Today we will …

• get some practice using Coulomb’s Law
• learn the concept of an Electric Field
Recall Coulomb’s Law

Force between charges \( q_1 \) and \( q_2 \) separated distance \( r \):

\[
F = k \frac{|q_1| |q_2|}{r^2}
\]

“Coulomb constant”
\[
k = 9 \times 10^9 Nm^2/C^2
\]

Opposite charges attract, like charges repel
Coulomb Law practice: Three Charges

- Calculate force on +2μC charge due to other two charges
  - Draw forces
  - Calculate force from +7μC charge
  - Calculate force from −7μC charge
  - Add (VECTORS!)
Three Charges – Calculate forces

- Calculate force on +2μC charge due to other two charges
  - Draw forces
  - Calculate force from +7μC charge
  - Calculate force from −7μC charge
  - Add (VECTORS!)
- Calculate magnitudes \( F = k \frac{q_1 q_2}{r^2} \)
  - Always \( \geq 0 \)

\[ F_{+7} = 9 \times 10^9 \left| \frac{2 \times 10^{-6} \cdot 7 \times 10^{-6}}{5^2} \right| \]

\[ F_{-7} = 9 \times 10^9 \left| \frac{2 \times 10^{-6} \cdot (-7 \times 10^{-6})}{5^2} \right| \]

\[ = 5 \times 10^{-3} N \]
Three charges – Adding Vectors $\vec{F}_{+7} + \vec{F}_{-7}$

- Calculate components of vectors $\vec{F}_{+7}$ and $\vec{F}_{-7}$:

$$\vec{F}_{+7,x} = F_{+7} \cos \theta = 5 \times 10^{-3} N \frac{3}{5}$$
$$\quad = 3 \times 10^{-3} N$$

$$\vec{F}_{+7,y} = F_{+7} \sin \theta = 5 \times 10^{-3} N \frac{4}{5}$$
$$\quad = 4 \times 10^{-3} N$$

$$\vec{F}_{-7,x} = F_{-7} \cos \theta = 5 \times 10^{-3} N \frac{3}{5}$$

$$\vec{F}_{-7,y} = -F_{-7} \sin \theta = -5 \times 10^{-3} N \frac{4}{5}$$

Watch Signs!
Three charges – Adding Vectors $\mathbf{F}_{+7} + \mathbf{F}_{-7}$

- Add like components of vectors $\mathbf{F}_{+7}$ and $\mathbf{F}_{-7}$:

  \[
  F_x = F_{+7,x} + F_{-7,x} = 6 \times 10^{-3} N \\
  F_y = F_{+7,y} + F_{-7,y} = 0
  \]

- Final vector $\mathbf{F}$ has magnitude and direction

  \[
  F = \sqrt{F_x^2 + F_y^2} = 6 \times 10^{-3} N \\
  \phi = \tan^{-1} \left( \frac{F_y}{F_x} \right) = 0
  \]

- Double-check with drawing
Electric Field

- Charged particles create electric fields.
  - Direction is the same as for the force that a + charge would feel at that location.
  - Magnitude given by:
    \[ E \equiv \frac{F}{q} = \frac{kq}{r^2} \]

**Example**

\[ Q_p = 1.6 \times 10^{-19} \text{ C} \]

\[ r = 1 \times 10^{-10} \text{ m} \]

\[ E = \frac{9 \times 10^9 \cdot 1.6 \times 10^{-19}}{(10^{-10})^2} \text{ N} = 1.4 \times 10^{11} \text{ N/C} \text{ (to the right)} \]
CheckPoint 2.1

What is the direction of the electric field at point A?

- 1) Up (7%)
- 2) Down (7%)
- 3) Left (2%)
- 4) Right (53%)
- 5) Zero (32%)
ACT: E Field

What is the direction of the electric field at point C?

A. Left
   Away from positive charge (right)

B. Right
   Towards negative charge (right)
   Net E field is to right.

C. Zero

Physics 102: Lecture 2, Slide 9
E Field from 2 Charges

- Calculate electric field at point A due to two unequal charges
  - Draw electric fields
  - Calculate $E$ from $+7\mu C$ charge
  - Calculate $E$ from $-3.5\mu C$ charge
  - Add (VECTORS!)

Note: this is similar to (but a bit harder than) my earlier example.

