Engineering Electromagnetic Field Theory
Lab 1

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***Abstract*—This experiment is to draw the electric field and potential distribution of multiple point charges in vacuum under different circumstances with MATLAB, so as to get familiar with the knowledge of the interaction between the electric field and potential of multiple point charges in vacuum. This experiment includes three cases, in each case, the potential distribution, contours distribution and electric field line distribution in the selected field are calculated and plotted respectively.**

1. Case1: The electric field distribution of two equal point charges

1.1. Declarations

In this case, we place two charges and analyze the distribution of the electrostatic field using the MATLAB. We place one charge $Q_1 = 1 \times 10^-9$ C on $P_1[-0.01, 0]$, and place another charge $Q_2 = 1 \times 10^-9$ C on $P_2[0.01, 0]$.

The codes of MATLAB about the declarations are as follows:

```
clear
clc
figure
k=9e9
Q1=1e-9
Q2=1e-9
x1 = -0.01; y1 = 0
x2 = 0.01; y2 = 0
xm=0.05
% Sets the range in the x direction of the field
ym=0.05
% Sets the range in the y direction of the field
x=linspace(-xm,xm,70)
% Divide the X-axis into 70 equal parts
y=linspace(-ym,ym,70)
% Divide the Y-axis into 70 equal parts
[X,Y]=meshgrid(x,y)
% Form the coordinates of each point in the field
```

1.2. Potential Distribution

1.2.1. MATLAB Codes.

We use MATLAB to calculate and plot the potential distribution of each point in the field and plot the graph of the potential distribution, the codes are as follows:

```
R1=sqrt((X-x1).^2+Y.^2);
% Calculate the distance from each point in the field to the
    first point charge
R2=sqrt((X-x2).^2+Y.^2);
% Calculate the distance from each point in the field to the
    second point charge
V=k*Q1./R1+k*Q2./R2;
% Calculate the potential at each point in the field
mesh(X,Y,V);
% Plot the distribution of potential
hold on;
title(["Potential distribution of two
    point charge electric fields in a
    vacuum ";" 12113010"],"fontsize",20);
xlabel("X(m)","fontsize",13);
% Draw the X-axis label
ylabel("Y(m)","fontsize",13);
% Draw the Y-axis label
```

1.2.2. Result and Analysis.

As the figure 1 shown, there are two peaks where the charges exist, because they have the same amount of charge the height of these two peaks are the same. As the distance between the field position and the charges position increases, the potential decreases rapidly.

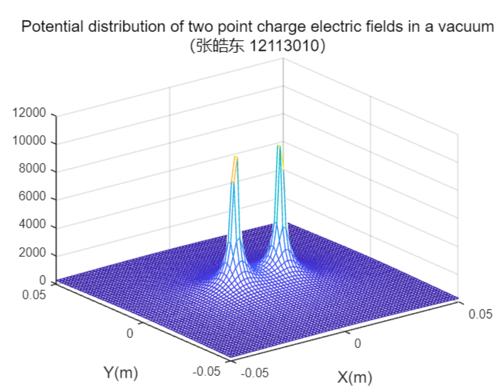

Figure 1: The Potential Distribution of Two Identical Point Charge

1.3. Contours Distribution

1.3.1. MATLAB Codes.

The contours mean that the potential in this line is equal in this field. We use MATLAB to calculate and plot the potential distribution of each point in the field and plot the graph of the contours distribution, the codes are as follows:

```
figure;
Vmin=0;
% Set the minimum potential value of equipotential line
Vmax=2000;
% Set the maximum potential value of equipotential line
Veq=linspace(Vmin,Vmax,10);
% Set the potential value of 10 equipotential lines
contour(X,Y,V,Veq);
grid on
hold on
plot(x1,y1,'o', 'MarkerSize',12)
plot(x2,y2,'o', 'MarkerSize',12)
title(["Equipotential line of two point
    charge electric fields in a vacuum";"
    12113010"], "fontsize", 13);
xlabel("X(m)", "fontsize", 15);
% Draw the X-axis label
ylabel("Y(m)", "fontsize", 15);
% Draw the Y-axis label
```

1.3.2. Result and Analysis.

As shown in Figure 2, the equipotential lines are distributed around two charges, and the closer the two charges are, the more dense the equipotential lines are, which means that the closer the two charges are, the greater the electric field intensity will be.

