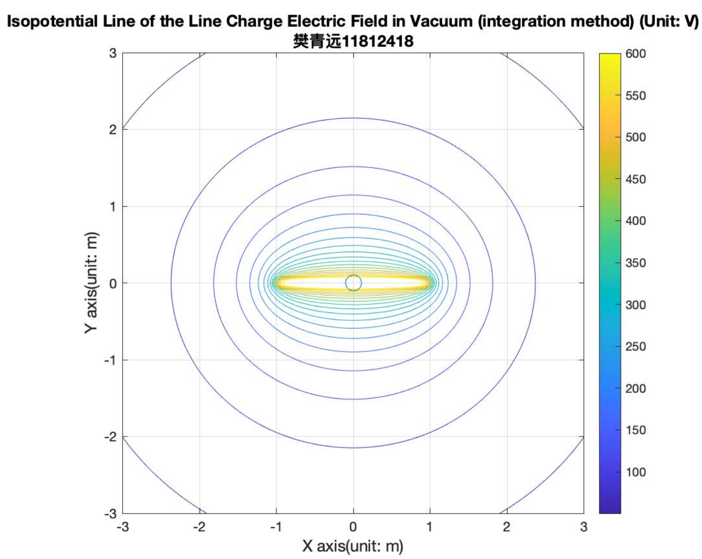

Figure 2: Isopotential Line

B.4 Isopotential Line and Power Line by Smooth Continuous Curves

B.4.1 Matlab Code

```matlab
%% part3
[Ex,Ey]=gradient(-sumV); % Calculation of two components of Electric Field intensity at each Point in the Field
del_theta=10; % Set the angle difference between adjacent field lines;
theta=(0:del_theta:360).*pi/180; % express the angle into radian
% difine the start of the electric field line
x1=-1;
y1=0;
x2=1;
y2=0;
xs = -1.2:0.15:1.2;
L = length(xs);
ys = 0.15 .* ones(L,1);
xs2 = -1.2:0.2:1.2;
L = length(xs2);
ys2 = -0.15 .* ones(L,1);

figure1 = figure;%define figure
hold on   % hold the plot
grid on;
contourf(X,Y,sumV,Veq);   % plot 100 equipotential lines
h=streamline(X,Y,Ex,Ey,xs,ys); % generate the field lines?
set(h,'linewidth',2,'color',[1 1 1]);
h=streamline(X,Y,Ex,Ey,xs2,ys2); % generate the field lines?
set(h,'linewidth',2,'color',[1 1 1]);

plot(0,0,'o', 'MarkerSize',12) % plot the point charge at the origin
title({' Isopotential Line and Power Line of the Line Charge Electric Field in vacuum';...
    '(integration method) Unit: V';'樊青远 11812418'} , 'fontsize',12);
pbaspect([1 1 1]);
xlabel('X axis(unit: m)','fontsize',12);% label the x axis
ylabel('Y axis(unit: m)','fontsize',12);% label the y axis
colorbar;
%xlim([-0.03 0.03]); % set the limit of axis
%ylim([-0.03 0.03]); % set the limit of axis
saveas(figure1,'../fig/A3.jpg');
```

B.4.2 Figure

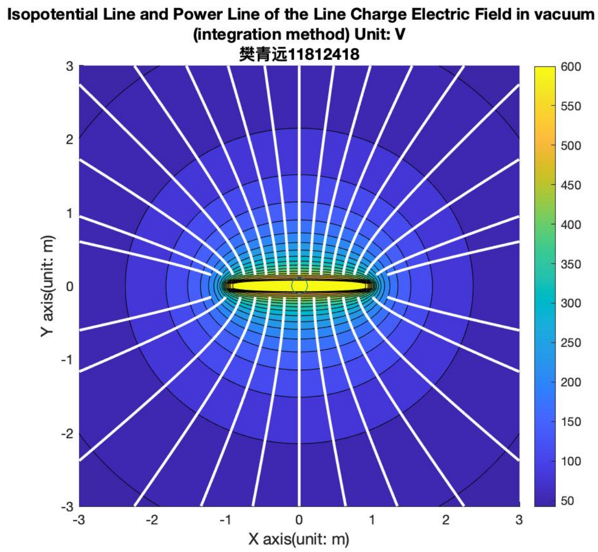

Figure 3: Isopotential Line and Power Line
(expressed by smooth continuous curves)

