Engineering Electromagnetic Theory
Lab 1 Report

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October 22, 2024

Abstract

Use Matlab to demonstrate particular field and potential for different charge configuration. Plot figures including electric potential distribution, equipotential line and power line represent by smooth continuous curves and normalized arrows.

1 Object of this lab

1.1 Familiar with the E-field of single and multiple Charge distribution

1.2 Learning to calculate and plot distribution of E via Matlab

1.3 Related points of this lab

E field generated by single point charge in vacuum is

$$\vec{E} = k\frac{Q}{R^2}\vec{a_R} \tag{1}$$

Where coefficient $k = 9 \times 10^9 F/m$, is the electrostatic constant. Q represents the total amount charge. R denotes the distance between the point in the electric field and the source charge.

If we take the reference point as the infinite distance, then the E=potential at a point in the field is expressed as

$$V = k\frac{Q}{R} \tag{2}$$

The electric field intensity can be expressed as the negtive gradient of the electric potential

$$\vec{E} = -\nabla V \tag{3}$$

The electric field generated by N point charge in the vacuum is expressed as:

$$V = \Sigma_{i=1}^{N} k\frac{Q_i}{R_i} \tag{4}$$

Similarly, the field magnitude generated by N point charges in the vacuum can be obtained through equation (3).

2 Case I: Two identical point charges

2.1 Matlab Codes

Listing 1 Matlab codes for two indentical point charges, Fig 1

```
clear;          % clear all variables in memory
clc;            % Clear the contents of the command window
k = 9e9;          % set electrostatic constant
Q = 1e-9;         % Set charge Q
xm = 0.05;        % Set the range of the field in x direction
ym = 0.05;        % Set the range of the field in y direction
x1 = 0.01;      % Set the position of Q1
x2 = -0.01;     % Set the position of Q2
x = linspace(-xm,xm,50);    % evenly divide the x axis into 50 segments
y = linspace(-ym,ym,50);    % evenly divide the y axis into 50 segments
[X,Y] = meshgrid(x,y);    % To form the coordinates of each point in the field
R1 = sqrt((X-x1).^2+Y.^2);  % calculate the distance between each point and Q1
R2 = sqrt((X-x2).^2+Y.^2);  % calculate the distance between each point and Q2
V = k*Q./R1 + k*Q./R2;   % calculate the electric potential of each point
figure();    % Create the figure object
surf(X,Y,V);  % plot the distribution of electric potential
colormap(parula(100));   % Define the colormap
zlim([0 5000]);   % Limit z-axis
hold on;
title('the plot of electric potential distribution
    of two point charge in vacuum');
% The title for the plot
xlabel('X axis(unit: m)');  % label the x axis
ylabel('Y axis(unit: m)');  % label the y axis
hold off
```

Listing 2 Matlab codes for two indentical point charges, Fig 2

```
% Fig.2
Vmin=200;
Vmax=2000;   % set limit value for equipotential lines
Veq=linspace(Vmin,Vmax,10);    % set the potential for equipotential lines
figure();   % Form the figure object
contour(X,Y,V,Veq);       % plot 10 equipotential lines
grid on;
hold on;  % from the grid and hold the plot
plot(x1,0,'o', 'MarkerSize',12,Color=[1 0 0]);    % plot the point charge Q1
plot(x2,0,'o', 'MarkerSize',12,Color=[1 0 0]);    % plot the point charge Q2
% title the plot
title('Isopotential Line of Double Point charge Electric Field in vacuum');
xlabel('X axis(unit: m)');   % label the x axis
ylabel('Y axis(unit: m)');   % label the y axis
% Calculation the Electric Field intensity at each Point in the Field
[Ex,Ey]=gradient(-V);
del_theta=20;  % Set the angle difference between adjacent field lines;
theta=(0:del_theta:360).*pi/180;      % express the angle into radian
% generate the x and y coordinate for the start of the field line
xs1=0.004*cos(theta)+x1;
xs2=0.004*cos(theta)+x2;
ys=0.004*sin(theta);
streamline(X,Y,Ex,Ey,xs1,ys)     % generate the field lines
streamline(X,Y,Ex,Ey,xs2,ys)     % generate the field lines
grid on; hold on;  % from the grid and hold the plot
contour(X,Y,V,Veq);     % plot 10 equipotential lines
% title the plot
title('Isopotential Line and Power Line of
    double Point charge Electric Field in vacuum')
subtitle(' (expressed by smooth continuous Curves)')
% label the x and y axis
xlabel('X axis(unit: m)'); ylabel('Y axis (unit: m)');
hold off
```

