Physics 122 – Class #16 – Outline

• Announcements
• Field of continuous charge distributions (by symmetry)
• Worked Problems
• Derivation of field of a line
• Equipotentials (next week's lab)
Readings

Read Chapter 28 for next week. Omit 28.3
Test #2 – Thursday 3/12

Chapters 25, 26 …

Look for additional homework and practice questions on chapter 26.

Test will cover lectures up through Tuesday 3/10.
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\[ \vec{E} = \frac{\sigma}{2\epsilon_0} \hat{n} \]

Planar symmetry

\[ \vec{E} = \frac{\lambda}{2\pi r \epsilon_0} \hat{r} \]

Cylindrical symmetry

\[ \vec{E} = \frac{Q}{4\pi r^2 \epsilon_0} \hat{r} \]

Spherical symmetry

Infinite parallel-plate capacitor

Coaxial cylinders

Concentric spheres
Field near a “large” vertical uniform sheet of charge

\[ \vec{E} = \frac{\sigma}{2 \varepsilon_0} \hat{n} \] \hspace{1cm} \sigma = \frac{Q}{A}

Field outside of a “long” line of charge.

\[ \vec{E} = \frac{\lambda}{2 \pi r \varepsilon_0} \hat{r} \] \hspace{1cm} \lambda = \frac{Q}{L}

Field outside of a uniform sphere of charge Q.

\[ \vec{E} = \frac{Q}{4 \pi r^2 \varepsilon_0} \hat{r} \] \hspace{1cm} \rho = \frac{Q}{V}
Estimating Electric Field using symmetry arguments

If you can't physically tell where you are with respect to a charge, a line, or a surface (or any Other charge distribution) then the Electric field direction cannot give you a hint.
Consider first an infinitely long cylinder.
Estimating Electric Field of Cylinder using symmetry arguments
(a) Is this a possible electric field of an infinitely long charged cylinder? Suppose the charge and the field are reflected in a plane perpendicular to the axis.
Electric Field of cylinder – B

There can’t be a component along axis

(b) The charge distribution is not changed by the reflection, but the field is. This field doesn’t match the symmetry of the cylinder, so the cylinder’s field can’t look like this.
Electric Field of cylinder – C

(a)

End view of cylinder

Reflection plane

The charge distribution is not changed by reflecting it in a plane containing the axis.
Electric Field of cylinder – D

The field cannot “rotate” around cylinder

This field *is* changed. It doesn’t match the symmetry of the cylinder, so the field can’t look like this.
Electric Field of cylinder – E

The field cannot “rotate” around cylinder.

End view of cylinder

Reflection plane

The charge distribution is not changed by reflecting it in a plane containing the axis.

Reflect

(b)

This field is changed. It doesn’t match the symmetry of the cylinder, so the field can’t look like this.
Electric Field of a cylinder

The ONLY field consistent with symmetry of an infinitely long cylinder points radially outward.
Electric Field of a plane of charge

Now imagine an infinite plane of charge.
Direction of Electric Field of a plane of charge

Because you can't tell what direction you are facing, the field must be ONLY Perpendicular to the plane.
How large is this picture?

[A] It's a part of a bathroom Floor (4'x6')

[B] It is a part of an oil painting 12” x 18”

[C] It is the floor of a warehouse 50'x75'

[D] It is an abandoned airfield 1000'x1500'

[E] Not enough info, can't tell
How large is this picture?

[A] (4'x6')
[B] 12” x 18”
[C] 50'x75'
[D] 1000'x1500'
[E] Not enough Info, can't tell
Magnitude of electric field of a plane of charge

Because you ALSO can't tell how far away you are from the plane, the field cannot change magnitude. It must be constant.
Direction of field from a sphere of charge

Because of spherical symmetry, the field must be radial (like a point charge)
\[ \vec{E} = \frac{\sigma}{2 \epsilon_0} \hat{j} \]

**Planar symmetry**

The field is perpendicular to the plane.

\[ \vec{E} = \frac{\lambda}{2 \pi r \epsilon_0} \hat{r} \]

**Cylindrical symmetry**

The field is radial toward or away from the axis.

\[ \vec{E} = \frac{Q}{4 \pi r^2 \epsilon_0} \hat{r} \]

**Spherical symmetry**

The field is radial toward or away from the center.

- Infinite parallel-plate capacitor
- Coaxial cylinders
- Concentric spheres
Field near a “large” vertical uniform sheet of charge
\[ \vec{E} = \frac{\sigma}{2 \epsilon_0} \hat{n} \]
\[ \sigma = \frac{Q}{A} \]

Field outside of a “long” line of charge.
\[ \vec{E} = \frac{\lambda}{2 \pi r \epsilon_0} \hat{r} \]
\[ \lambda = \frac{Q}{L} \]

Field outside of a uniform sphere of charge Q.
\[ \vec{E} = \frac{Q}{4 \pi r^2 \epsilon_0} \hat{r} \]
\[ \rho = \frac{Q}{V} \]
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Problem 26-39

• The electric field 5.0 cm from a very long charged wire is 2000 N/C (toward the wire). What is the charge on 1.0 cm of the wire?
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Capacitor
A capacitor is made with 2 m x 2 m square plates 2 cm apart. The plates have charges of + and −10 uC respectively. What is the field inside the capacitor (and outside).
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Clicker

You are 1 cm away from a 10 meter long charged wire, and the electric field has magnitude 27 N/C. What is the field if you go 3 cm away?