B.5 Isopotential Line and Power Line by Normalized Arrowhead

B.5.1 Electric potential distribution

```
%% part4
E=sqrt(Ex.^2+Ey.^2); % calculate the magnitude of electric field magnitude at each point.
Ex=Ex./E;
Ey=Ey./E;   % normalize the magnitude of the electric field
figure1 = figure;%define figure
hold on
index1 = 5 : 5 : 95;
index2 = index1;
p1 = X(index1, index2); p2 = Y(index1, index2);
% scaling of electric field lines: unit length
p3 = Ex(index1, index2)./(E(index1,index2));
p4 = Ey(index1, index2)./(E(index1,index2));
% no scaling of electric field lines
%  p3 = Ex(index1, index2); p4 = Ey(index1, index2);
contourf(X,Y,sumV,Veq);% plot the equipotential lines
h = quiver(p1,p2,p3,p4,'autoscalefactor',0.5);
set(h,'color',[1 1 1],'linewidth',1.2)

pbaspect([1 1 1]);
title({'Equipotential lines and electric field lines of'; 'the Line Charge Electric Field in vacuum';...
    '(integration method) Unit: V';'樊青远 11812418'} , 'fontsize',12);
xlabel('X axis(unit: m)','fontsize',12);% label the x axis
ylabel('Y axis(unit: m)','fontsize',12);% label the y axis
colorbar; %enable colour bar
saveas(figure1,'../fig/A4.jpg');
%% Saving MAT
```

```
    sumV_integration = sumV;
    save('../var/sumV_integration.mat','sumV_integration');
```

B.5.2 Figure

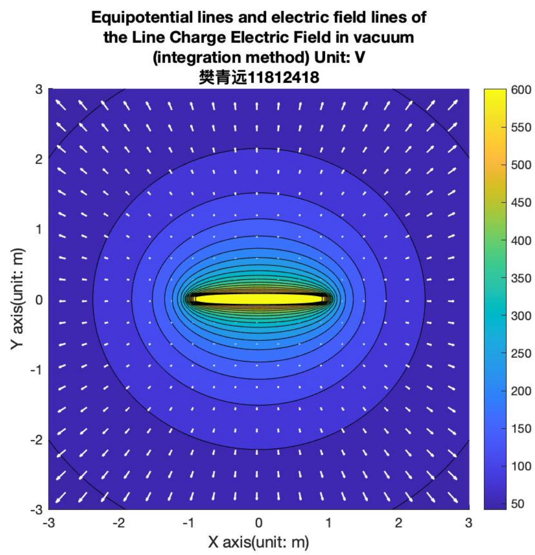

Figure 4: Equipotential lines and electric field lines (represented by normalized arrowhead)

C Distribution of Electric Potential (Infinitesimal Method) (20 Segments)

C.1 Define the parameters

C.1.1 Matlab Code

```
clear;% clear all variables in memory
clc;% Clear the contents of the command window
%% define
k=9e9; % set electrostatic constant
xm=3;% Set the range of the field in x direction
ym=3;% Set the range of the field in y direction
segments=20; %set the segment
EF_density=10e-9;
L_length=2;
tiles=100;
Q=(L_length/segments)*EF_density;

%define the func
EF_func = @(x,X0,Y0) k*(EF_density./sqrt((x-X0).^2+Y0.^2));

x=linspace(-xm,xm,tiles);% evenly divide the x axis into 100 segments
y=linspace(-ym,ym,tiles);% evenly divide the y axis into 100 segments
[X,Y]=meshgrid(x,y);  % To form the coordinates of each point in the field.
sumV=zeros(tiles,tiles);
summV=zeros(tiles,tiles);
for x1 = -1:(L_length/segments):1
y1=0; %define the location of the charges
R1=sqrt((X-x1).^2+(Y-y1).^2); % calculate the distance between each point and the source charge (the origin).
V1=k*Q./R1; %calculate the electric potential
sumV = sumV + V1;
end
```

C.2 Electric Potential Distribution

C.2.1 Matlab Code

```
%% part1
sumV = V1+V2; % plot the distribution of electric potential
figure1 = figure;%define figure
surf(X,Y,sumV);
shading interp; %disable the grid
colormap default; %set the colour map
hold on;
title({'the plot of electric potential distribution of two identical point charges in the vacuum';'樊青远 11812418'}, 'f
pbaspect([1 1 1]);
xlabel('X axis(unit: m)','fontsize',12);% label the x axis
ylabel('Y axis(unit: m)','fontsize',12);% label the y axis
zlabel('Electric Potential (unit: V/m)','fontsize',12); %label the z axis
```

```
colorbar;
saveas(figure1,'../fig/B1.jpg');
```