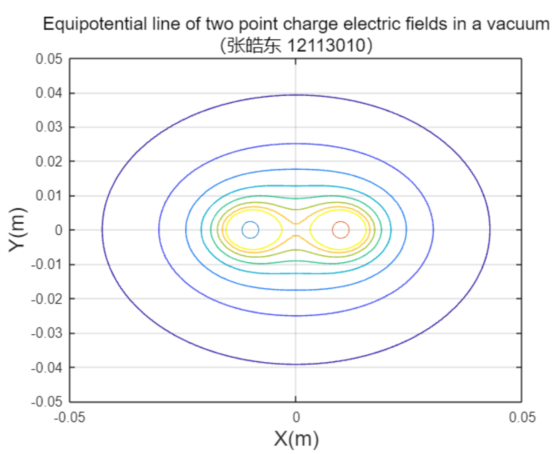

Figure 2: The Contours Distribution of Two Identical Point Charge

1.4. Contours and Electric Fluxline Distribution (With Smooth Continuous Curves)

1.4.1. MATLAB Codes.

The electric fluxline is used to represent the direction of the electric field intensity, because the direction of the electric field intensity is the tangential direction of the electric fluxline. The electric field intensity can be obtained by calculating the gradient of the potential in MATLAB, and then using streamline() function to generate two clusters of electric fluxline respectively with two charges as the starting point, and the electric fluxline in the whole field can be obtained. The codes are as follows:

```
figure;
[Ex,Ey]=gradient(-V);
% Calculate the two components of the electric field
    intensity at each point in the field
del_theta=20;
% Set the Angle difference between adjacent electric
    fluxline
theta=(0:del_theta:360).*pi/180;
% Generating the radian value of the electric fluxline
xs_1=x1+0.001*cos(theta);
% Generates the X-axis coordinate of the starting point of
    the electric fluxline at the first charge
ys_1=0.001*sin(theta);
% Generates the Y-axis coordinate of the starting point of
    the electric fluxline at the first charge
xs_2=x2+0.001*cos(theta);
% Generates the X-axis coordinate of the starting point of
    the electric fluxline at the second charge
ys_2=0.001*sin(theta);
% Generates the Y-axis coordinate of the starting point of
    the electric fluxline at the second charge
streamline(X,Y,Ex,Ey,xs_1,ys_1)
% Generating the electric fluxline
streamline(X,Y,Ex,Ey,xs_2,ys_2)
% Generating the electric fluxline
grid on
hold on
contour(X,Y,V,Veq);
title(["Contours and Electric Fluxline
    Distribution o" ; ...
     "smooth continuous curves"+"
        12113010"], "fontsize", 12);
xlabel("X(m)", "fontsize", 12);
% Draw the X-axis label
ylabel("Y(m)", "fontsize", 12);
% Draw the Y-axis label
```

1.4.2. Result and Analysis.

As shown in Figure 3, the electric fluxline starts from two charges and extends outward. It can be observed that the electric fluxline is perpendicular to the equipotential line, and a phenomenon can be found: As the electric fluxline gets farther and farther away from the two charges, the arc of the electric fluxline decreases. This is because when the distance becomes large enough, the distance between the two charges gradually approaches zero, so the arc of the electric fluxline acts like a single point charge.

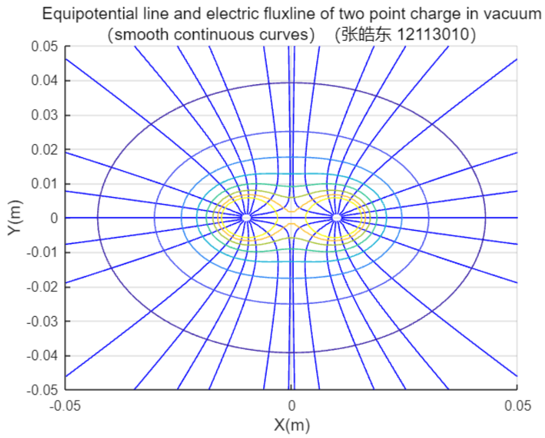

Figure 3: The Contours and Electric Fluxline Distribution of Two Identical Point Charge (With Smooth Continuous Curves)