Listing 3 Matlab codes for two indentical point charges, Fig 3

```
% fig.3
% calculate the magnitude of electric field magnitude at each point.
E=sqrt(Ex.^2+Ey.^2);
Ex=Ex./E;      % normalize the magnitude of the electric field
Ey=Ey./E;      % normalize the magnitude of the electric field
figure();      % Create the figure object
plot(x1,0,'o', 'MarkerSize',12,Color=[1 0 0])
hold on;
plot(x2,0,'o', 'MarkerSize',12,Color=[1 0 0])
contour(X,Y,V,Veq);     % plot the equipotential lines
% Slice the grids before plot the arrows in order to make it clear
X = X(1:2:end,1:2:end);
Y = Y(1:2:end,1:2:end);
Ex = Ex(1:2:end,1:2:end);
Ey= Ey(1:2:end,1:2:end);
quiver(X,Y,Ex,Ey);    % using normalized arrows to represent electric field
title('Equipotential lines and electric field lines
    of double point charge electric field in vacuum');
subtitle('(represented by normalized arrowhead ')      % title the graph
xlabel('X  axis(unit: m)');            % label the X axis
ylabel('Y  axis(unit: m)');            % label the Y axis
hold off
```

2.2 Results and Analysis

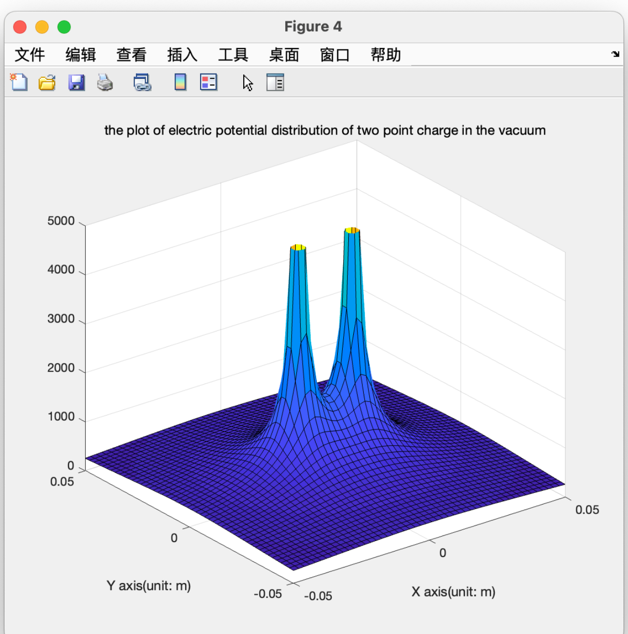
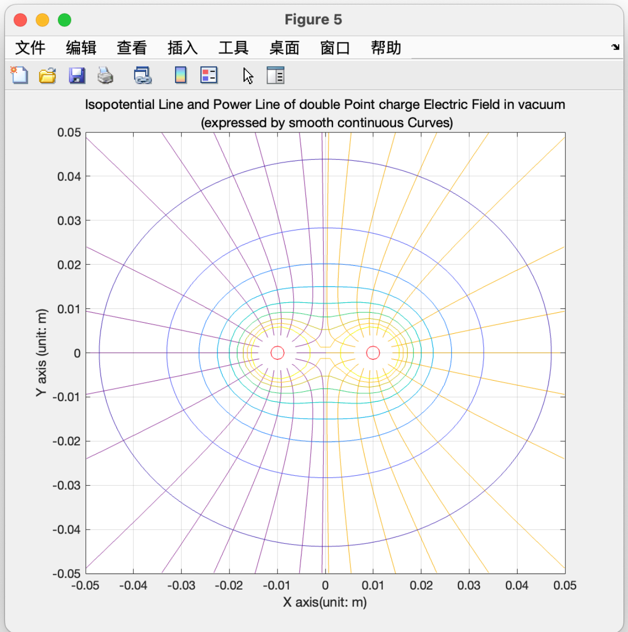