C.2.2 Figure

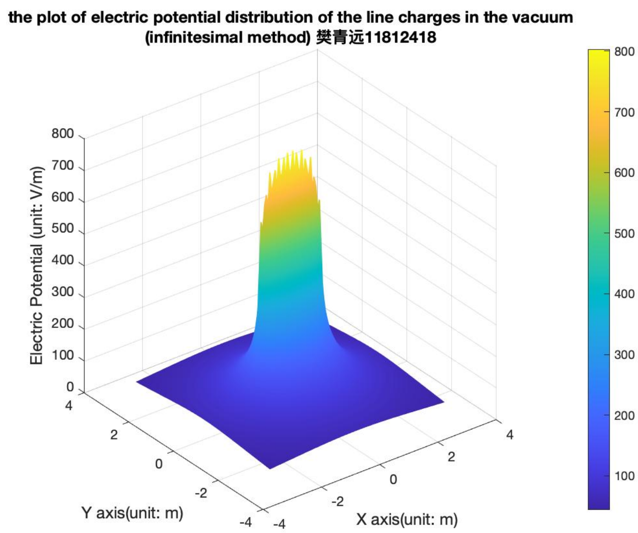

Figure 5: The plot of electric potential distribution (20 Segments)

C.3 Isopotential Line

C.3.1 Matlab Code

```
%% part2

Tmax=max(max(sumV)); %find the maximum potential value
Tmin=min(min(sumV)); %find the maximum potential value
Vmin=20; % set the minimum potential value for a family of equipotential lines
Vmax=600; % set the maxmium potential value for a family of equipotential lines
Veq=linspace(Vmin,Vmax,20); % set the potential for 10 equipotential lines
figure1 = figure;%define figure
contour(X,Y,sumV,Veq);  % plot 10 equipotential lines
grid on;  % form a grid  % hold the plot
hold on;
plot(0,0,'o', 'MarkerSize',12) % plot a charge at the origin
title({'Isopotential Line of the Line Charge Electric Field in Vacuum (Unit: V)';'(infinitesimal method) 樊青远 11812418
pbaspect([1 1 1]);
xlabel('X axis(unit: m)','fontsize',12);% label the x axis
ylabel('Y axis(unit: m)','fontsize',12);% label the y axis
colorbar;
hold off;
saveas(figure1,'../fig/B2.jpg');
```

C.3.2 Figure

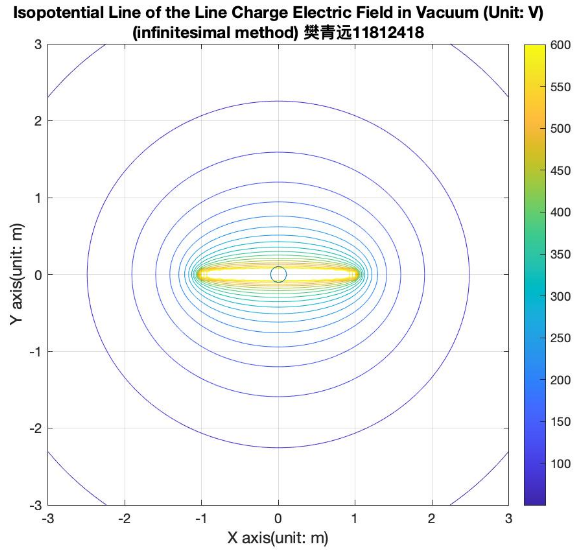

Figure 6: Isopotential Line (20 Segments)