[A] 27 N/C  
[B] 13.5 N/C  
[C] 9 N/C  
[D] 3 N/C

\[
\vec{E}_{\text{PLANE}} = \frac{\sigma}{2 \epsilon_0} \hat{i} \quad \vec{E}_{\text{LINE}} = \frac{\lambda}{2 \pi r \epsilon_0} \hat{r} \quad \vec{E}_{\text{SPHERE}} = \frac{Q}{4 \pi r^2 \epsilon_0} \hat{r}
\]
You are 1 cm away from a 10 m square charged to 2 nCoul. What is the electric field?

[A] 1.13 V/m
[B] 2.26 V/m
[C] 113 N/C
[D] $2 \times 10^{-9}$ V/m
[E] $2 \times 10^{-11}$ V/m
Clicker

You are 100 m away from a 10 m square charged to 2 nCoul. What is the electric field?

[A] 1.13 V/m

[B] $1.13 \times 10^{-2}$ V/m

[C] 113 V/m

[D] $18 \times 10^{-2}$ V/m

[E] $18 \times 10^{-4}$ V/m
Problem
What is line charge density on a long wire if a 10 microgram particle carrying 3 nC orbits at 300 m/s?

\[ \vec{E}_{\text{wire}} = 2k \frac{\lambda}{r} \hat{r} \]

\[ \lambda = \frac{Q}{L} \]
Problem

What is line charge density on a long wire if a 10 microgram particle carrying 3 nC orbits at 300 m/s?

\[ \vec{E}_{wire} = 2 \, k \, \frac{\lambda \hat{r}}{r} \]

\[ \lambda = \frac{Q}{L} \]
Electric field of a charged wire – Derivation

\[ \vec{E}_{\text{wire}} = 2 k \frac{\lambda}{r} \hat{r} \]

\[ \lambda = \frac{Q}{L} \]

\[ \vec{E} = \int k \frac{dq}{r^2} \hat{r} \]
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Electric field of three charges

This is the point at which we will calculate the electric field.
Electric field of three charges

This is the point at which we will calculate the electric field.
Electric field of charged wire

What is the electric field at this point?

The linear charge density is $\lambda = \frac{Q}{L}$. 
1. Choose a coordinate system with the origin at the center of the rod.

2. Identify the point at which we’re going to calculate the field.

3. Divide the rod into $N$ small segments of length $\Delta y$ and charge $\Delta Q = \lambda \Delta y$.

4. Draw the field vector of charge segment $i$.

5. Note that the field from a symmetrically located charge segment will cancel $(E_i)_y$. 

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1. Identify the point at which we’re going to calculate the field.

2. Draw the field vector of charge segment $i$.

3. Note that the field from a symmetrically located charge segment will cancel $(E)_y$. 

Diagram shows a section of a charged plate with segments $\lambda \Delta y$.
Electric field of a charged wire
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Potential Energy (Unit: Joule)
The energy an object gains as it moves from point A to point B for a given applied force. An object with high potential energy will spontaneously convert it to kinetic energy if released.

Potential energy is INDEPENDENT of path from A to B.
Electric Potential (Unit: Volt)
The energy a one Coulomb charge would gain as it moves from point A to B in an electric field. A positive charge at high voltage will spontaneously convert it to kinetic energy if released.

An “equipotential line” is one at which the potential is the same everywhere (and at which identical charges would have identical potential energies). It takes NO WORK to move a charge from one part of an equipotential line to another.
Parallel Plates

Equipotentials are equally spaced lines.

\[ V = \frac{\sigma}{\epsilon_0} x \]

Electric field is constant in magnitude.

\[ \vec{E} = \frac{\sigma}{\epsilon_0} \hat{n} \]
Coaxial Cylinders

Equipotentials are circles and closer together near center electrode

$$V = \frac{\lambda}{2 \pi \epsilon_0} \ln \left( \frac{r}{r_1} \right)$$

Electric field is radial
And decreases with distance

$$\vec{E} = \frac{\lambda}{2 \pi r \epsilon_0} \hat{r}$$
Cylinder over plane
Near plane, equipotentials are equally spaced.

Near cylinder, equipotentials look more like Coax.
<table>
<thead>
<tr>
<th>Field Lines</th>
<th>Equipotentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Originate at positive charges.</td>
<td>The voltage is the same everywhere on an equipotential</td>
</tr>
<tr>
<td>Terminate at negative.</td>
<td></td>
</tr>
<tr>
<td>Closer spacing means larger fields.</td>
<td>Closer spacing means larger fields.</td>
</tr>
<tr>
<td>Never cross.</td>
<td>Never cross.</td>
</tr>
<tr>
<td>Are at right angles to conductors.</td>
<td>Are at right angles to field lines. (Are parallel to conductors)</td>
</tr>
</tbody>
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