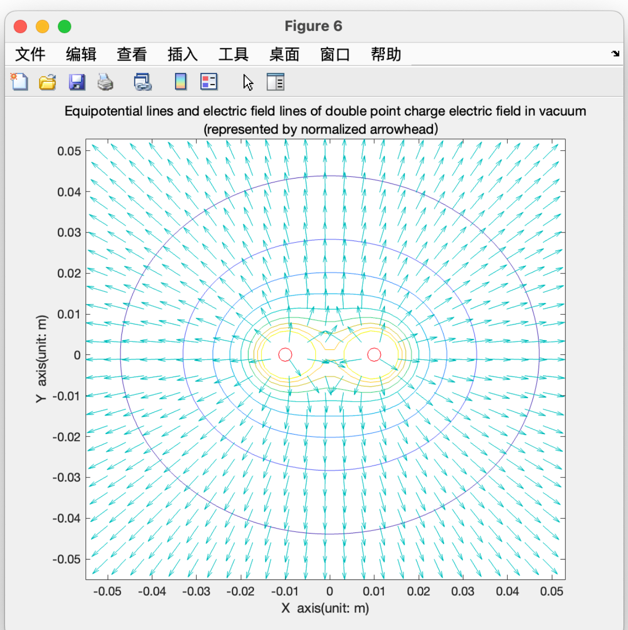
Figure 1: Two Identical Point Charges - Potential Distribution

As shown in this figure, there are two infinite peaks in the potential field, which is in line with the expectations.



As shown in this figure,the streamlines are perpendicular to the equipotential lines, which conforms to the theoretical derivation.

Figure 2: Two Identical Point Charges - Equipotential Lines and Streamlines Distributions (Smooth Continuous Curves)



As shown in this figure, the streamlines are perpendicular to the equipotential lines, which conforms to the theoretical derivation.

Figure 3: Two Identical Point Charges - Equipotential Lines and Streamlines Distributions (Smooth Continuous Curves)

3 Case II: Two opposite point charges with the same magnitude

3.1 Matlab codes

Listing 4 Matlab codes for two opposite point charges with the same magnitude, Fig 1

```
clear;    % clear all variables in memory
clc;      % Clear the contents of the command window
k=9e9;    % set electrostatic constant
Q=5e-9;       % Set charge Q
xm=5;         % Set the range of the field in x direction
ym=5;         % Set the range of the field in y direction
[x1, x2] = [-2, 2];  % Set the position of two charges
x=linspace(-xm,xm,100);   % evenly divide the x axis into 50 segments
y=linspace(-ym,ym,100);   % evenly divide the y axis into 50 segments
[X,Y]=meshgrid(x,y);   % To form the coordinates of each point in the field.
% calculate the distance between each point and the source charge
R1=sqrt((X+x1).^2+Y.^2);
R2=sqrt((X+x2).^2+Y.^2);
V=k*Q./R1-k*Q./R2;   % calculate the electric potential of each point
figure();
surf(X,Y,V);  % plot the distribution of electric potential
colormap(parula(100));  % Set the colormap
hold on;
title('the plot of electric potential distribution
    of two point charge in the vacuum');
% The title for the plot
xlabel('X axis(unit: m)');  % label the x axis
ylabel('Y axis(unit: m)');  % label the y axis
hold off
```