C.4 Isopotential Line and Power Line by Smooth Continuous Curves

C.4.1 Matlab Code

```matlab
%% part3
[Ex,Ey]=gradient(-sumV); % Calculation of two components of Electric Field intensity at each Point in the Field
del_theta=10; % Set the angle difference between adjacent field lines;
theta=(0:del_theta:360).*pi/180; % express the angle into radian
% difine the start of the electric field line
x1=-1;
y1=0;
x2=1;
y2=0;
xs = -1.2:0.15:1.2;
L = length(xs);
ys = 0.15 .* ones(L,1);
xs2 = -1.2:0.2:1.2;
L = length(xs2);
ys2 = -0.15 .* ones(L,1);

figure1 = figure;%define figure
hold on   % hold the plot
grid on;
contourf(X,Y,sumV,Veq);   % plot 100 equipotential lines
h=streamline(X,Y,Ex,Ey,xs,ys); % generate the field lines?
set(h,'linewidth',2,'color',[1 1 1]);
h=streamline(X,Y,Ex,Ey,xs2,ys2); % generate the field lines?
set(h,'linewidth',2,'color',[1 1 1]);

```

```
    plot(0,0,'o', 'MarkerSize',12) % plot the point charge at the origin
    title({' Isopotential Line and Power Line of the Line Charge Electric Field in vacuum';...
        'Unit: V';'(infinitesimal method) 樊青远 11812418'} , 'fontsize',12);
    pbaspect([1 1 1]);
    xlabel('X axis(unit: m)','fontsize',12);% label the x axis
    ylabel('Y axis(unit: m)','fontsize',12);% label the y axis
    colorbar;
    %xlim([-0.03 0.03]); % set the limit of axis
    %ylim([-0.03 0.03]); % set the limit of axis
    saveas(figure1,'../fig/B3.jpg');
```

C.4.2 Figure

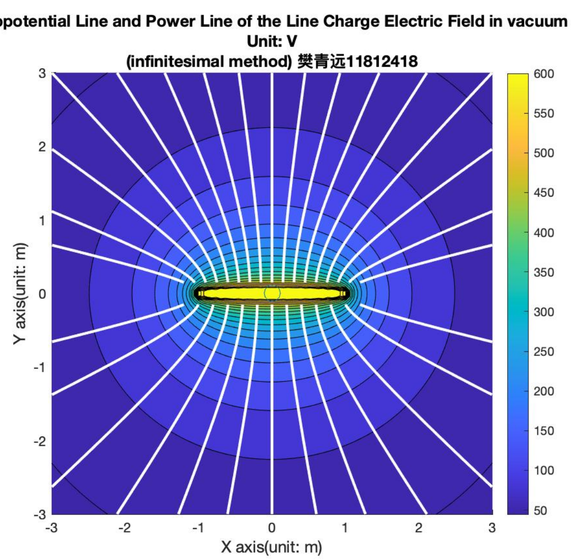

Figure 7: Isopotential Line and Power Line (20 Segments)
(expressed by smooth continuous curves)

C.5 Isopotential Line and Power Line by Normalized Arrowhead

C.5.1 Electric potential distribution

```
    %% part4
    E=sqrt(Ex.^2+Ey.^2); % calculate the magnitude of electric field magnitude at each point.
    Ex=Ex./E;
    Ey=Ey./E;   % normalize the magnitude of the electric field
    figure1 = figure;%define figure
    hold on
    index1 = 5 : 5 : 95;
    index2 = index1;
    p1 = X(index1, index2); p2 = Y(index1, index2);
    % scaling of electric field lines: unit length
    p3 = Ex(index1, index2)./(E(index1,index2));
    p4 = Ey(index1, index2)./(E(index1,index2));
```

```matlab
    % no scaling of electric field lines
    %  p3 = Ex(index1, index2); p4 = Ey(index1, index2);
    contourf(X,Y,sumV,Veq);% plot the equipotential lines
    h = quiver(p1,p2,p3,p4,'autoscalefactor',0.5);
    set(h,'color',[1 1 1],'linewidth',1.2)

    pbaspect([1 1 1]);
    title({'Equipotential lines and electric field lines of'; 'the Line Charge Electric Field in vacuum';...
        'Unit: V';'(infinitesimal method) 樊青远 11812418'} , 'fontsize',12);
    xlabel('X axis(unit: m)','fontsize',12);% label the x axis
    ylabel('Y axis(unit: m)','fontsize',12);% label the y axis
    colorbar; %enable colour bar
    saveas(figure1,'../fig/B4.jpg');

    %% Saving MAT
    sumV_infinitesimal = sumV;
    save('../var/sumV_infinitesimal.mat','sumV_infinitesimal');
```

