Theory of Electromagnetic Fields, Experiment 2

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Abstract—There are two ways to compute the electric field and express them by potential distribution, equipotential line distribution, and electric field line distribution, which is integral method and infinitive method. The result of infinitive method also varies with the number of segments. The experiment focus on the difference of above methods to find out whether the integral computation can be simplified by infinitive method. It comes out that, with enough number of segments in infinitive method (about 40), the error is small enough to be ignored. When the distance of testing point and the line charge is far larger than the length of it, the integral computation can be replaced by infinitive method.

I. Experiment Principle

The electric field strength E produced by a point charge in a vacuum is:

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

where the coefficient $k=9\times 10^9 F/m$, is the electrostatic force measure, Q is the charge of the point charge, and R is the distance of this point charge to the field point.

If we take infinity as the point of zero potential, the potential generated by a point charge in a vacuum is:

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

The electric field strength can also be expressed as a negative gradient of the potential:

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

The potential generated by N point charges in a vacuum is:

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

Similarly, the electric field strength generated by N point charges in vacuum can be found from equation (3).

For line charge, we can use integral to calculate the electric potential of it, the principle is as follows:

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

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

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

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

When the source of the electric field is a continuous distribution of charge, the problem can be solved by the method of differential element method or integral. The specific operation steps of the micro-element method:

- 1) Uniformly divide the line charge into a number of small segments of charge;
- 2) Take each small segment of charge as a point charge to deal with, use the formula (2) to solve for the potential generated in space;
- 3) Use formula (4) to get the entire line charge generated by the potential;
- 4) Use formula (3) to solve for the entire line charge generated by the electric field intensity.

There is a certain error between the result obtained by the calculus method and the real value, which depends on the number of segments in step 1 above, and in general, the more segments, the smaller the error. In some cases, it is also possible to use calculus to solve for the true electric field distribution. This makes it possible to study the relationship between the error caused by the calculus method and the number of segments.

II. Key Code Implementation

A. Compute the Electric Field by Integral Method

```
%select region
k=9e9;%electric constant
p=1e-9;%charge density
xm=2;%set x region
```

B. Compute the Electric Field by Infinitive Method

```
1 |%select region
2 | k=9e9; %electric constant
3 p=1e-9;%charge density
4 | xm=2;%set x region
5 ym=2;%set y region
6 | x=linspace(-xm,xm,100); \% divide x
      axis
  y=linspace(-ym,ym,100);\% divide y
   [X,Y] = meshgrid(x,y); %form coordinate
9
  V=0;
  for i = 1:20
10
11 | r = sqrt((X-0.1*i+1.05).^2+Y.^2);\%
      compute r of every dx
  V=V+k*p/10./r;%compute V
12
13
   end
```

C. Obeserve the Electric Field

```
1 %draw volt graph
2 | figure; %create figure
  mesh(X,Y,V); %draw potential figure
  grid on; %set grid on
5 hold on: %several graphs
6 |%label and title
   title (sprintf ('Potential Graph of
      Line Charge in Vaccum\n(By
      Integral Method)'), 'Ying Yiwen
      ,12210159', 'FontSize',14);%title
  xlabel('X-axis(unit:m)', 'FontSize')
       ,10);%xlabel
  ylabel ('Y-axis (unit:m)', 'FontSize'
       ,10);%ylabel
  zlabel ('V(unit:v)', 'FontSize', 10);%
10
      zlabel
11 |%save figure
  saveas (gcf, 'figure1-1.jpg');
```

D. Obeserve the Equipotential Line

```
%Select value of equipotential
  Vmin=0; minimum equipotential
3 Vmax=100; maximum equipotential
  Veg=linspace (Vmin, Vmax, 101); %divide
      equipotential line
  %draw equipotential graph
  figure; % create figure
6
   contour (X, Y, V, Veq); %draw
      equipotential figure
   grid on; %set grid on
   hold on; % several graphs
  %label and title
10
   plot([-1,1], [0,0], 'r', 'LineWidth',
       3);%draw the line charge
   title (sprintf ('Equipotential Graph of
       Line Charge in Vaccum\n(By
      Integral Method)'), 'Ying Yiwen
      ,12210159', 'FontSize',14);%title
  xlabel('X-axis(unit:m)', 'FontSize')
       ,10);%xlabel
   ylabel('Y-axis(unit:m)', 'FontSize')
       ,10);%ylabel
  %save figure
15
  | saveas(gcf, 'figure1 - 2.jpg') ;
```

E. Compute the Electric Field Line

```
%compute electric field line
[Ex,Ey]=gradient(-V);%compute
    electric field intensity
del_theta=10;%set division
theta=(0:del_theta:360).*pi/180;%
    divide angle
sxs1=-1.2:0.1:1.2;%compute x value of
    location 1
sx2=-1.2:0.1:1.2;%compute x value of
    location 2
sys1=0.05*ones(length(xs1),1);%compute
    y value of location 1
sys2=-0.05*ones(length(xs1),1);%
    compute y value of location 2
```