Listing 5 Matlab codes for two opposite point charges with the same magnitude, Fig 2

```
Vmin=-35;  % set the minimum value for equipotential lines
Vmax=35;   % set the minimum value for equipotential lines
Veq=linspace(Vmin,Vmax,10);    % set the potential for equipotential lines
figure();   % Create the figure object
contour(X,Y,V,Veq);       % plot 10 equipotential lines
grid on    % form a grid
hold on    % hold the plot
% plot the two point charges
plot(x1,0,'o', 'MarkerSize',12,Color=[1 0 0])
plot(x2,0,'o', 'MarkerSize',12,Color=[1 0 0])
title('Isopotential Line of Double Point charge Electric Field in vacuum');
% title the plot
xlabel('X axis(unit: m)');   % label the x axis
ylabel('Y axis(unit: m)');   % label the y axis
[Ex,Ey]=gradient(-V);
% Calculation of two components of Electric Field
    intensity at each Point in the Field
del_theta=20;     % Set the angle difference between adjacent field lines;
theta=(0:del_theta:360).*pi/180;      % express the angle into radian
% generate the x coordinate for the start of the field line
xs1=0.004*cos(theta)+x1;
xs2=0.004*cos(theta)+x2;
% generate the y coordinate for the start of the field line
ys=0.004*sin(theta);
streamline(X,Y,Ex,Ey,xs1,ys)
streamline(X,Y,Ex,Ey,xs2,ys)     % generate the field lines
grid on   % from the grid
hold on   % hold the plot
contour(X,Y,V,Veq);     % plot 10 equipotential lines
title('Isopotential Line and Power Line of
    double Point charge Electric Field in vacuum')
subtitle(' (expressed by smooth continuous Curves)')   % title the plot
xlabel('X axis(unit: m)');     % label the x axis
ylabel('Y axis (unit: m)');     % label the y axis
hold off
```

Listing 6 Matlab codes for two opposite point charges with the same magnitude, Fig 3

```
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
figure();  % Create the figure object
% plot the charges
plot(x1,0,'o', 'MarkerSize',12,Color=[1 0 0])
hold on;
plot(x2,0,'o', 'MarkerSize',12,Color=[0 0 1])
contour(X,Y,V,Veq);     % plot the equipotential lines
% Slice the grids before plot the arrows in order to make it clear
X = X(1:5:end,1:5:end);
Y = Y(1:5:end,1:5:end);
Ex = Ex(1:5:end,1:5:end);
Ey= Ey(1:5:end,1:5:end);
% using normalized arrowhead to represent electric field
quiver(X,Y,Ex,Ey,Color=[0 0.7 0.7]);
title('Equipotential lines and electric field lines
    of double point charge electric field in vacuum');
subtitle('(represented by normalized arrowhead')      % title the graph
xlabel('X  axis(unit: m)');     % label the X axis
ylabel('Y  axis(unit: m)');     % label the Y axis
```

3.2 Results and Analysis

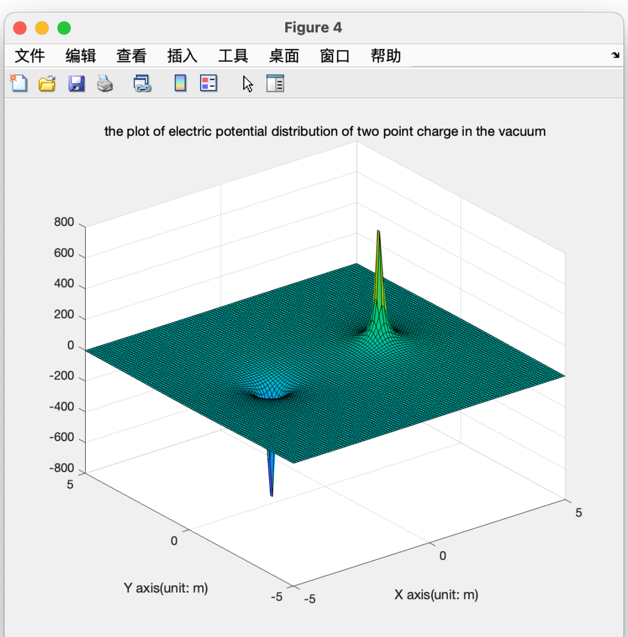
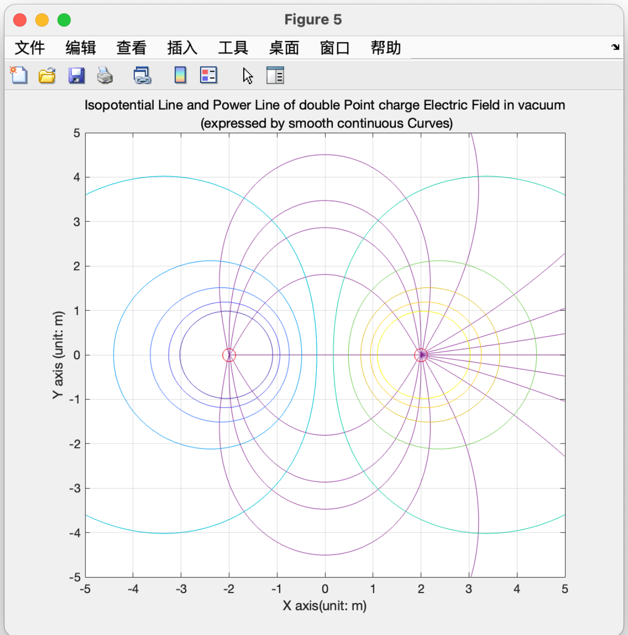