1.5. Contours and Electric Fluxline Distribution (With Normalized Arrow)

1.5.1. MATLAB Codes.

Finally we use another method to draw streamlines distributions. We just simply draw the arrows to indicate the electric intensity field E. The codes are as follows:

```
figure;
E=sqrt(Ex.^2+Ey.^2);
% Calculate the amplitude of the electric field intensity at each point in the field
Ex=Ex./E;
Ey=Ey./E;
% Normalized electric field intensity value (even if the field intensity amplitude at each point is 1)
quiver(X(1:4:length(X)*length(X)),Y(1:4:length(X)*length(X)),Ex(1:4:length(X)*length(X)),Ey(1:4:length(X)*length(X)));
% Normalized arrows are used to represent the direction of the electric field intensity at each point in the field. Because there are too many arrows, it is more appropriate to choose one at every four points
hold on;
contour(X,Y,V,Veq);
plot(x1,y1,'o', 'MarkerSize',12)
plot(x2,y2,'o', 'MarkerSize',12)
title(["Equipotential line and electric fluxline of two point charge in vacuum" ; ...
    "normalized arrow"+" 12113010"], "fontsize", 12);
xlabel("X(m)", "fontsize", 12);
% Draw the X-axis label
ylabel("Y(m)", "fontsize", 12);
% Draw the Y-axis label
```

1.5.2. Result and Analysis.

As shown in Figure 4, the direction of the electric field intensity can be seen more clearly in the diagram indicated by arrows, and it can be found more clearly that the direction of the electric field intensity is perpendicular to the equipotential line

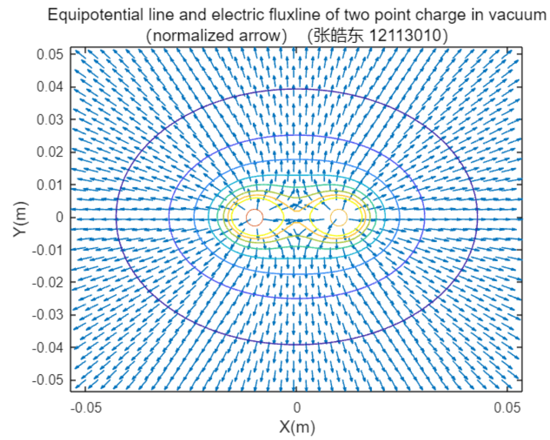

Figure 4: The Contours and Electric Fluxline Distribution of Two Identical Point Charge (With Normalized Arrow)

2. Case2: The electric field distribution of two opposite point charges with the same magnitude

2.1. Declarations

In this case, we place two charges and analyze the distribution of the electrostatic field using the MATLAB. We place one charge $Q_1 = 5 \times 10^{-9}$ C on $P_1[-2, 0]$, and place another charge $Q_2 = -5 \times 10^{-9}$ C on $P_2[2, 0]$.

The codes of MATLAB about the declarations are as follows:

```
clear
clc
figure
k=9e9
Q1=5e-9;
Q2=-5e-9;
x1 = -2; y1 = 0;
x2 = 2; y2 = 0;
xm=4;
% Sets the range in the x direction of the field
ym=4;
% Sets the range in the y direction of the field
x=linspace(-xm,xm,40);
% Divide the X-axis into 40 equal parts
y=linspace(-ym,ym,40);
% Divide the Y-axis into 40 equal parts
[X,Y]=meshgrid(x,y)
% Form the coordinates of each point in the field
```

2.2. Potential Distribution

2.2.1. MATLAB Codes.

We use MATLAB to calculate and plot the potential distribution of each point in the field and plot the graph of the potential distribution, the codes are as follows:

```
R1=sqrt((X-x1).^2+Y.^2);
% Calculate the distance from each point in the field to the
    first point charge
R2=sqrt((X-x2).^2+Y.^2);
% Calculate the distance from each point in the field to the
    second point charge
V=k*Q1./R1+k*Q2./R2;
% Calculate the potential at each point in the field
mesh(X,Y,V);
% Plot the distribution of potential
hold on;
title(["Potential distribution of two
    opposite point charge electric fields
    in a vacuum ";" 12113010"],"fontsize
    ",20);
xlabel("X(m)","fontsize",13);
% Draw the X-axis label
ylabel("Y(m)","fontsize",13);
% Draw the Y-axis label
```

2.2.2. Result and Analysis.

As the figure 5 shown, there are two peaks where the charges exist, because they have the same magnitude of charge but is opposite the height of these two peaks are the same and the direction is opposite. As the distance between the field position and the charges position increases, the potential decreases rapidly.