F. Observe the Electric Field Line

```
1 %Plot the distribution of electric
        field lines in the field
2 figure;%create figure
3 hold on;%several graphs
4 %label and title
5 a=streamline(X,Y,Ex,Ey,xs1,ys1);%
        Electric field line1
```

```
6 set (a, 'linewidth', 1.5, 'color'
       , [0.5, 0, 0.6]); \%set line type
  b=streamline (X, Y, Ex, Ey, xs2, ys2); %
       Electirc field line2
   set (b, 'linewidth', 1.5, 'color'
       , [0.5, 0, 0.6]); %set line type
   contour (X, Y, V, Veq); %draw
       equipotential figure
   plot([-1,1], [0,0], 'r', 'LineWidth',
       3);%draw the line charge
   grid on; %set grid on
11
   title (sprintf ('Electirc Field Line of
12
       Line Charge in Vaccum\n(By
       Integral Method)'), 'Ying Yiwen
       ,12210159', 'FontSize',14); %title
   xlabel('X-axis(unit:m)', 'FontSize')
13
       ,10);%xlabel
14
   ylabel('Y-axis(unit:m)', 'FontSize')
       ,10);%ylabel
  %save figure
   saveas (gcf, 'figure1 -3.jpg'); %save
      current figure
```

G. RMS calculation

```
%draw the difference of various
      divisons
  %integral method
  r1=1-X+sqrt((1-X).^2+Y.^2);%calculate
  r2=-1-X+sqrt((-1-X).^2+Y.^2);
      calculate r2
  V=k.*p.*log(r1./r2);%calculate
      potential
   differ = []; %an array to save the
      difference
  %infinitive method, 50 parts
  for i = 5:5:100
  temp=0;
9
  for j = 1:i
  r = sqrt((X-(2/i)*j+1+(1/i)).^2+Y.^2);\%
11
      compute r of every dx
  temp=temp+2*k*p/i./r;%compute V
12
13
  difference=sum(sum((V-temp).^2))
14
      /10000;%compute the total of
      difference
   differ = [differ difference];
15
16
  x = 5:5:100;%x-axis
17
  figure; % create new figure
18
  plot(x, differ, '-o');%plot the line
      chart
```

```
grid on; %set grid on
21
  %label and title
   title (sprintf ('Potential Difference
22
      Graph of Line Charge in Vaccum\n(
      Integral Method & Infinitive
      Method)'), 'Ying Yiwen, 12210159', '
      FontSize',14);%title
   xlabel ('Number of Segements','
23
      FontSize',10);%xlabel
   ylabel ('RMS', 'FontSize', 10); %ylabel
24
  %save figure
25
   saveas(gcf, 'figure5-4.jpg'); %save
      current figure
```

Above are the main code of the experiment. Little changes are applied to get different results in different background as follows. The complete code is shown in the appendix.

III. The Electric Field Computed by Integral Method

As there is no use of approximation, the Integral method can give the exact amount of electric potential at everywhere in the region we determined. The result of that can also be used as reference to compare the result of the infinitive method.

To show the electric field easily, we choose region as x:[-2,2], y:[-2,2], precision as 0.04 to draw the graph. It should be clarified that, outside that region, there is also electric field, which is just not shown for our observation.

By further computation, we can get the potential graph, equipotential graph, and electric field line graph, as follows:

Fig.1.Potential Graph of Line Charge in Vaccum Fig.2.Equipotential Graph of Line Charge in Vaccum Fig.3.Electirc Field Line of Line Charge in Vaccum

Those three figures shows the electric field of line charge computed by integral method in different ways.

The red line at the center represents the line charge. Around the line charge, the electric potential is the highest in the region, and the equipotential line is also the most dense. Electric field lines, represented by purple lines, radiate outward from the line charge.

IV. The Electric Field Computed by Infinitive Method

An integral can be mathematically approximated as the sum of the results of countless calculations of tiny segments. Therefore, for integrals that are difficult to calculate in many cases, we choose from time to time to use the method of infinitive instead. Within acceptable

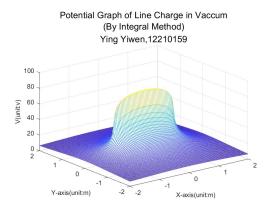


Fig. 1. Potential Graph of Line Charge in Vaccum

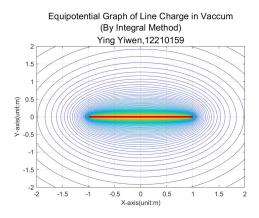


Fig. 2. Equipotential Graph of Line Charge in Vaccum

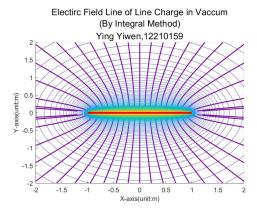


Fig. 3. Electirc Field Line of Line Charge in Vaccum

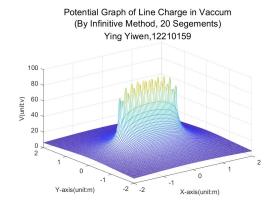


Fig. 4. Potential Graph of Line Charge in Vaccum

limits, the object of the calculation is approximated in order to simplify the calculation.

In this experiment, we are going to explore what kind of approximation can be made in the calculation of the electric field distribution, using the infinitive method instead of the integral calculation. The experiment is carried out to observe the calculation results by means of potential diagrams, equipotential curves, and electric field lines, and to compare them with the exact results obtained in the previous section.

A. Divide the Line Charge into 20 Segments

After divide the line charge into 20 segments, as each part of the line charge is small, we can see them as 20 point charges. For point charges, it's easy to compute the electric field led by them.

By further computation, we can get the potential graph, equipotential graph, and electric field line graph, as follows:

Fig.4.Potential Graph of Line Charge in Vaccum Fig.5.Equipotential Graph of Line Charge in Vaccum Fig.6.Electirc Field Line of Line Charge in Vaccum

From figure4, we can easily find that, there are many spines, especially near the line charge. That may be due to the division is not precise enough. However, the general tendency of potential graph is similar to that of the reference (integral method).