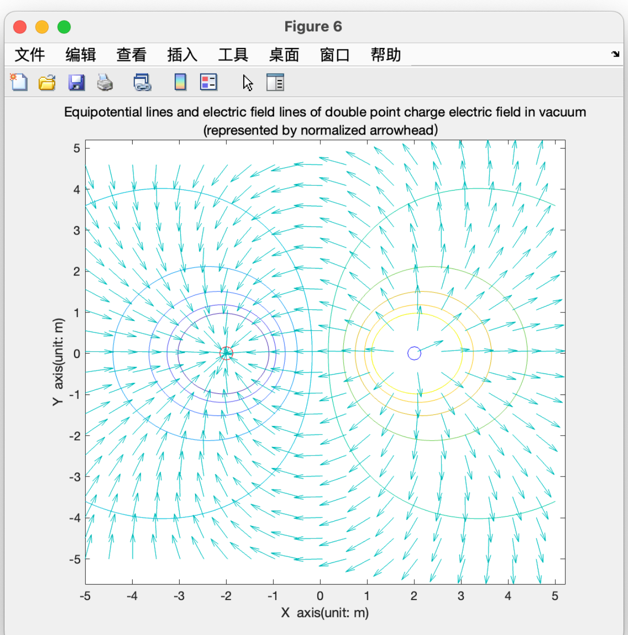
Figure 4: Two Opposite Point Charges - Potential Distribution

As shown in this figure, there are two opposite infinite peaks in the potential field, which is in line with the expectations.



As shown in this figure, the equipotential lines are distributed around the charges and conform to the potential distribution diagram above.

Figure 5: Two Opposite Point Charges - Equipotential Lines and Streamlines Distributions (Smooth Continuous Curves)



As shown in this figure, the arrows are consistent with E.

Figure 6: Two Opposite Point Charges - Equipotential Lines and Streamlines Distributions (Normalized Arrowheads)

4 Case III: Electric Field Distribution of three identical point charges located at the vertices of an equilateral triangle

4.1 Matlab Codes

Listing 7 Matlab codes for three identical point charges located at the vertices of an equilateral triangle, Fig 1

```
clear;    % clear all variables in memory
clc;      % Clear the contents of the command window
k=9e9;    % set electrostatic constant
Q=8e-9;   % Set charge Q
xm=5;     % Set the range of the field in x direction
ym=5;     % Set the range of the field in y direction
[x1, y1] = [-sqrt(3), -1];
[x2, y2] = [sqrt(3), -1];
[x3, y3] = [0, 2];
x=linspace(-xm,xm,100);   % evenly divide the x axis into 50 segments
y=linspace(-ym,ym,100);   % evenly divide the y axis into 50 segments
[X,Y]=meshgrid(x,y);   % To form the coordinates of each point in the field.
% calculate the distance between each point and the source charge
R1 = sqrt((X-x1).^2+(Y-y1).^2);
R2 = sqrt((X-x2).^2+(Y-y2).^2);
R3 = sqrt((X-x3).^2+(Y-y3).^2);
% calculate the electric potential of each point
V=k*Q./R1+k*Q./R2+k*Q./R3;
figure();
surf(X,Y,V);  % plot the distribution of electric potential
colormap(parula(100));  % Set the colormap
hold on;
title('the plot of electric potential distribution
    of two point charge in the vacuum');
% The title for the plot
xlabel('X axis(unit: m)');  % label the x axis
ylabel('Y axis(unit: m)');  % label the y axis
hold off
```

