Physics 2102
Lecture: 03 FRI 16 JAN
Electric Fields I

Charles-Augustin de Coulomb (1736-1806)

Version: 1/14/09
What Are We Going to Learn?
A Road Map

- Electric charge
  - Electric force on other electric charges
  - Electric field, and electric potential

- Moving electric charges: current

- Electronic circuit components: batteries, resistors, capacitors

- Electric currents – Magnetic field
  - Magnetic force on moving charges

- Time-varying magnetic field è Electric Field

- More circuit components: inductors.

- Electromagnetic waves – light waves

- Geometrical Optics (light rays).

- Physical optics (light waves)
Coulomb’s Law

\[ |F_{12}| = \frac{k |q_1| |q_2|}{r_{12}^2} \]

For Charges in a Vacuum

\[ k = 8.99 \times 10^9 \frac{Nm^2}{C^2} \]

Often, we write \( k \) as:

\[ k = \frac{1}{4\pi \varepsilon_0} \quad \text{with} \quad \varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2} \]
E-Field is E-Force Divided by E-Charge

**Definition of Electric Field:**

\[ \vec{E} = \frac{\vec{F}}{q} \]

\[ |\vec{F}_{12}| = \frac{k|q_1||q_2|}{r_{12}^2} \]

\[ |\vec{E}_{12}| = \frac{k|q_2|}{r_{12}^2} \]

Units: \( F = [N] = [\text{Newton}] \); \( E = [N/C] = [\text{Newton/Coulomb}] \)
Electric Fields

- Electric field $E$ at some point in space is defined as the force experienced by an imaginary point charge of $+1$ C, divided by $1$ C.
- Note that $E$ is a VECTOR.
- Since $E$ is the force per unit charge, it is measured in units of $\text{N/C}$.
- We measure the electric field using very small “test charges”, and dividing the measured force by the magnitude of the charge.

$$|E| = \frac{k|q|}{R^2}$$

Electric Field of a Point Charge
Superposition of F and E

• **Question**: How do we figure out the force or field due to several point charges?

• **Answer**: consider one charge at a time, calculate the field (a vector!) produced by each charge, and then add all the vectors! (“superposition”)

• Useful to look out for SYMMETRY to simplify calculations!
• 4 charges are placed at the corners of a square as shown.
• What is the direction of the electric field at the center of the square?

(a) Field is ZERO!
(b) Along +y
(c) Along +x
Electric Field Lines

- Field lines: useful way to visualize electric field $E$
- Field lines start at a positive charge, end at negative charge
- $E$ at any point in space is tangential to field line
- Field lines are closer where $E$ is stronger

Example: a negative point charge — note spherical symmetry
Direction of Electric Field Lines

E-Field Vectors Point **Away** from Positive Charge — Field **Source**!

E-Field Vectors Point **Towards** Negative Charge — Field **Sink**!
Electric Field of a Dipole

- Electric dipole: two point charges $+q$ and $-q$ separated by a distance $d$
- Common arrangement in Nature: molecules, antennae, ...
- Note axial or cylindrical symmetry
- Define “dipole moment” vector $\mathbf{p}$: from $-q$ to $+q$, with magnitude $qd$

Cancer, Cisplatin and electric dipoles: http://chemcases.com/cisplat/cisplat01.htm
Electric Field On Axis of Dipole

Superposition: \( \vec{E} = \vec{E}_+ + \vec{E}_- \)

\[
\vec{E}_+ = \frac{kq}{\left( x - \frac{a}{2} \right)^2} \\
\vec{E}_- = -\frac{kq}{\left( x + \frac{a}{2} \right)^2}
\]

\[
\vec{E} = kq \left[ \frac{1}{\left( x - \frac{a}{2} \right)^2} - \frac{1}{\left( x + \frac{a}{2} \right)^2} \right] = kq \frac{2xa}{\left( x^2 - \frac{a^2}{4} \right)^2}
\]
Electric Field **On Axis of Dipole**

\[ E = kq \left( \frac{2xa}{x^2 - \frac{a^2}{4}} \right)^2 = \frac{2kpx}{\left( x^2 - \frac{a^2}{4} \right)^2} \]

What if \( x \gg a \) (i.e. very far away)?

\[ E \approx \frac{2kpx}{x^4} = \frac{2kp}{x^3} \]

\[ |\vec{E}| \propto \frac{\vec{p}}{r^3} \]

\( E = \frac{p}{r^3} \) is actually true for ANY point far from a dipole (not just on axis)
**Force on a Charge in Electric Field**

**Definition of Electric Field:**

\[ \vec{E} = \frac{\vec{F}}{q} \]

**Force on Charge Due to Electric Field:**

\[ \vec{F} = q\vec{E} \]
Force on a Charge in Electric Field

Positive Charge
Force in **Same** Direction as E-Field

Negative Charge
Force in **Opposite** Direction as E-Field
Electric Dipole in a Uniform Field

- Net force on dipole = 0; center of mass stays where it is.
- Net TORQUE $\tau$: INTO page. Dipole rotates to line up in direction of $E$.
- $|\tau| = 2(qE)(d/2)(\sin \theta)$
  $= (qd)(E)\sin \theta$
  $= |p| E \sin \theta$
  $= |p \times E|$
- The dipole tends to “align” itself with the field lines.
- What happens if the field is NOT UNIFORM??

Distance Between Charges = d
"I think you should be more explicit here in step two."