C.5.2 Figure

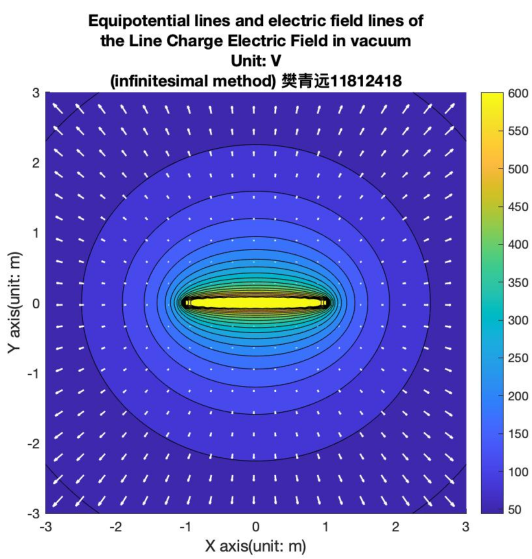

Figure 8: Equipotential lines and electric field lines (20 Segments) (represented by normalized arrowhead)

D Distribution of Electric Potential (Infinitesimal Method) (50 Segments)

The code of different segments division are quite similar except the value of the variable ”segments”

D.1 Define the parameters

D.1.1 Matlab Code

```
...
segments=100; %set the segment
...
```

D.2 Electric Potential Distribution

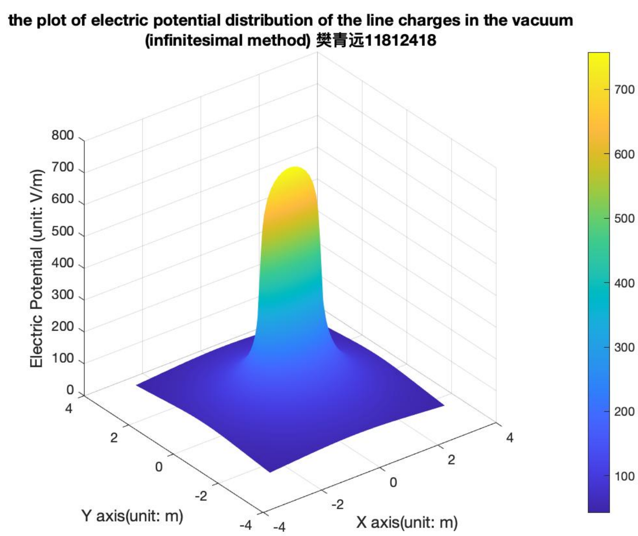

Figure 9: The plot of electric potential distribution (50 Segments)

D.3 Isopotential Line

D.3.1 Figure

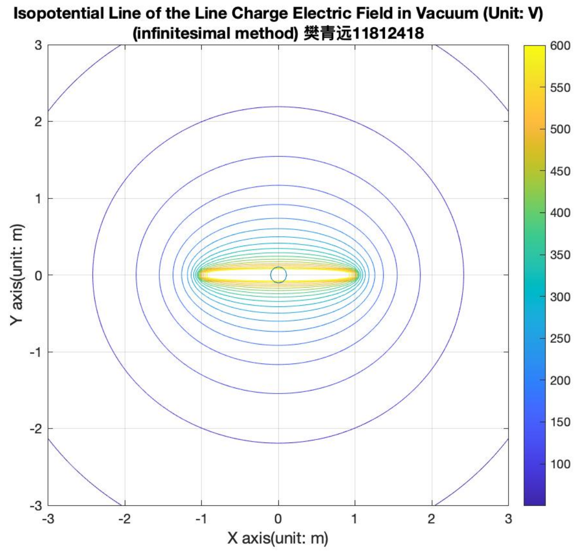

Figure 10: Isopotential Line (50 Segments)

D.4 Isopotential Line and Power Line by Smooth Continuous Curves

D.4.1 Figure

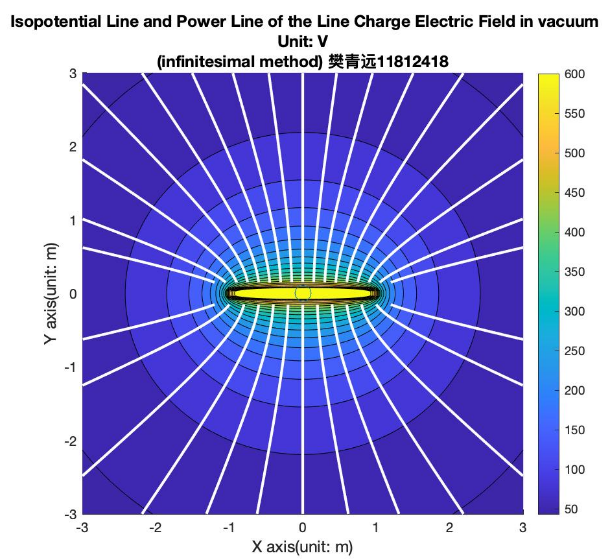

Figure 11: Isopotential Line and Power Line (50 Segments)
(expressed by smooth continuous curves)