As a result, we can try the computation based on different number of segments in dividing the line charge.

B. Divide the Line Charge into 50 Segments

We divide the line charge into 50 segments, which can be seen as 50 point charges. In the same way, we can work

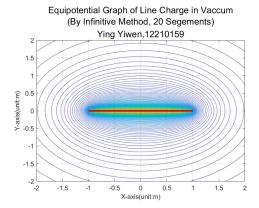


Fig. 5. Equipotential Graph of Line Charge in Vaccum

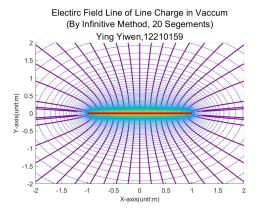


Fig. 6. Electirc Field Line of Line Charge in Vaccum

out the electric field and observe them in the potential graph, equipotential graph, and electric field line graph, as follows:

Fig.7.Potential Graph of Line Charge in Vaccum Fig.8.Equipotential Graph of Line Charge in Vaccum Fig.9.Electirc Field Line of Line Charge in Vaccum

Comparing figure.1 and figure.7, we can come out that the electric field computed by infinitive method is similar with that by integral method this time. For equipotential graph and electric field line graph, the shape of them are also simalr to the results from the integral method.

In practice, we need to note what level of precision is appropriate. In other words, we should explore the variation of the results with the number of segments and its marginal effect. In this way, we can rationally choose the most economical method in practical engineering applications without compromising the accuracy of our results.

Therefore, we should continue to investigate whether

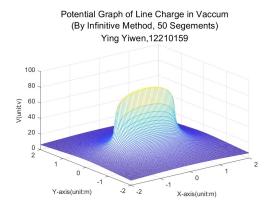


Fig. 7. Potential Graph of Line Charge in Vaccum

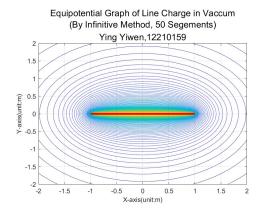


Fig. 8. Equipotential Graph of Line Charge in Vaccum

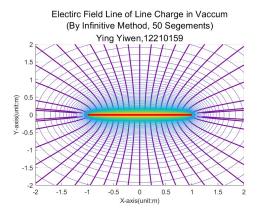


Fig. 9. Electirc Field Line of Line Charge in Vaccum

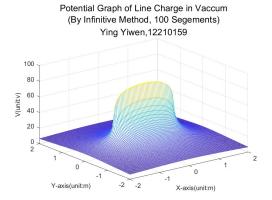


Fig. 10. Potential Graph of Line Charge in Vaccum

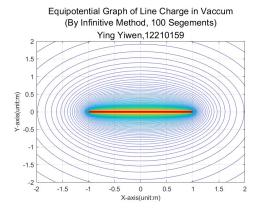


Fig. 11. Equipotential Graph of Line Charge in Vaccum

there are very good results as the number of segments continues to increase.

C. Divide the Line Charge into 100 Segments

This time, each part is rather small. From theory, the result should be rather better. Similarly, we divide the line charge into 100 segments. Then, we can work out the electric field and observe them in the potential graph, equipotential graph, and electric field line graph, as follows:

Fig.10.Potential Graph of Line Charge in Vaccum Fig.11.Equipotential Graph of Line Charge in Vaccum

Fig.12. Electirc Field Line of Line Charge in Vaccum

From the graph, we really get results very similar to the reference. However, we're sad to find that, the results have little difference compared to that in the division of 50 segments.

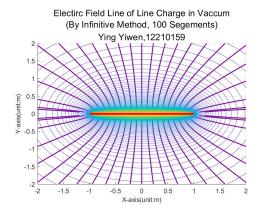


Fig. 12. Electirc Field Line of Line Charge in Vaccum

It can be suggested that, when the number of segments is extremely high, there may be little difference in the precision of the outcome. After a typical number of segments, the cost of time and space still increases when the number of sements increases, while the result is almost the same.

Thus, it's important for us to find that typical number, so that we can get the number we should use in practice. Comparing the result from different number of segments, maybe we can deduce that conclusion.

V. The Threshold Value for the division

First, for 20 segments, 50 segments, and 100 segments, which are discussed above by the graphs, we give a new standard to measure aganist the precision. It's easy to show the graph of the difference of electric potential by set the z-axis as $V_{integral} - V_{infinitive}$.

We can see the difference in electric potential by the potential graph as follows:

Fig.13.Potential Difference Graph of Line Charge in Vaccum, 20 Segments

Fig.14.Potential Difference Graph of Line Charge in Vaccum, 50 Segments

Fig.15.Potential Difference Graph of Line Charge in Vaccum, 100 Segments

Taking a look at the three pictures, we can see that the results of the integral method and the infinitive method produce a large difference at the neighbouring line charge. On the one hand, this may be due to the fact that the potential gradient at that location is larger and the absolute value is also larger, so the absolute difference value will also be larger. On the other hand, the infinitive method treats the tiny line charge as a point charge, whereas close to the line charge, the scale difference between the distance from the line charge and the length of the line charge is not large, so it is not