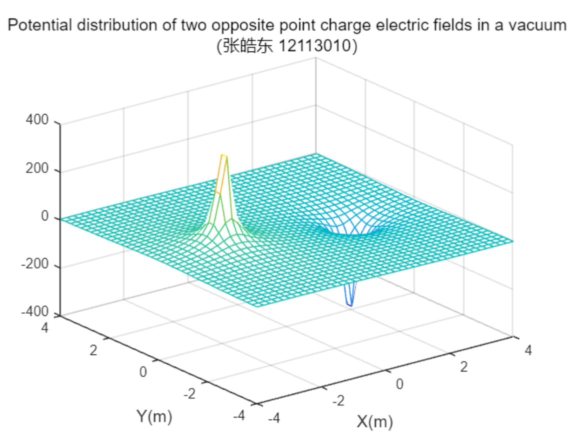

Figure 5: The Potential Distribution of Two Opposite Point Charges with the Same Magnitude

2.3. Contours Distribution

2.3.1. MATLAB Codes.

The contours mean that the potential in this line is equal in this field. We use MATLAB to calculate and plot the potential distribution of each point in the field and plot the graph of the contours distribution, the codes are as follows:

```
figure;
Vmin=-100;
% Sets the minimum potential value of the contours
Vmax=100;
% Sets the maximum potential value of the contours
Veq=linspace(Vmin,Vmax,25);
% Set the potential values of the 25 alleles including 0
plot(x2,y2,'o', 'MarkerSize',12)
plot(x1,y1,'o', 'MarkerSize',12)
contour(X,Y,V,Veq);
% Set the potential values of the 25 alleles including 0
grid on
hold on
title(["Equipotential line of two point
    charge electric fields in a vacuum";"
    12113010"], "fontsize", 12);
xlabel("X(m)", "fontsize", 12);
ylabel("Y(m)", "fontsize", 12);
```

2.3.2. Result and Analysis.

As shown in Figure 6, the equipotential lines are distributed around two charges, and the closer the two charges are, the more dense the equipotential lines are, which means that the closer the two charges are, the greater the magnitude electric field intensity will be.

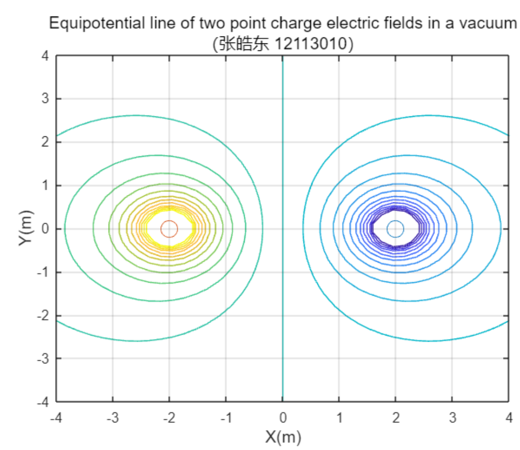

Figure 6: The Contours Distribution of Two Opposite Point Charges with the Same Magnitude