D.5 Isopotential Line and Power Line by Normalized Arrowhead

D.5.1 Electric potential distribution

D.5.2 Figure

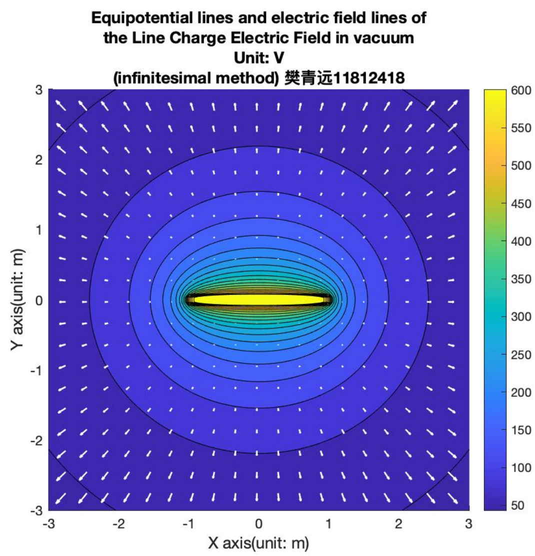

Figure 12: Equipotential lines and electric field lines (50 Segments)
(represented by normalized arrowhead)

E Distribution of Electric Potential (Infinitesimal Method) (100 Segments)

The code of different segments division are quite similar except the value of the variable ”segments”

E.1 Define the parameters

E.1.1 Matlab Code

```
...
segments=50; %set the segment
...
```

E.2 Electric Potential Distribution

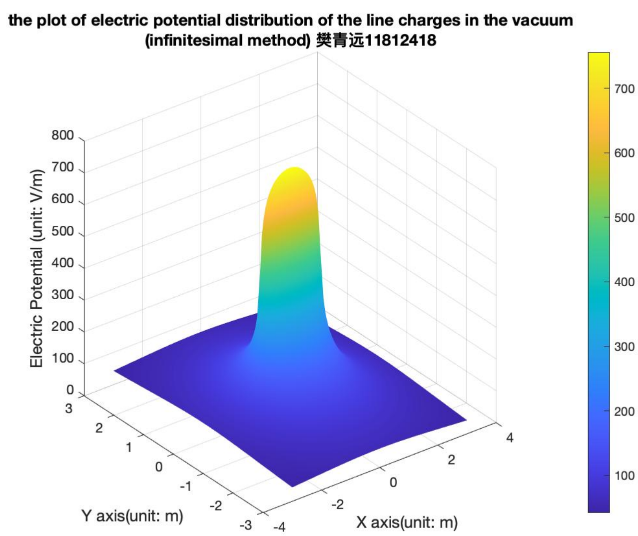

Figure 13: The plot of electric potential distribution (100 Segments)

E.3 Isopotential Line

E.3.1 Figure

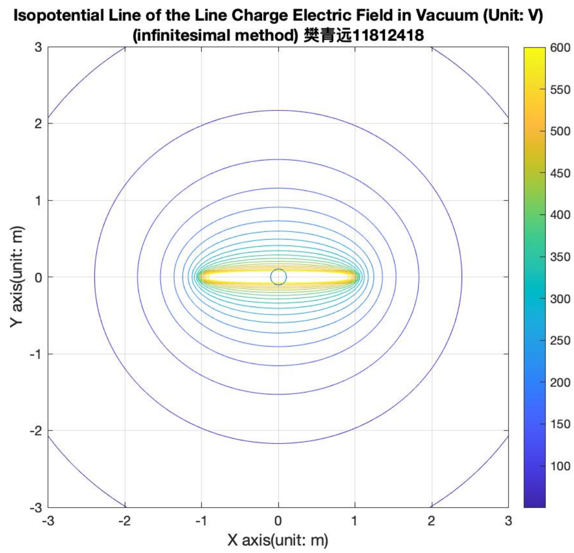

Figure 14: Isopotential Line (100 Segments)