(Integral Method & Infinitive Method,20 Segements) Ying Yiwen,12210159

Potential Difference Graph of Line Charge in Vaccum

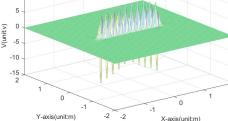


Fig. 13. Potential Difference Graph of Line Charge in Vaccum, 20 Segments

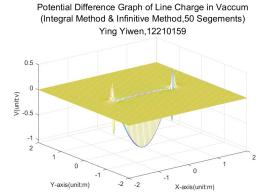


Fig. 14. Potential Difference Graph of Line Charge in Vaccum, $50\,$ Segments

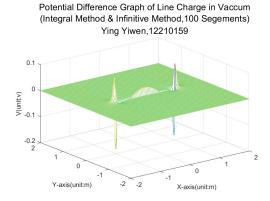


Fig. 15. Potential Difference Graph of Line Charge in Vaccum, $100 \; {\rm Segments}$

Line Chart of Potential Difference Graph of Line Charge in Vaccum (Integral Method & Infinitive Method)

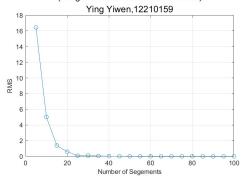


Fig. 16. Line Chart of Potential Difference Graph of Line Charge in Vaccum

possible to make such an approximation, and therefore a larger value of the absolute difference will be produced.

In addition, at both ends of the line charge, the difference between both methods is the largest of all points.

It is also noticeable that there is essentially no difference between the results of the integral and micrometric methods at other points in the selected region.

Comparing these three graphs, we can see that the difference between the two methods decreases significantly as the number of segmentation segments grows.

In judging the results, instead of graph, root-mean-square is also counted to judge the precision of the result. The RMS can give only one value for each case, which makes it easier to compare the effect of different numbers of segments on the accuracy of the results.

To find the threshold value for the division, we should try enough examples to select a best one.

Comparing the RMS results, we can plot the line chart: Fig.16.Line Chart of Potential Difference Graph of Line Charge in Vaccum.

It can be found that, the threshold value may be between 20 and 60. We can zoom in and look at the difference to find the most appropriate value, which is plot in the line chart:

Fig.17.Line Chart of Potential Difference Graph of Line Charge in Vaccum.

Through this figure, we deduce that the threshold may be about 40.

VI. Conclusion

Observing the potential field graph, equipotential graph, and electric field line graph, the infinitive method

Line Chart of Potential Difference Graph of Line Charge in Vaccum (Integral Method & Infinitive Method)

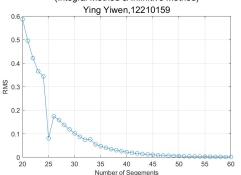


Fig. 17. Line Chart of Potential Difference Graph of Line Charge in Vaccum

can generally estimate the potential field of the line charge instead of integral method, and it's true that the infinitive method is easier to compute in most cases.

The error is little enough to be ignored when the division is about 40 segments or more, or the testing point is far away from the line charge (the distance between the testing point and the line charge is much bigger than the length of the line charge).

Experience:

Try myself to complete the code with different methods.

Use line chart of root-mean-square to find the threshold.

Try the format of science paper writing.

VII. Appendix: Matlab Code

A. Calculate the potential distribution, equipotential line distribution, and electric field line distribution of a line charge at each point in a two-dimensional plane using calculus methods

```
clc, clear, close all;
why integral
%select region
k=9e9;%electric constant
p=1e-9;%charge density
xm=2;%set x region
ym=2;%set y region
x=linspace(-xm,xm,100);% divide x
axis
y=linspace(-ym,ym,100);% divide y
axis
[X,Y]=meshgrid(x,y);%form coordinate
r1=1-X+sqrt((1-X).^2+Y.^2);%calculate
r1
```

```
12 \mid r2 = -1 - X + sqrt((-1 - X).^2 + Y.^2);
       calculate r2
   V=k.*p.*log(r1./r2);%calculate
13
       potential
   %draw volt graph
   figure; % create figure
15
   mesh(X,Y,V); %draw potential figure
16
17
   grid on; %set grid on
   hold on; % several graphs
18
   %label and title
19
   title (sprintf ('Potential Graph of
20
       Line Charge in Vaccum\n(By
       Integral Method)'), 'Ying Yiwen
       ,12210159', 'FontSize',14);%title
   xlabel('X-axis(unit:m)', 'FontSize')
21
       ,10);%xlabel
   vlabel ('Y-axis (unit:m)', 'FontSize'
22
       ,10);%ylabel
23
   zlabel('V(unit:v)', 'FontSize', 10);%
       zlabel
   %save figure
24
   saveas(gcf, 'figure1 -1.jpg');
25
   %Select value of equipotential
26
27
   Vmin=0;%minimum equipotential
28
   Vmax=100; maximum equipotential
   Veg=linspace (Vmin, Vmax, 101); %divide
29
       equipotential line
   %draw equipotential graph
   figure; % create figure
31
32
   contour (X, Y, V, Veq); %draw
       equipotential figure
   grid on; %set grid on
33
   hold on; % several graphs
34
35
   %label and title
   plot([-1,1], [0,0], 'r', 'LineWidth',
36
        3); %draw the line charge
   title (sprintf ('Equipotential Graph of
        Line Charge in Vaccum\n(By
       Integral Method)'), 'Ying Yiwen
       ,12210159', 'FontSize',14);%title
   xlabel('X-axis(unit:m)', 'FontSize')
       ,10);%xlabel
   ylabel('Y-axis(unit:m)', 'FontSize'
       ,10); %ylabel
   %save figure
40
   saveas(gcf, 'figure1 -2.jpg');
41
42
   %compute electric field line
   [Ex, Ey] = gradient(-V);\%compute
43
       electric field intensity
   del theta=10;%set division
44
   theta = (0: del theta: 360).* pi / 180;\%
45
       divide angle
   xs1 = -1.2:0.1:1.2;%compute x value of
46
      location 1
```

```
47 | xs2 = -1.2:0.1:1.2;%compute x value of
       location 2
   ys1 = 0.05*ones(length(xs1),1);%compute
        y value of location 1
   ys2 = -0.05*ones(length(xs1),1);%
       compute y value of location 2
   %Plot the distribution of electric
       field lines in the field
   figure; % create figure
51
  hold on; % several graphs
52
   %label and title
53
   a=streamline(X,Y,Ex,Ey,xs1,ys1);
54
       Electric field line1
   set (a, 'linewidth', 1.5, 'color'
55
       , [0.5, 0, 0.6]); \%set line type
   b=streamline(X,Y,Ex,Ey,xs2,ys2);\%
56
       Electirc field line2
   set(b, 'linewidth', 1.5, 'color')
57
       , [0.5, 0, 0.6]); \%set line type
   contour (X,Y,V,Veq);%draw
       equipotential figure
   \operatorname{plot}\left(\left[-1,1\right],\ \left[0,0\right],\ 'r',\ '\operatorname{LineWidth}',\right.
        3);%draw the line charge
   grid on; %set grid on
   title (sprintf ('Electirc Field Line of
61
        Line Charge in Vaccum\n(By
       Integral Method)'), 'Ying Yiwen
       ,12210159', 'FontSize',14);%title
   xlabel('X-axis(unit:m)', 'FontSize'
62
       ,10);%xlabel
   ylabel('Y-axis(unit:m)', 'FontSize'
63
       ,10);%ylabel
  %save figure
64
   saveas (gcf, 'figure1-3.jpg'); %save
65
       current figure
```