We’ll do some of this here… you try the rest at home!
E Field from 2 Charges

- Calculate electric field at point A due to charges
  - Calculate E from +7μC charge
  - Calculate E from −3.5μC charge
  - Add* 

\[ E = \frac{kq}{r^2} \]

\[ E_7 = \frac{(9 \times 10^9)(7 \times 10^{-6})}{25} \text{ N/C} \]

\[ E_7 = 2.5 \times 10^{+3} \text{ N/C} \]

\[ E_3 = \frac{(9 \times 10^9)(3.5 \times 10^{-6})}{25} \text{ N/C} \]

\[ E_3 = 1.25 \times 10^{+3} \text{ N/C} \]

Physics 102: Lecture 2, Slide 11
Adding Vectors $E_7 + E_3$

- Decompose into x and y components.

\[
E_{7x} = E_7 \cos(\theta) = E_7 \left( \frac{3}{5} \right) \\
= 1.5 \times 10^3 \text{N/C}
\]

\[
E_{7y} = E_7 \sin(\theta) = E_7 \left( \frac{4}{5} \right) \\
= 2 \times 10^3 \text{N/C}
\]
Adding Vectors \( \mathbf{E}_7 + \mathbf{E}_3 \)

- Decompose into x and y components.
- Add components.

\[
\begin{align*}
E_{7x} &= 1.5 \times 10^3 \text{ N/C} \\
E_{3x} &= 0.75 \times 10^3 \text{ N/C} \\
E_{7y} &= 2 \times 10^3 \text{ N/C} \\
E_{3y} &= -1 \times 10^3 \text{ N/C}
\end{align*}
\]

\[
\begin{align*}
E_x &= 2.25 \times 10^3 \text{ N/C} \\
E_y &= 1.0 \times 10^3 \text{ N/C}
\end{align*}
\]

\[
|\mathbf{E}| = \sqrt{E_x^2 + E_y^2} = 2.5 \times 10^3 \text{ N/C}
\]
Comparison: Electric Force vs. Electric Field

- **Electric Force** ($F$) – the force felt by a charge at some location
- **Electric Field** ($E$) – found for a location only (any location) – tells what the electric force *would be* if a $+$ charge were located there:
  \[ F = Eq \]
- Both are vectors, with magnitude and direction.

Ok, what is $E$ actually good for?
Electric Field Map

• Electric field defined at any location
Electric fields:
A useful record-keeping tool!

Calculate once for fixed charges, use to find force on other charges (like ions/electrons in neurons, heart tissue, and cell membranes)

Eisenberg, BU
**Electric Field Lines**

- Closeness of lines shows field strength (lines never cross)
- Number of lines at surface $\propto Q$
- Arrow gives direction of $E$ (Start on +, end on –)

This is becoming a mess!!!
Charge A is positive.

Field lines start on positive charge, end on negative.

1) positive 93%
2) negative 4%
3) unknown 3%

Physics 102: Lecture 2, Slide 18
CheckPoint 3.2 / ACT

Compare the ratio of charges $Q_A / Q_B$ # lines proportional to Q

A) $Q_A = 0.5Q_B$  
B) $Q_A = Q_B$  
C) $Q_A = 2Q_B$

15%  
17%  
53%
The electric field is stronger when the lines are located closer to one another.

The magnitude of the electric field at point X is greater than at point Y

1) True 18%  2) False 82%  Density of field lines gives E
E inside of conductor

- Conductor $\equiv$ electrons free to move
  - Electrons feels electric force - will move until they feel no more force ($F=0$)
  - $F=Eq$: if $F=0$ then $E=0$

- $E=0$ inside a conductor (Always!)
Demo: E-field from dipole
Recap

• **E Field has magnitude and direction:**
  – \( E \equiv F/q \)
  – Calculate just like Coulomb’s law
  – Careful when adding vectors

• **Electric Field Lines**
  – Density gives strength (# proportional to charge.)
  – Arrow gives direction (Start + end on –)

• **Conductors**
  – Electrons free to move \( \Rightarrow E = 0 \)
To Do

• Campus closed on Monday; no office hours.
• Homework 1 due **Wednesday, Jan 23 @ 8 AM**!
• Do your Checkpoint by 8:00 AM Wednesday.