Physics 6C
Introduction to Physics III
Electricity and Magnetism

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Electric “Field”

Electric force per unit charge: \[ \vec{E} = \frac{\vec{F}}{q} \]

**Force Vector**

\[ F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Qq}{r^2} \]

**Field Vector**

\[ E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q}{r^2} \]

*This is the electric field from only the charge Q. The charge q just served as a “test charge” that allowed us to detect the presence of the field.*
The charge $Q$ at the origin is surrounded by an invisible electric field.

How can we detect and measure the $E$ field at point $a=(a_x,a_y,a_z)$?

Place a test charge $q$ at point $a$ and measure the force on it.

Divide the force $F$ by $q$ to calculate the field $E=F/q$ at point $a$. 

Electric Field
Now, we can do the same at any other point in space, such as point $b = (b_x, b_y, b_z)$

Using the test charge again, we measure $F$ and then calculate $E$.

The field is 4 times what we found at point $a$, because $a$ is twice as far from $Q$ as $b$ is.
Point $a$ DOES NOT lie on the field vector shown here.

This $E$ vector represents the field strength and direction at point $b$ only.

It does NOT represent a distance in space!

$E$ has units of N/C, not meters!

There is an uncountably infinite set of points on this graph, and at every one of them we could calculate and draw an $E$ field vector.
Field vectors point away from a positive charge and toward a negative charge.

Some field vectors from a positive point charge.

Some field vectors from a negative point charge.
**Dipole Field**

Principle of superposition!

Use Coulomb’s law to find the field at point \( P \) from the positive charge.

Then the same for the negative charge.

Add those two vectors to get the total electric field at point \( P \).

This is doable by hand at a few points.

But a computer can make quick work of calculating the total electric field at many, many points!

http://webphysics.davidson.edu/physletprob/ch15_efield/default.html

http://www.falstad.com/emstatic/
Concept Test

At the position of the dot, the electric field points

1. Left.
2. Down.
3. Right.
5. The electric field is zero.
Visualizing Electric Fields

Dipole Field

Vector Display

Field Line Display

The field is stronger where the lines are closer together.
Visualizing Electric Fields

Field of two like-sign charges
Physlets

• At your convenience, please go to the web site: http://webphysics.davidson.edu/physletprob/
• Click on Ch 9: E & M
• Click on 9.1 Electrostatics
• Play around with some or all of the exercises there to become familiar with electrostatic fields.
• These visualizations can be very helpful in building a correct intuition of electrostatic fields and forces.

• Another useful applet for electrostatics is http://www.falstad.com/emstatic/
• But note that the E vectors are all the same length!
  – Brightness and color represent the field strength.
• I especially recommend the Physlets
  – 9.1.1: force vector on a charge due to several other charges
  – 9.1.2: concept of a test charge (which should be small enough not to disturb the field being investigated)
  – 9.1.4: visualization of electric field lines
  – 9.1.7: forces on a test charge and its motion in an electrostatic field due to two charges (opposite or equal)
  – 9.1.ap 3: make the computer draw as many field lines as you want
“Test Charge”

• When we put a test charge into an existing electric field, we use it to measure the field at some point.
• Introduction of the test charge itself will, of course, change the field at all other points in space, but we aren’t interested in that.
• It may be useful to imagine that the test charge is so small that its effect on the overall field is negligible.

http://webphysics.davidson.edu/physletprob/ch9_problems/ch9_1_electrostatics/default.html
Electric Field Demo

- Small, neutral wood chips are suspended in oil.
- The electric field polarizes the chips, when they then tend to line up with the electric field vectors.
**Dipole Field Calculation Example**

- Problem 37 in Chapter 26: calculate $E$ on x axis

$$E_+ > E_- \text{ because the + charge is closer.}$$

The dipole electric field at this point is in the positive y-direction.

The dipole electric field at this point is in the negative y-direction.

A dipole has no net charge.

For $r \gg s$, in the plane perpendicular to the dipole moment:

$$\vec{E}_{\text{dipole}} = -K \frac{\vec{p}}{r^3}$$

The dipole moment $\vec{p}$ is a vector pointing from the negative to the positive charge with magnitude $qs$. 
“Continuous” Charge Distribution

• In nature, at the microscopic level charges are always discrete point charges (e.g. the electron).

• But when there is a large number of charges spread over a macroscopic object, it is useful mathematically to think of them as forming a *continuous* distribution.

• Suppose we have a line, with charge $Q$ *uniformly* distributed over the distance $L$.

  $\lambda = \frac{Q}{L}$

• The *linear charge density* then is $\lambda = \frac{Q}{L}$

• Now, suppose I cut my line of charge into two parts, one 3 times the length of the other.
  
  – What is the charge density of each part?

  – Still $\lambda = \frac{Q}{L}$ for both parts!
A piece of plastic is uniformly charged with surface charge density $\eta_1$. The plastic is then broken into a large piece with surface charge density $\eta_2$ and a small piece with surface charge density $\eta_3$. Rank in order, from largest to smallest, the surface charge densities $\eta_1$ to $\eta_3$.

1. $\eta_1 > \eta_2 > \eta_3$
2. $\eta_1 > \eta_2 = \eta_3$
3. $\eta_1 = \eta_2 = \eta_3$
4. $\eta_2 = \eta_3 > \eta_1$
5. $\eta_3 > \eta_2 > \eta_1$
For a continuous charge distribution, Coulomb’s law must be integrated.

The only way to add vectors by integration is to do a separate integral for each component!
This is our integral (with + sign), but be careful, because here $x$ is what we called $y$, and $a$ is what we called $x$. 

Integral Table