E.4 Isopotential Line and Power Line by Smooth Continuous Curves

E.4.1 Figure

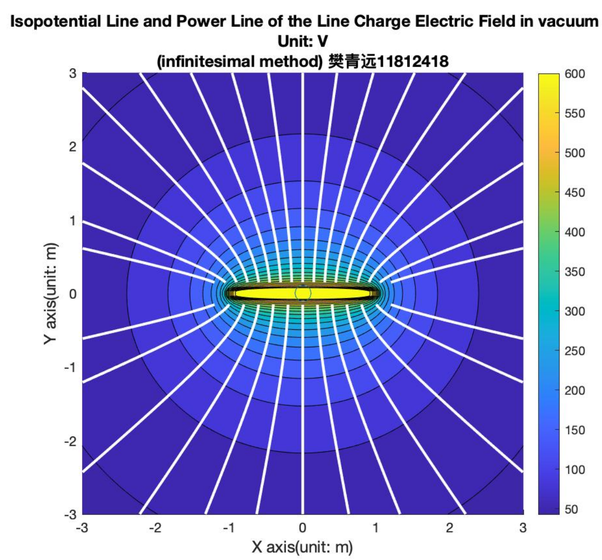

Figure 15: Isopotential Line and Power Line (100 Segments)
(expressed by smooth continuous curves)

E.5 Isopotential Line and Power Line by Normalized Arrowhead

E.5.1 Electric potential distribution

E.5.2 Figure

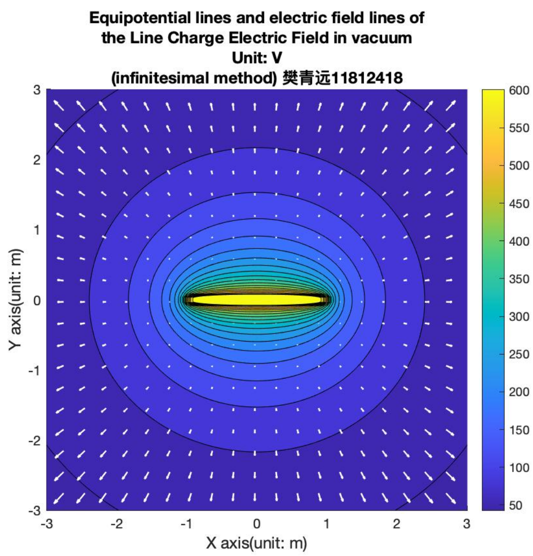

Figure 16: Equipotential lines and electric field lines (100 Segments)
(represented by normalized arrowhead)

F Comparation

F.1 Potential Difference over the Plane

To do the comparation, we first load the mat data file that prevoiusly exported from the program above.

F.2 Difference on the potential distribution

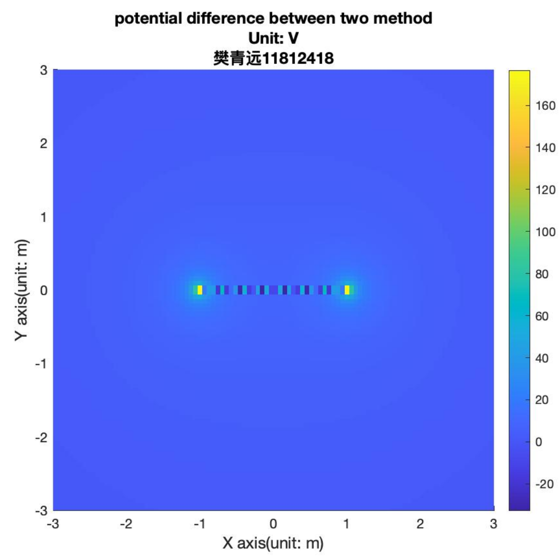

Figure 17: Comparation on electric potential distribution
(integration - infinitesimal(20 segments))

From the figure above, we could find that the difference between two method mainly occurs on the line charge. This may be caused by the defect of the infinitesimal method, which make the line charge discontinuous by divide the line charge into point charges.