Listing 8 Matlab codes for three identical point charges located at the vertices of an equilateral triangle, Fig 2

```
Vmin=0;   % set the minimum value for equipotential lines
Vmax=450;  % set the maximum value for equipotential lines
Veq=linspace(Vmin,Vmax,10);   % set the potential for equipotential lines
figure();  % Create the figure object
contour(X,Y,V,Veq);     % plot 10 equipotential lines
grid on    % form a grid
hold on    % hold the plot
% plot the point charges
plot(x1,y1,'o', 'MarkerSize',12,Color=[1 0 0])
plot(x2,y2,'o', 'MarkerSize',12,Color=[1 0 0])
plot(x3,y3,'o', 'MarkerSize',12,Color=[1 0 0])
title('Isopotential Line of
    Triple Point charge Electric Field in vacuum');
% title the plot
xlabel('X axis(unit: m)');   % label the x axis
ylabel('Y axis(unit: m)');   % label the y axis
% Calculation of two components of Electric Field intensity at each Point in the Field
[Ex,Ey]=gradient(-V);
del_theta=20;    % Set the angle difference between adjacent field lines;
theta=(0:del_theta:360).*pi/180;   % express the angle into radian
% generate the x coordinate for the start of the field line
xs1=0.004*cos(theta)+x1;
xs2=0.004*cos(theta)+x2;
xs3 = 0.004*cos(theta)+x3;
% generate the y coordinate for the start of the field line
ys1=0.004*sin(theta)+y1;
ys2=0.004*sin(theta)+y2;
ys3=0.004*sin(theta)+y3;
% generate the field lines
streamline(X,Y,Ex,Ey,xs1,ys1)
streamline(X,Y,Ex,Ey,xs2,ys2)
streamline(X,Y,Ex,Ey,xs3,ys3)
grid on   % from the grid
hold on   % hold the plot
contour(X,Y,V,Veq);     % plot 10 equipotential lines
title('Isopotential Line and Power Line of
    Triple Point charge Electric Field in vacuum')
subtitle(' (expressed by smooth continuous Curves)')   % title the plot
xlabel('X axis(unit: m)');     % label the x axis
ylabel('Y axis (unit: m)');     % label the y axis
hold off
```

Listing 9 Matlab codes for three identical point charges located at the vertices of an equilateral triangle, Fig 3

```
% calculate the magnitude of electric field magnitude at each point.
E=sqrt(Ex.^2+Ey.^2);
% normalize the magnitude of the electric field
Ex=Ex./E;
Ey=Ey./E;
figure();  % Create the figure object
% plot the position of the charges
plot(x1,y1,'o', 'MarkerSize',12,Color=[1 0 0])
hold on;
plot(x2,y2,'o', 'MarkerSize',12,Color=[1 0 0])
plot(x3,y3,'o', 'MarkerSize',12,Color=[1 0 0])
contour(X,Y,V,Veq);     % plot the equipotential lines
% lower the density of arrows to make the figure more clear
X = X(1:5:end,1:5:end);
Y = Y(1:5:end,1:5:end);
Ex = Ex(1:5:end,1:5:end);
Ey= Ey(1:5:end,1:5:end);
% using normalized arrowhead to represent electric field
quiver(X,Y,Ex,Ey,Color=[0 0.7 0.7]);
title('Equipotential lines and electric field lines of
    triple point charge electric field in vacuum');
subtitle('(represented by normalized arrowhead ')     % title the graph
xlabel('X  axis(unit: m)');           % label the X axis
ylabel('Y  axis(unit: m)');           % label the Y axis
```