B. Calculate the potential distribution, equipotential line distribution, and electric field line distribution of a line charge at each point in a two-dimensional plane using the microelement method

1)Divide into 20 segments

```
clc, clear, close all;
why infinitive method, 20 parts
select region
k=9e9; %electric constant
p=1e-9; %charge density
xm=2; %set x region
ym=2; %set y region
x=linspace(-xm,xm,100); % divide x
axis
y=linspace(-ym,ym,100); % divide y
axis
```

```
V=0:
11
   for i = 1:20
12
   r = sqrt((X-0.1*i+1.05).^2+Y.^2);\%
13
      compute r of every dx
   V=V+k*p/10./r;%compute V
14
15
   end
  %draw volt graph
16
   figure; % create figure
17
   mesh(X,Y,V); %draw potential figure
18
   grid on; %set grid on
19
   hold on; % several graphs
20
  %label and title
   title (sprintf ('Potential Graph of
22
      Line Charge in Vaccum\n(By
      Infinitive Method, 20 Segements)')
       , 'Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
   xlabel('X-axis(unit:m)', 'FontSize'
23
       ,10);%xlabel
   ylabel('Y-axis(unit:m)', 'FontSize'
       ,10);%ylabel
   zlabel('V(unit:v)', 'FontSize',10);%
25
      zlabel
  %save figure
26
   saveas(gcf, 'figure2-1.jpg'); %save
27
      current figure
  %Select value of equipotential
   Vmin=0; minimum equipotential
29
  Vmax=100; maximum equipotential
30
   Veq=linspace (Vmin, Vmax, 101); %divide
31
      equipotential line
  %draw equipotential graph
32
33
   figure; % create figure
   contour (X, Y, V, Veq); %draw
34
      equipotential figure
   grid on; %set grid on
   hold on; % several graphs
36
  %label and title
37
   plot([-1,1], [0,0], 'r', 'LineWidth',
38
        3); %draw the line charge
   title (sprintf ('Equipotential Graph of
       Line Charge in Vaccum\n(By
      Infinitive Method, 20 Segements)')
       , 'Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
   xlabel('X-axis(unit:m)','FontSize'
       ,10);%xlabel
   ylabel('Y-axis(unit:m)', 'FontSize'
41
       ,10);%ylabel
  %save figure
42
   saveas (gcf, 'figure2 -2.jpg'); %save
43
      current figure
44 | %compute electric field line
```

[X,Y] = meshgrid(x,y); %form coordinate

```
[Ex, Ey] = gradient(-V); % compute
      electric field intensity
   del_theta=10;%set division
46
   theta = (0: del theta: 360) .* pi / 180;\%
47
      divide angle
   xs1 = -1.2:0.1:1.2;%compute x value of
48
      location 1
   xs2 = -1.2:0.1:1.2;%compute x value of
49
      location 2
   ys1=0.05*ones(length(xs1),1);%compute
50
       y value of location 1
   ys2 = -0.05*ones(length(xs1),1);\%
      compute y value of location 2
  %Plot the distribution of electric
52
      field lines in the field
   figure; % create figure
53
  hold on; % several graphs
54
  %label and title
  a=streamline(X,Y,Ex,Ey,xs1,ys1);
56
      Electric field line1
   set(a, 'linewidth', 1.5, 'color'
57
       , [0.5, 0, 0.6]); %set line type
58
   b=streamline(X,Y,Ex,Ey,xs2,ys2);
      Electirc field line2
   set (b, 'linewidth', 1.5, 'color'
59
       ,[0.5,0,0.6]);%set line type
   contour (X,Y,V,Veq);%draw
60
      equipotential figure
   plot([-1,1], [0,0], 'r', 'LineWidth',
61
       3);%draw the line charge
   grid on; %set grid on
62
   title (sprintf ('Electirc Field Line of
63
       Line Charge in Vaccum\n(By
      Infinitive Method, 20 Segements)')
       , 'Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
   xlabel('X-axis(unit:m)', 'FontSize'
       ,10);%xlabel
   ylabel ('Y-axis (unit:m)', 'FontSize'
       ,10);%ylabel
  %save figure
66
  saveas (gcf, 'figure2-3.jpg'); %save
      current figure
```