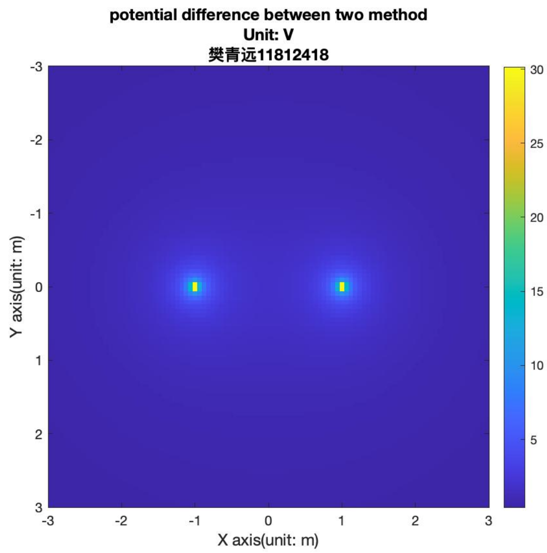

Figure 18: Comparation on electric potential distribution
(integration - infinitesimal(100 segments))

With the increase of the value of the segments, the difference between two method gradually becomes smaller.

Lastly, the difference between the two method mainly happens on the endpoints of the line charge, though it still has the potential difference as high of 21 Volt.

F.3 Potential Difference on the x Axis

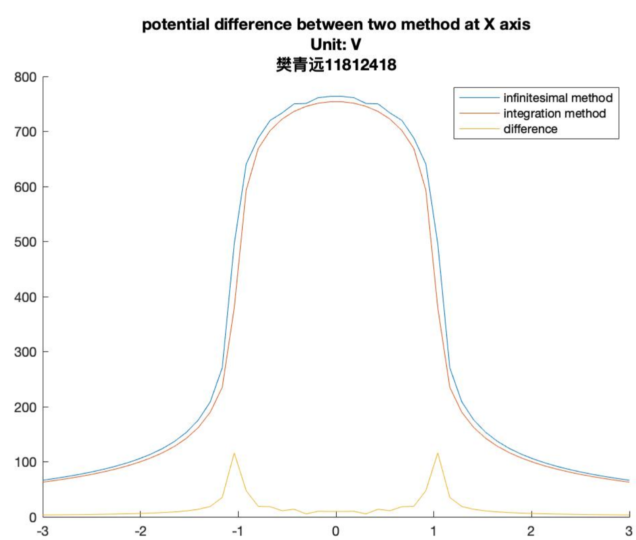

Figure 19: Comparation on electric potential distribution at x axis
(20 segments)

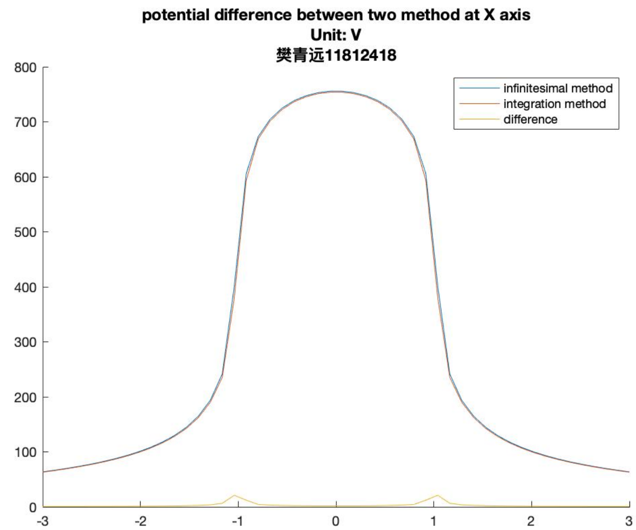

Figure 20: Comparation on electric potential distribution at x axis (100 segments)

From the figures above, we could also find the difference from the plots intuitively. The potential could have the potential difference as high as 116 Volts.

However, with the increase of the segments, the difference becomes less and less recognizable. At 100 segments, the maxium potential differece betweeen two method is only about 21 Volt.

F.4 Conclusion

Generally speaking, the more segments are taken, smaller deviation between two method would be generated, and higher accuracy could be got.

Besides, we also find that the integration method has a faster excuting speed (0.010629s) compare to the infinitesimal method (0.024052s). So, if we need shorter excuting time and higher accuracy, we may choose the integration method. However, if we encounters some complex charge distribution, the coventional infinitesimal method could let the equation simpler.

G Summary

From this lab, we have learned the different methods to calculate the electric field and potential distribution in a 2D plane. The methods and the thought to analyze through the image could be quite useful when we encountered some complex charges that is hard to calculate.