Physics 202, Lecture 2

Today’s Topics

- Electric Force and Electric Fields
  - Electric Charges and Electric Forces
  - Coulomb’s Law
  - Physical Field
  - The Electric Field
  - Electric Field Lines
- Motion of Charged Particle in Electric Field

Demo: Two Types of Electric Charges

Opposite signs attract  Like signs repel

Properties of Electric Charges

- 2+1 types: positive, negative (+neutral).
- Unit: Coulomb (C). 1 C= charge of $6.24 \times 10^{18}$ protons.
- Building blocks of matters:
  - Electric charge is quantized: $q=\pm Ne$, $e=1.602 \times 10^{-19}$ C
  - Electric charge is conserved: charges can be moved around, but the total charge remains the same.
  - For deep thinkers: Why electrons and protons have the same electric charge?

<table>
<thead>
<tr>
<th>Charge (C)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>$-e=1.602 \times 10^{-19}$</td>
</tr>
<tr>
<td>Proton</td>
<td>$+e=1.602 \times 10^{-19}$</td>
</tr>
<tr>
<td>Neutron</td>
<td>0</td>
</tr>
</tbody>
</table>

Electric Force And Coulomb’s Law

- Electric forces exist between two charged particles
- The direction of electric force depends on the signs of the charges:
  - forces between opposite sign charges are attractive
  - forces between like sign charges are repulsive
- The magnitude of the electric forces for point charges (Coulomb’s Law)
  $$F = \frac{kq_1q_2}{r^2}$$
  Coulomb Constant: $k = 8.987 \times 10^9$ Nm$^2$/C$^2 = \frac{1}{4\pi \varepsilon_0}$
  $\varepsilon_0$: permittivity of free space

Numeric Examples: Electric Force Is Strong

- Electric force between two 1C charges 1 meter apart: $F=8.99 \times 10^9$N
- Proton and electron in a hydrogen atom:
  - $q_{\text{electron}}= -1.6 \times 10^{-19}$ C, $q_{\text{proton}}= 1.6 \times 10^{-19}$ C, $r=5.3 \times 10^{-11}$m
  - Electric force $F= 8.2 \times 10^{-4}$ N.
  - This force is large:
    - Compared to the mass of proton: $1.673 \times 10^{-27}$ kg
    - Compared to the gravitational forces between them: $F_0 = 3.6 \times 10^{-24}$N (recall: $F_0=Gm_1m_2/r^2$)
- Four fundamental forces:
  - Strong > Electromagnetic > Weak >> Gravitational

Coulomb’s Law in Vector Form

E. Force on $q_2$ by $q_1$: $\vec{F}_{12} = k \frac{q_1q_2}{r^2} \hat{r}$

E. Force on $q_1$ by $q_2$: $\vec{F}_{21} = k \frac{q_2q_1}{r^2} \hat{r} = -\vec{F}_{12}$

- Exercise:
  Use this vector form to verify the attractive/repulsive feature
- Note:
  Multiple particles on charge i, $\vec{F}_i = \vec{F}_{1i} + \vec{F}_{2i} + \vec{F}_{3i} + \ldots$
Quick Quiz

- Two charges, \( q_1 = 0.1 \text{C} \) and \( q_2 = 5q_1 \) (i.e. \( 0.5 \text{C} \)), are separated by a distance \( r = 1 \text{m} \). Let \( F_2 \) denote the force on \( q_1 \) (exerted by \( q_2 \)), and \( F_1 \) denotes the force on \( q_2 \) (exerted by \( q_1 \)). Which of the following relationship is true?
  - \( F_1 = 5F_2 \)
  - \( F_1 = -5F_2 \)
  - \( F_2 = -5F_1 \)
  - \( F_1 = -F_2 \)

Properties of the Electric Force

- It is one of four fundamental forces: Strong > Electromagnetic > weak >> gravity
- It is proportional to \( 1/r^2 \): double \( r \) \( \rightarrow \) \( \frac{1}{4} F \)
- Its direction is charge sign dependent: like sign \( \rightarrow \) repulsive, opposite sign \( \rightarrow \) attractive
- It is a conservative force. (Work independent of path)

\[ W = \int \vec{F} \cdot d\vec{r} = -\frac{k q_1 q_2}{r_f} + \frac{k q_1 q_2}{r_i} = (-U_f) - (-U_i) \]

\[ U = \frac{k q_1 q_2}{r} \]

Note the similarities and differences to gravity

A Very Important Concept: Field

- What is a physical “field”? 

Field: A physical quantity which has a physical value* at each point in space (i.e. a distribution).

Examples of physical fields:
- temperature, wind speed, electric field, magnetic field, ...

- In this course, we consider only scalar and vector forms of physical quantities.

Example of Scalar and Vector Fields

- Temperature (scalar)
- Wind speed (vector)

Measurement can be made at any point on the map.

The Coulomb’s Law Revisited

- Original (Coulomb’s) view of electric force: \( q_1 \) directly applies an electric force on \( q_2 \)

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

- Field view of electric force:
  - \( q_1 \) creates an electric field \( \vec{E} \) around it
  - The electric field \( \vec{E} \) applies a force on \( q_2 \)

\[ \vec{F}_2 = K \frac{q_1 q_2}{r_{12}^2} \]

In this field view:
- \( q_1 \): source charge
- \( q_2 \): test charge
- \( \vec{E} \) independent of \( q_2 \)

Electric Field and Electric Force

- \( q_1 \): source charge
- \( \vec{E} \): field by \( q_1 \)
- \( q_2 \): test charge
- \( \vec{F} = q_2 \vec{E} \) force on \( q_2 \) by \( \vec{E} \)
Visualization of Electric Field: Field Lines

- Use of field lines is a convenient way to visualize electric fields
- Simple rules for drawing field lines:
  - line direction: direction of E vector
  - line density: relative strength of E. (denser = larger)

Field Lines e.g.: Point-Like Charges

Magnitude \( E = k \frac{q}{r^2} \)

Example 2: Two Charged Particles

Each field line always starts from a +q and end at a -q (or \( \infty \))

Motion Of Charged Particle In The Electric Field

- Fundamental Formulas:
  - \( \mathbf{F} = q \mathbf{E} \)
  - \( \mathbf{a} = \frac{\mathbf{F}}{m} = \frac{q \mathbf{E}}{m} \)
  - \( \mathbf{v} = \mathbf{v}_i + \mathbf{a} t \)

- If initially rest (\( \mathbf{v}_i = 0 \)), then \( \mathbf{v} = \mathbf{a} t = \left( \frac{q \mathbf{E}}{m} \right) t \)
- Motion of +q: Same dir. as \( \mathbf{E} \)
- Motion of -q: Opposite dir. as \( \mathbf{E} \)

Exercise: An Electron in a Uniform E. Field

- Find out vertical displacement after the electron pass through a downward uniform electric field \( \mathbf{E} \)
- For an electron charge \( e \) and mass \( m \)
- Answer: \( dy = - \frac{1}{2} at^2 = - \frac{1}{2} \left( \frac{qF}{m} \right) t^2 \)

Exercise: Electric Forces Due to Two Charged Particles

- Find the electric force on \( q_3 \).