2)Divide into 50 segments

```
clc, clear, close all;
why infinitive method, 50 parts
%select region
k=9e9;%electric constant
p=1e-9;%charge density
xm=2;%set x region
ym=2;%set y region
x=linspace(-xm,xm,100);% divide x
axis
```

```
9 |y=linspace(-ym,ym,100);\% divide y
   [X,Y] = meshgrid(x,y); %form coordinate
10
  V=0:
11
12
   for i = 1:50
  r = sqrt((X-0.04*i+1.02).^2+Y.^2);\%
13
      compute r of every dx
   V=V+k*p/25./r;%compute V
14
15
  %draw volt graph
16
   figure; % create figure
17
   \operatorname{mesh}(X,Y,V);%draw potential figure
18
   grid on; %set grid on
   hold on; % several graphs
20
  %label and title
21
   title (sprintf ('Potential Graph of
22
      Line Charge in Vaccum\n(By
       Infinitive Method, 50 Segements)')
       , 'Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
   xlabel('X-axis(unit:m)', 'FontSize'
       ,10);%xlabel
   ylabel('Y-axis(unit:m)','FontSize'
24
       ,10);%ylabel
   zlabel('V(unit:v)', 'FontSize',10);%
25
       zlabel
  %save figure
26
   saveas (gcf, 'figure3-1.jpg'); %save
       current figure
  %Select value of equipotential
   Vmin=0; minimum equipotential
29
   Vmax=100; maximum equipotential
30
   Veg=linspace (Vmin, Vmax, 101); %divide
31
       equipotential line
  %draw equipotential graph
   figure; % create figure
33
   contour(X,Y,V,Veq);%draw
34
       equipotential figure
   grid on; %set grid on
   hold on; % several graphs
36
37
   %label and title
   plot([-1,1], [0,0], r', 'LineWidth',
38
        3);%draw the line charge
   title (sprintf ('Equipotential Graph of
39
        Line Charge in Vaccum\n(By
       Infinitive Method, 50 Segements)')
       , 'Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
   xlabel('X-axis(unit:m)', 'FontSize'
40
       ,10);%xlabel
   vlabel ('Y-axis (unit:m)', 'FontSize'
41
       ,10);%ylabel
  %save figure
42.
43 | saveas (gcf, 'figure 3 - 2.jpg'); %save
```

```
current figure
  %compute electric field line
44
   [Ex, Ey] = gradient(-V);\%compute
       electric field intensity
   del theta=10;%set division
   theta = (0: del theta: 360) .* pi / 180;%
47
       divide angle
   xs1 = -1.2:0.1:1.2;%compute x value of
48
      location 1
   xs2 = -1.2:0.1:1.2;%compute x value of
49
      location 2
   ys1=0.05*ones(length(xs1),1);%compute
       y value of location 1
   ys2 = -0.05*ones(length(xs1),1);\%
51
      compute y value of location 2
  %Plot the distribution of electric
52
       field lines in the field
   figure; % create figure
  hold on; % several graphs
54
  %label and title
  a=streamline(X,Y,Ex,Ey,xs1,ys1);
56
       Electric field line1
57
   set (a, 'linewidth', 1.5, 'color'
       , [0.5, 0, 0.6]); \%set line type
   b=streamline(X,Y,Ex,Ey,xs2,ys2);\%
58
       Electirc field line2
   set (b, 'linewidth', 1.5, 'color'
59
       , [0.5, 0, 0.6]); \%set line type
   contour (X,Y,V,Veq);%draw
60
       equipotential figure
   \operatorname{plot}([-1,1], [0,0], \operatorname{r}, \operatorname{LineWidth},
61
        3); %draw the line charge
   grid on; %set grid on
62
   title (sprintf ('Electirc Field Line of
63
       Line Charge in Vaccum\n(By
       Infinitive Method, 50 Segements)')
       , 'Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
   xlabel('X-axis(unit:m)', 'FontSize')
       ,10);%xlabel
   ylabel('Y-axis(unit:m)', 'FontSize')
       ,10);%ylabel
  %save figure
  saveas (gcf, 'figure3 -3.jpg'); %save
67
       current figure
```

3) Divide into 100 segments

```
clc, clear, close all;
2 | %by infinitive method, 100 parts
3 |%select region
4 k=9e9; %electric constant
5 p=1e-9;%charge density
6 xm=2;%set x region
7 | ym=2;%set y region
```

```
x=linspace(-xm, xm, 100);% divide x
   y=linspace(-ym,ym,100);\% divide y
      axis
   [X,Y] = meshgrid(x,y); % form coordinate
  V=0:
11
12
   for i = 1:100
13
   r = sqrt((X-0.02*i+1.01).^2+Y.^2);\%
      compute r of every dx
  V=V+k*p/50./r;%compute V
14
15
  %draw volt graph
16
17
   figure; % create figure
   mesh(X,Y,V); %draw potential figure
18
   grid on; %set grid on
19
   hold on; % several graphs
20
  %label and title
21
22
   title (sprintf ('Potential Graph of
      Line Charge in Vaccum\n(By
      Infinitive Method, 100 Segements)
      ), 'Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
23
   xlabel ('X-axis (unit:m)', 'FontSize'
       ,10);%xlabel
   ylabel('Y-axis(unit:m)', 'FontSize')
24
       ,10);%ylabel
   zlabel ('V(unit:v)', 'FontSize',10);%
25
      zlabel
  %save figure
26
   saveas (gcf, 'figure4-1.jpg'); %save
27
      current figure
  %Select value of equipotential
  Vmin=0; minimum equipotential
29
30
   Vmax=100; maximum equipotential
  Veq=linspace (Vmin, Vmax, 101); %divide
      equipotential line
  %draw equipotential graph
   figure; % create figure
33
   contour (X, Y, V, Veq); %draw
      equipotential figure
   grid on; %set grid on
   hold on; % several graphs
36
   %label and title
37
   plot([-1,1], [0,0], 'r', 'LineWidth',
38
        3);%draw the line charge
   title (sprintf ('Equipotential Graph of
       Line Charge in Vaccum\n(By
      Infinitive Method, 100 Segements);
      ), 'Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
   xlabel ('X-axis (unit:m)', 'FontSize'
       ,10);%xlabel
   ylabel('Y-axis(unit:m)', 'FontSize')
41
```