2.4. Contours and Electric Fluxline Distribution (With Smooth Continuous Curves)

2.4.1. MATLAB Codes.

The electric fluxline is used to represent the direction of the electric field intensity, because the direction of the electric field intensity is the tangential direction of the electric fluxline. The electric field intensity can be obtained by calculating the gradient of the potential in MATLAB, and then using streamline() function to generate two clusters of electric fluxline respectively with two charges as the starting point or ending point, and the electric fluxline in the whole field can be obtained. The codes are as follows:

```
figure;
[Ex,Ey]=gradient(-V);
% Calculate the two components of the electric field
    intensity at each point in the field
del_theta=20;
% Set the Angle difference between adjacent electric
    fluxline
theta=(0:del_theta:360).*pi/180;
% Generating the radian value of the electric fluxline
xs_1=x1+0.05*cos(theta);
ys_1=0.05*sin(theta);
xs_2=x2+0.05*cos(theta);
ys_2=0.05*sin(theta);
streamline(X,Y,Ex,Ey,xs_1,ys_1)
% Generating the electric fluxline
streamline(X,Y,-Ex,-Ey,xs_2,ys_2)
% Generating the electric fluxline
grid on
hold on
contour(X,Y,V,Veq);
title(["Contours and Electric Fluxline
    Distribution" ; ...
     "smooth continuous curves"+"
         12113010"], "fontsize", 12);
xlabel("X(m)", "fontsize", 12);
% Draw the X-axis label
ylabel("Y(m)", "fontsize", 12);
% Draw the Y-axis label
```

2.4.2. Result and Analysis.

As shown in Figure 7, the electric fluxline starts from one positive charge and extends to another negative charge and outward. It can be observed that the electric fluxline is perpendicular to the equipotential line. And especially in the middle where the zero potential energy surface is we can see clearly that the field line is perpendicular to the equipotential line.

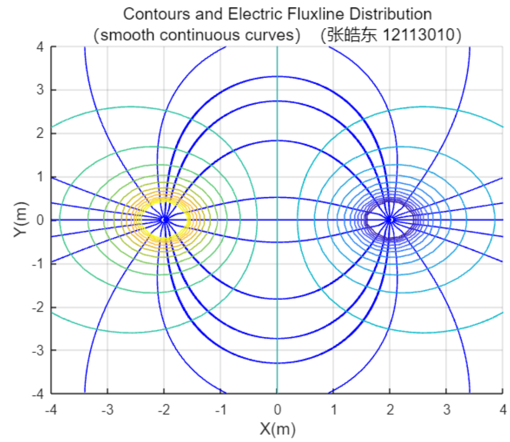

Figure 7: The Contours and Electric Fluxline Distribution of Two Opposite Point Charges (With Smooth Continuous Curves)

2.5. Contours and Electric Fluxline Distribution (With Normalized Arrow)

2.5.1. MATLAB Codes.

Finally we use another method to draw streamlines distributions. We just simply draw the arrows to indicate the electric intensity field E. The codes are as follows:

```
figure;
E=sqrt(Ex.^2+Ey.^2);
% Calculate the amplitude of the electric field intensity at
    each point in the field
Ex=Ex./E;
Ey=Ey./E;
% Normalized electric field intensity value (even if the
    field intensity amplitude at each point is 1)
quiver(X(1:4:length(X)*length(X)),Y(1:4:
    length(X)*length(X)),Ex(1:4:length(X)
    *length(X)),Ey(1:4:length(X)*length(X
    )));
% Normalized arrows are used to represent the direction of
    the electric field intensity at each point in the field.
    Because there are too many arrows, it is more
    appropriate to choose one at every four points
hold on;
plot(x2,y2,'o', 'MarkerSize',12)
plot(x1,y1,'o', 'MarkerSize',12)
contour(X,Y,V,Veq);
title(["Equipotential line and electric
    fluxline of two point charge in
    vacuum" ; ...
     "normalized arrow"+" 12113010"], "
        fontsize", 12);
xlabel("X(m)", "fontsize", 12);
% Draw the X-axis label
ylabel("Y(m)", "fontsize", 12);
% Draw the Y-axis label
```

2.5.2. Result and Analysis.

As shown in Figure 8, the direction of the electric field intensity can be seen more clearly in the diagram indicated by arrows, and it can be found more clearly that the direction of the electric field intensity is perpendicular to the equipotential line

