From Last Time...

Static electric charges

Interactions between charges

Properties of electric charge

- Two types of charges
  - Positive and negative
- Interactions between charges
  - Like charges repel
  - Unlike charges attract
  - Interaction decreases with increasing distance

Vector Nature of Electric Force

a) The force is repulsive if charges are of like sign
b) The force is attractive if charges are of opposite sign

The force is a conservative force

Electrical forces obey Newton’s Third Law:

\[ F_{21} = -F_{12} \]

Magnitude of force: Coulomb’s Law

- Electrical force between two stationary charged particles
  \[ F_e = k_e \frac{|q_1| |q_2|}{r^2} \]
- The SI unit of charge is the coulomb (C), \( \mu C = 10^{-6} \) C
- 1 C corresponds to 6.24 x 10^{18} electrons or protons
- \( k_e = \text{Coulomb constant} \approx 9 \times 10^9 \) N m^2/C^2 = 1/(4\pi \varepsilon_0)
- \( \varepsilon_0 = \text{permittivity of free space} = 8.854 \times 10^{-12} \) C^2 / N m^2

Quick Quiz

About what is the force between two particles 1 m apart, each with charge 100 micro-Coulomb?

A. 100 N
B. 1 N
C. 1000 N
D. 0.1 N
E. 0.001

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Quick Quiz
Equal but opposite charges are connected by a rigid insulating rod. They are placed near a negative charge as shown. What is the net force on the two connected charges?
A) Left
B) Right
C) Up
D) Down
E) Zero

The electric dipole
• Can all be approximated by electric dipole.
• Two opposite charges magnitude $q$ separated by distance $\mathbf{s}$

\[ F = \frac{kq_1q_2}{r^2} \]

Dipole moment
Vector $\mathbf{p}$
Points from -charge to +charge
Has magnitude $qs$

Induced dipoles (charge redistribution)

Bring negative charge close. Electrons on sphere move away from rod.

Induced dipole in insulators
• A process similar to induction can take place in insulators
• The charges within the molecules of the material are rearranged

Quick Quiz
Two uniformly-charge spheres are firmly fastened to, and electrically insulated from, frictionless pucks on an air table. The charge on sphere 2 is three times the charge on sphere 1. Which choice below correctly shows the magnitude and direction of the forces?
A
B
C
D
E

The idea of electric fields
• EM wave made up of oscillating electric and magnetic fields.
• But what is an electric field?
• Electric field is a way to describe the force on a charged particle due to other charges around it.
• Force = charge × electric field
• The direction of the force is the direction of the electric field.
Electric field of a point charge

Force on this charge...
$$\vec{F} = k \frac{Q_1 Q_2}{r^2} \hat{r}$$
...due to this charge

Force = (Charge) × (Electric field)

Question

• Which vector best represents the electric field at the red dot?

A
B
C
D
E

Relationship Between \( F \) and \( E \)

• \( F_e = qE \)
• This is valid for a test charge small enough that it does not disturb the source charge distribution
• If \( q \) is positive, \( F \) and \( E \) are in the same direction

\[ E = \frac{(9 \times 10^9)(1.6 \times 10^{-19})}{(1 \times 10^{-10})^2} \text{N} = 2.9 \times 10^{11} \text{ N/C} \]

Electric Field Direction

• a) \( q \) is positive, \( F \) is directed away from \( q \)
• b) The direction of \( E \) is also away from the positive source charge
• c) \( q \) is negative, \( F \) is directed toward \( q \)
• d) \( E \) is also toward the negative source charge

Superposition with Electric Fields

• At any point \( P \), the total electric field due to a group of source charges equals the vector sum of electric fields of all the charges

\[ \vec{E} = \vec{k} \sum \frac{Q_i}{r_i^2} \hat{r}_i \]

Find the electric field due to \( q_1, E_1 \)
Find the electric field due to \( q_2, E_2 \)
\[ \vec{E} = \vec{E}_1 + \vec{E}_2 \]
Remember, the fields add as vectors

Quick Quiz

Which is the direction of the electric field at dot?
A. Left
B. Right
C. Up
D. Down
E. Zero

Net \( E \) field is to right.
Quick Quiz

A. Up
B. Down
C. Left
D. Right
E. Zero

Electric field: summary

- Electric field \( \rightarrow \) will be a force on a charged particle.
- This force and electric field can arise from electric charges (via Coulomb's law)
- But once electric field is known, don’t need to know the charges that produce it.

Electric field lines

- Local electric field tangent to field line
- Density of lines proportional to electric field strength
- Fields lines can only start on + charge
- Can only end on - charge.
- Electric field lines can never cross

Pictorial representation of E: Electric Field Lines

Electric field of a dipole

Electric field of two + charges