,10);%ylabel

```
%save figure
   saveas (gcf, 'figure4-2.jpg'); %save
      current figure
  %compute electric field line
44
   [Ex, Ey] = gradient(-V); % compute
       electric field intensity
46
   del theta=10;%set division
   theta = (0: del_{theta} : 360) .* pi / 180;\%
47
       divide angle
   xs1 = -1.2:0.1:1.2;%compute x value of
48
      location 1
   xs2 = -1.2:0.1:1.2;%compute x value of
      location 2
   ys1=0.05*ones(length(xs1),1);%compute
50
       y value of location 1
   ys2 = -0.05*ones(length(xs1),1);%
51
      compute y value of location 2
  %Plot the distribution of electric
       field lines in the field
   figure; % create figure
  hold on; % several graphs
54
   %label and title
56
   a=streamline(X,Y,Ex,Ey,xs1,ys1);
       Electric field line1
   set (a, 'linewidth', 1.5, 'color'
57
       , [0.5, 0, 0.6]); %set line type
   b=streamline (X, Y, Ex, Ey, xs2, ys2); %
58
       Electirc field line2
   set (b, 'linewidth', 1.5, 'color'
59
       , [0.5, 0, 0.6]); %set line type
   contour (X,Y,V,Veq);%draw
60
       equipotential figure
   \operatorname{plot}([-1,1], [0,0], \operatorname{r}, \operatorname{LineWidth},
61
        3);%draw the line charge
   grid on; %set grid on
   title (sprintf ('Electirc Field Line of
63
        Line Charge in Vaccum\n(By
       Infinitive Method, 100 Segements);
      ), 'Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
   xlabel('X-axis(unit:m)', 'FontSize'
       ,10);%xlabel
   ylabel('Y-axis(unit:m)', 'FontSize')
       ,10);%ylabel
  %save figure
66
   saveas (gcf, 'figure4-3.jpg'); %save
67
       current figure
```