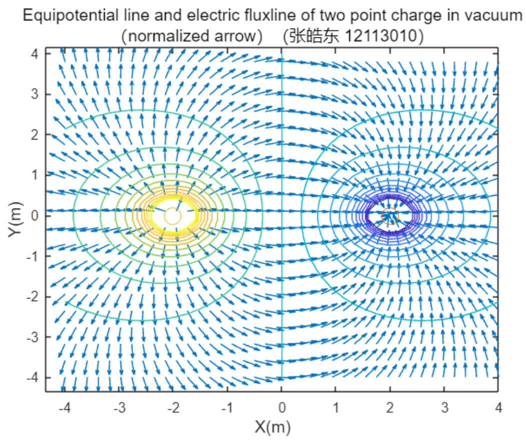

Figure 8: The Contours and Electric Fluxline Distribution of Two Opposite Point Charges (With Normalized Arrow)

3. Case3: The electric field distribution of two equal point charges

3.1. Declarations

In this case, we place three charges and analyze the distribution of the electrostatic field using the MATLAB. We place one charge $Q_1 = 8 \times 10^-9$ C on $P_1[-\sqrt{3}, -1]$, and place one charge $Q_2 = 8 \times 10^-9$ C on $P_2[\sqrt{3}, -1]$ and place another charge $Q_3 = 8 \times 10^-9$ C on $P_2[0, 2]$.

The codes of MATLAB about the declarations are as follows:

```
clear
clc
figure
k=9e9
Q1=8e-9;
Q2=8e-9;
Q3=8e-9;
x1 = -sqrt(3); y1 = -1;
x2 = sqrt(3); y2 = -1;
x3 = 0; y3 = 2;
xm=5;
% Sets the range in the x direction of the field
ym=5;
% Sets the range in the y direction of the field
x=linspace(-xm,xm,40)
% Divide the X-axis into 40 equal parts
y=linspace(-ym,ym,40)
% Divide the Y-axis into 40 equal parts
[X,Y]=meshgrid(x,y)
% Form the coordinates of each point in the field
```

3.2. Potential Distribution

3.2.1. MATLAB Codes.

We use MATLAB to calculate and plot the potential distribution of each point in the field and plot the graph of the potential distribution, the codes are as follows:

```
R1=sqrt((X-x1).^2+(Y-y1).^2);
% Calculate the distance from each point in the field to the
    first point charge
R2=sqrt((X-x2).^2+(Y-y2).^2);
% Calculate the distance from each point in the field to the
    second point charge
R3=sqrt((X-x3).^2+(Y-y3).^2);
% Calculate the distance from each point in the field to the
    third point charge
V=k*Q1./R1+k*Q2./R2+k*Q3./R3;
% Calculate the potential at each point in the field
mesh(X,Y,V);
% Plot the distribution of potential
hold on;
title(["Potential distribution of three
    point charge electric fields in a
    vacuum ";" 12113010"],"fontsize",12);
xlabel("X(m)","fontsize",12);
% Draw the X-axis label
ylabel("Y(m)","fontsize",12);
% Draw the Y-axis label
```

3.2.2. Result and Analysis.

As the figure 9 shown, there are three peaks where the charges exist, because they have the same amount of charge the height of these three peaks are the same. As the distance between the field position and the charges position increases, the potential decreases rapidly.