4.2 Results and Analysis

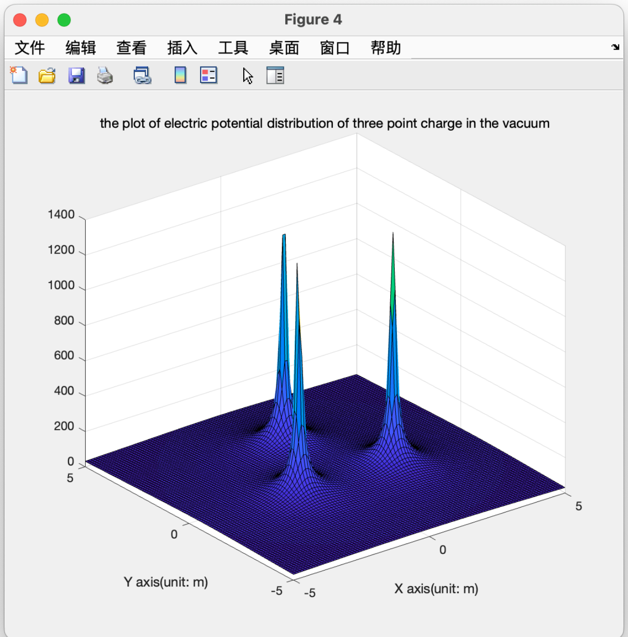
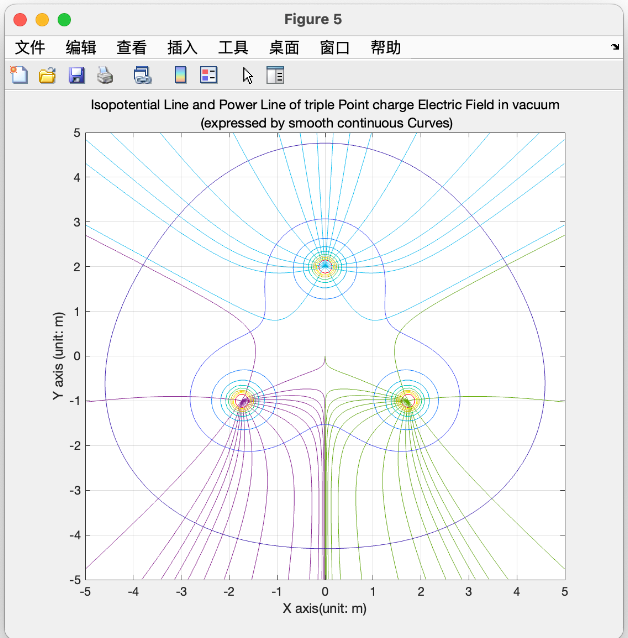


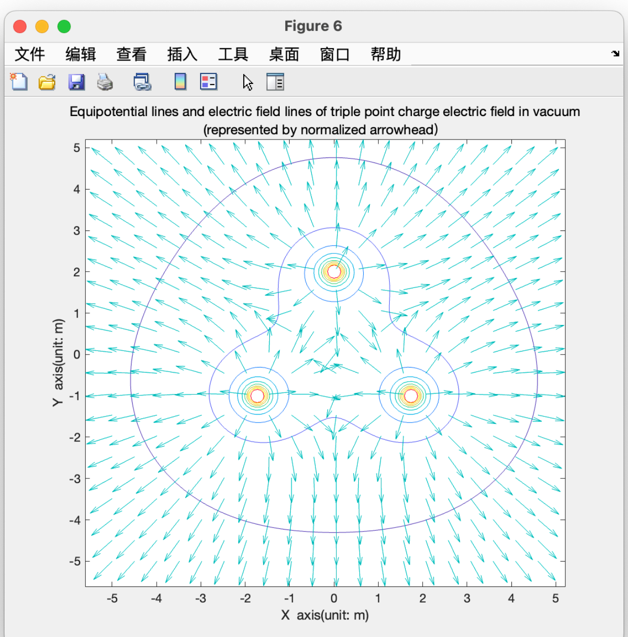
Figure 7: Three Identical Point Charges - Potential Distribution

As shown in this figure, there are three same infinite peaks in the potential field, which is in line with the expectations.



As shown in this figure, the equipotential lines are distributed around the charges and conform to the potential distribution diagram above.

Figure 8: Three Identical Point Charges - Equipotential Lines and Streamlines Distributions (Smooth Continuous Curves)



As shown in this figure, the arrows are consistent with E.

Figure 9: Three Identical Point Charges - Equipotential Lines and Streamlines Distributions (Normalized Arrowheads)

5 Conclusion

From this laboratory we have learnt that how to use fundamental functions in MATLAB to plot the vector fields, like meshgrid, contour, streamline and quiver.

Also, the clear and intuitive images deepened our understanding of what we have learned in class.

In particular, unlike the theoretical analysis, the results of the numerical analysis are very dependent on the setting of the sampling points. In order to get the appropriate results, we need to design a reasonable sampling density and sampling range.