C. Calculate the difference between the calculus and microelement

1)Linearly calculate the difference

```
1 clc, clear, close all;
```

```
2 % difference between integral method
      and infinitive method with 20
      parts
  %select region
3
  k=9e9;%electric constant
  p=1e-9;%charge density
  xm=2;%set x region
  ym=2;%set y region
  x=linspace(-xm,xm,100);\% divide x
      axis
  y=linspace(-ym, ym, 100);% divide y
      axis
   [X,Y] = meshgrid(x,y); %form coordinate
  %infinitive method, 20 parts
11
  V1=0;
12
  for i = 1:20
13
   r = sqrt((X-0.1*i+1.05).^2+Y.^2);\%
14
      compute r of every dx
  V1=V1+k*p/10./r; % compute V
15
  %integral method
17
   r1=1-X+sqrt((1-X).^2+Y.^2); %calculate
18
   r2=-1-X+sqrt((-1-X).^2+Y.^2);
      calculate r2
   V2=k.*p.*log(r1./r2);%calculate
      potential
21
  V=V2-V1;%calculate the difference
  %draw volt graph
22
   figure; % create figure
23
  \operatorname{mesh}(X,Y,V);%draw potential figure
24
   grid on; %set grid on
  %label and title
26
27
   title (sprintf ('Potential Difference
      Graph of Line Charge in Vaccum\n(
      Integral Method & Infinitive
      Method, 20 Segements)'), 'Ying Yiwen
      ,12210159', 'FontSize',14);%title
   xlabel ('X-axis (unit:m)', 'FontSize'
       ,10);%xlabel
   ylabel ('Y-axis (unit:m)', 'FontSize'
       ,10);%ylabel
   zlabel('V(unit:v)', 'FontSize',10);%
      zlabel
  %save figure
31
   saveas(gcf, 'figure5-1.jpg'); %save
32
      current figure
  %infinitive method, 50 parts
33
  V1=0;
34
   for i = 1:50
35
  r = sqrt((X-0.04*i+1.02).^2+Y.^2);\%
      compute r of every dx
  V1=V1+k*p/25./r;%compute V
37
38 end
```

```
39 V=V2-V1;%calculate the difference
                                               4 k=9e9; %electric constant
40 %draw volt graph
                                                 p=1e-9;%charge density
  figure; % create figure
                                                 xm=2;%set x region
42 \operatorname{mesh}(X,Y,V);%draw potential figure
                                                 ym=2;%set y region
                                               7
  grid on; %set grid on
                                                 x=linspace(-xm,xm,100);\% divide x
  %label and title
44
   title (sprintf ('Potential Difference
                                                 y=linspace(-ym, ym, 100);% divide y
      Graph of Line Charge in Vaccum\n(
                                                     axis
      Integral Method & Infinitive
                                                 [X,Y]=meshgrid(x,y);%form coordinate
      Method, 50 Segements)'), 'Ying Yiwen
                                                 %integral method
                                              11
      ,12210159', 'FontSize', 14);%title
                                                 r1=1-X+sqrt((1-X).^2+Y.^2); %calculate
   xlabel('X-axis(unit:m)', 'FontSize')
      ,10);%xlabel
                                                 r2=-1-X+sqrt((-1-X).^2+Y.^2);
   ylabel('Y-axis(unit:m)', 'FontSize'
                                                     calculate r2
47
       ,10);%ylabel
                                                 V=k.*p.*log(r1./r2);%calculate
   zlabel('V(unit:v)', 'FontSize',10);%
                                                     potential
48
                                                  differ = []; %an array to save the
      zlabel
                                              15
                                                     difference
  %save figure
49
   saveas (gcf, 'figure5 -2.jpg'); %save
                                                 %infinitive method
                                              16
50
      current figure
                                                  for i = 5:5:100
                                              17
  %infinitive method, 100 parts
                                                 temp=0;
                                              18
51
  V1=0:
                                                 for j = 1:i
52
                                              19
                                                 r = sqrt((X-(2/i)*j+1+(1/i)).^2+Y.^2);%
53
  for i = 1:100
                                              20
  r = sqrt((X-0.02*i+1.01).^2+Y.^2);\%
                                                     compute r of every dx
      compute r of every dx
                                                 temp=temp+2*k*p/i./r;%compute V
                                              21
  V1=V1+k*p/50./r;\%compute V
                                              22
55
                                                  difference=sum(sum((V-temp).^2))
56
                                              23
  V=V2-V1:%calculate the difference
                                                     /10000;%compute the total of
57
  %draw volt graph
                                                     difference
58
   figure; % create figure
                                                  differ = [differ difference];
59
                                              24
  mesh(X,Y,V);%draw potential figure
                                              25
                                                 end
60
  grid on; %set grid on
                                                 x = 5:5:100;%x-axis
                                              26
62 | % label and title
                                                 figure; % create new figure
                                              27
                                                 plot(x, differ, '-o'); %plot the line
63
   title (sprintf ('Potential Difference
      Graph of Line Charge in Vaccum\n(
                                                     chart
      Integral Method & Infinitive
                                                  grid on; %set grid on
      Method, 100 Segements)'), 'Ying
                                                 %label and title
                                              30
      Yiwen, 12210159', 'FontSize', 14);%
                                                  title (sprintf ('Line Chart of
                                              31
                                                     Potential Difference Graph of Line
      title
64 | xlabel ('X-axis (unit:m)', 'FontSize'
                                                      Charge in Vaccum\n(Integral
       ,10);%xlabel
                                                     Method & Infinitive Method)'),'
   ylabel('Y-axis(unit:m)', 'FontSize')
                                                     Ying Yiwen, 12210159', 'FontSize'
       ,10);%ylabel
                                                     ,14);%title
   zlabel('V(unit:v)', 'FontSize',10);%
                                                 xlabel ('Number of Segements','
66
      zlabel
                                                     FontSize',10);%xlabel
  %save figure
                                                  ylabel ('RMS', 'FontSize', 10); %ylabel
67
                                              33
68 | saveas (gcf, 'figure 5 -3.jpg'); %save
                                              34 %save figure
      current figure
                                                 saveas (gcf, 'figure 5 -4.jpg'); %save
                                              35
                                                     current figure
   2)Calculate the RMS
```

clc, clear, close all;
%draw the difference of various
divisons
%select region

1 clc, clear, close all;
%draw the difference of various
divisons
3 %select region
3 %select region

```
4 | k=9e9; %electric constant
5 p=1e-9;%charge density
6 xm=2;%set x region
7 ym=2;%set y region
  x=linspace(-xm,xm,100);\% divide x
  y=linspace(-ym,ym,100);\% divide y
      axis
  [X,Y] = meshgrid(x,y); % form coordinate
  %integral method
11
12 | r1=1-X+sqrt((1-X).^2+Y.^2); %calculate
  r2=-1-X+sqrt((-1-X).^2+Y.^2);
      calculate r2
  V=k.*p.*log(r1./r2);%calculate
14
      potential
  differ = []; %an array to save the
15
      difference
  %infinitive method
16
  | for i = 20:1:60
17
  temp=0;
18
  for j = 1:i
19
  r = sqrt((X-(2/i)*j+1+(1/i)).^2+Y.^2);\%
20
      compute r of every dx
  temp=temp+2*k*p/i./r;%compute V
21
22
  difference=sum(sum((V-temp).^2))
23
      /10000;%compute the total of
      difference
   differ = [differ difference];
24
25
  end
  x = 20:1:60;%x - axis
  figure; % create new figure
27
  plot(x, differ, '-o');%plot the line
      chart
  grid on; %set grid on
29
  %label and title
30
  title (sprintf ('Line Chart of
31
      Potential Difference Graph of Line
       Charge in Vaccum\n(Integral
      Method & Infinitive Method)'),'
      Ying Yiwen, 12210159', 'FontSize'
       ,14);%title
  xlabel ('Number of Segements','
      FontSize',10);%xlabel
  ylabel ('RMS', 'FontSize', 10); %ylabel
33
34 | %save figure
35 | saveas (gcf, 'figure5 -5.jpg'); %save
      current figure
```