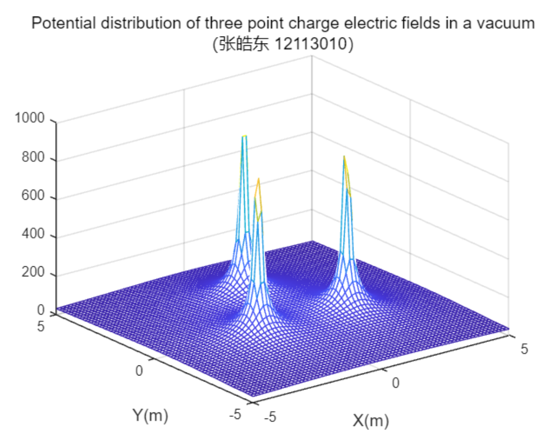

Figure 9: The Potential Distribution of Three Identical Point Charges

3.3. Contours Distribution

3.3.1. MATLAB Codes.

The contours mean that the potential in this line is equal in this field. We use MATLAB to calculate and plot the potential distribution of each point in the field and plot the graph of the contours distribution, the codes are as follows:

```
figure;
Vmin=0;
% Set the minimum potential value of equipotential line
Vmax=200;
% Set the maximum potential value of equipotential line
Veq=linspace(Vmin,Vmax,25);
% Set the potential value of 25 equipotential lines
contour(X,Y,V,Veq);
grid on
hold on
plot(x1,y1,'o', 'MarkerSize',12)
plot(x2,y2,'o', 'MarkerSize',12)
plot(x3,y3,'o', 'MarkerSize',12)
title(["Equipotential line of two point
    charge electric fields in a vacuum";"
    12113010"], "fontsize", 12);
xlabel("X(m)", "fontsize", 12);
% Draw the X-axis label
ylabel("Y(m)", "fontsize", 12);
% Draw the Y-axis label
```

3.3.2. Result and Analysis.

As shown in Figure 10, the equipotential lines are distributed around three charges, and the closer the three charges are, the more dense the equipotential lines are, which means that the closer the three charges are, the greater the electric field intensity will be.

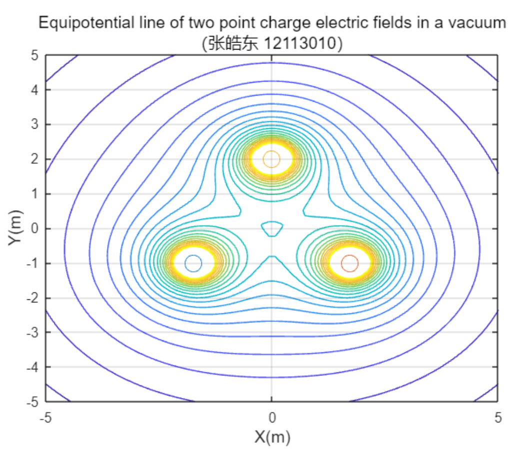

Figure 10: The Contours Distribution of Three Identical Point Charge

3.4. Contours and Electric Fluxline Distribution (With Smooth Continuous Curves)

3.4.1. MATLAB Codes.

The electric fluxline is used to represent the direction of the electric field intensity, because the direction of the electric field intensity is the tangential direction of the electric fluxline. The electric field intensity can be obtained by calculating the gradient of the potential in MATLAB, and then using streamline() function to generate three clusters of electric fluxline respectively with three charges as the starting point, and the electric fluxline in the whole field can be obtained. The codes are as follows:

```
figure;
[Ex,Ey]=gradient(-V);
% Calculate the two components of the electric field
    intensity at each point in the field
del_theta=20;
% Set the Angle difference between adjacent electric
    fluxline
theta=(0:del_theta:360).*pi/180;
% Generating the radian value of the electric fluxline
xs_1=x1+0.05*cos(theta);
ys_1=y1+0.05*sin(theta);
xs_2=x2+0.05*cos(theta);
ys_2=y2+0.05*sin(theta);
xs_3=x3+0.05*cos(theta);
ys_3=y3+0.05*sin(theta);
streamline(X,Y,Ex,Ey,xs_1,ys_1)
% Generating the electric fluxline
streamline(X,Y,Ex,Ey,xs_2,ys_2)
% Generating the electric fluxline
streamline(X,Y,Ex,Ey,xs_3,ys_3)
% Generating the electric fluxline
grid on
hold on
contour(X,Y,V,Veq);
title(["Contours and Electric Fluxline
    Distribution" ; ...
     "smooth continuous curves"+"
        12113010"], "fontsize", 12);
xlabel("X(m)", "fontsize", 12);
% Draw the X-axis label
ylabel("Y(m)", "fontsize", 12);
% Draw the Y-axis label
```

3.4.2. Result and Analysis.

As shown in Figure 11, the electric fluxline starts from three charges and extends outward. It can be observed that the electric fluxline is perpendicular to the equipotential line.

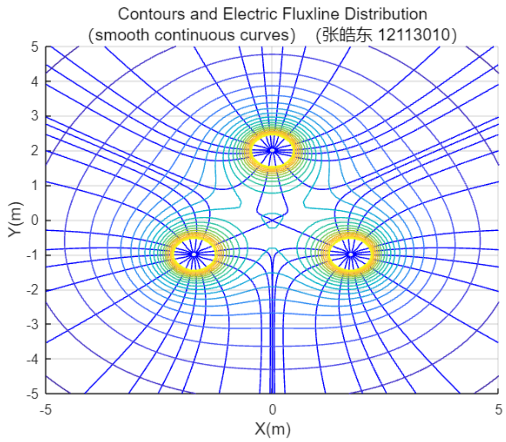

Figure 11: The Contours and Electric Fluxline Distribution of Three Identical Point Charge (With Smooth Continuous Curves)

3.5. Contours and Electric Fluxline Distribution (With Normalized Arrow)

3.5.1. MATLAB Codes.

Finally we use another method to draw streamlines distributions. We just simply draw the arrows to indicate the electric intensity field E. The codes are as follows:

```
figure;
E=sqrt(Ex.^2+Ey.^2);
% Calculate the amplitude of the electric field intensity at
    each point in the field
Ex=Ex./E;
Ey=Ey./E;
% Normalized electric field intensity value (even if the
    field intensity amplitude at each point is 1)
quiver(X(1:4:length(X)*length(X)),Y(1:4:
    length(X)*length(X)),Ex(1:4:length(X)
    *length(X)),Ey(1:4:length(X)*length(X
    )));
% Normalized arrows are used to represent the direction of
    the electric field intensity at each point in the field.
    Because there are too many arrows, it is more
    appropriate to choose one at every four points
hold on;
contour(X,Y,V,Veq);
plot(x1,y1,'o', 'MarkerSize',12)
plot(x2,y2,'o', 'MarkerSize',12)
plot(x3,y3,'o', 'MarkerSize',12)
title(["Equipotential line and electric
    fluxline of two point charge in
    vacuum" ; ...
     "normalized arrow"+" 12113010"], "
        fontsize", 12);
xlabel("X(m)", "fontsize", 12);
% Draw the X-axis label
ylabel("Y(m)", "fontsize", 12);
% Draw the Y-axis label
```

3.5.2. Result and Analysis.

As shown in Figure 12, the direction of the electric field intensity can be seen more clearly in the diagram indicated by arrows, and it can be found more clearly that the direction of the electric field intensity is perpendicular to the equipotential line

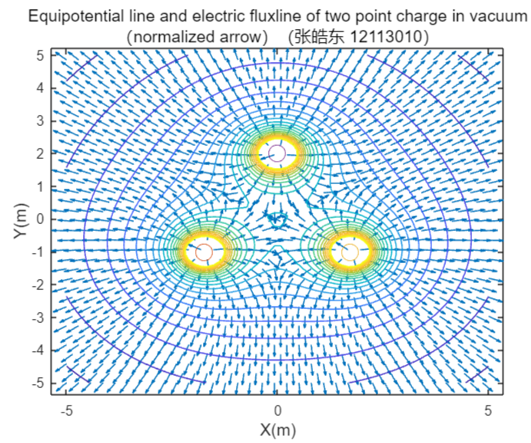

Figure 12: The Contours and Electric Fluxline Distribution of Three Identical Point Charge (With Normalized Arrow)

4. Experimental Experience

In this experiment, we learned a lot of knowledge.

First of all, we have learnt a few functions in MATLAB that we probably haven't used before to plot the electric field distribution, such as (meshgrid, contour, streamline,) and (quiver). We're going to get a little bit more familiar with these functions.

Secondly, we have a more intuitive understanding of the electric field distribution, contours distribution and electric fluxline distribution of multiple point charges, which deepens our understanding of the knowledge in class and makes a deeper impression on the knowledge of "electric field intensity is the gradient of electric potential" and "electric field line is perpendicular to the isoppotential surface" and etc.

Thirdly, in the process of experiment, we also injected much thinking because different parameters would achieve different effects in many cases. In order to achieve the expected results, we would constantly debug and change some parameters. For example, different scales of axes and different numbers of electric field lines or equipotential lines are chosen in different situations to achieve better results. In addition, for example, when drawing an electric field diagram represented by arrows, the too many number of arrows drawn directly will affect our perception, so we will draw arrows every few values in different situations rather than all of them. In addition, for example, when drawing a contours distribution of two charges of equal magnitude and opposite poles, we choose the different maximum, minimum and quantity of potential, so that we can draw a line with zero potential, because this line is very meaningful.