Lecture 1.2: Electric Force and Electric Field

Lecture Outline:
Charging Objects
Coulomb’s Law
Electric Field

Textbook Reading:
Ch. 25.3 - 25.5

Jan. 15, 2015
Announcements

• Quiz in class next Thu. (Jan. 22) covers Ch. 25 material.

• Mastering Physics HW0 is a questionnaire I’d like you to complete by Jan. 27. Easy 100% for you, and helpful to me.

• Mastering Physics HW1 due online by next Tuesday (Jan. 20) at 9am. Please don’t wait until Monday night to start on this.

• If you are having any issues finding a copy of the text or registering for Mastering Physics, please let me know SOON. Don’t wait until Monday night…no extensions will be granted.

• If you are having trouble finding a clicker or registering it, let me know.
Electric Charge is a property of matter.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (kg)</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>$1.67 \times 10^{-27}$</td>
<td>$+e$</td>
</tr>
<tr>
<td>Electron</td>
<td>$9.11 \times 10^{-31}$</td>
<td>$-e$</td>
</tr>
</tbody>
</table>

- $e$ = fundamental unit of electric charge (not defined yet).
- Protons are TIGHTLY bound in nucleus – they don’t go anywhere.
- Electrons are more loosely bound.
- Object Charge ($q$) = $N_p e - N_e e = (N_p - N_e)e$
Clicker Question #1

Which is the right ordering of amount of charge of the following objects, from most positive to most negative:

i. 1 electron
ii. 1 proton
iii. 19 electrons and 17 protons
iv. 10,000,000 electrons, 10,000,000 protons
v. glass ball missing 3 electrons

a. v > iv > ii = i > iii
b. iv > iii > ii > v > i
c. v > ii > iv > i > iii
d. none of the above
Clicker Question #1

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a. \( v > iv > ii = i > iii \)
b. \( iv > iii > ii > v > i \)

\( \star \) c. \( v > ii > iv > i > iii \)
d. none of the above
• Introduced **insulators** as materials where charge does not flow freely, and **conductors** as materials where charge does flow freely.

• A neutral atom in an insulator is polarized when charge is brought nearby, forming an **Electric Dipole**.
Last Lecture...

External charge

Polarized atoms

Insulator

Net force
Charging Objects

• We’ve seen examples of how to charge insulators by rubbing/friction (example: rub a balloon on your hair, or rub acrylic/PVC cylinders in demo).

• It’s also possibly to charge neutral objects by bringing them into contact (without rubbing/friction) with a charged object.
We can also charge a neutral object without any contact between it and the charged object. This is called charging by induction. At the end, how does the charge on the electroscope and human compare? Why?
Charging Objects

Discharging an object, by bringing it into contact with a conductor, allows any charge in that object to be removed.

**Grounding** an object to the earth (connecting with a conductor) prevents the object from building up any electric charge.
Coulomb’s Law

• We need to have a quantitative way of specifying the force an object feels due to electric charges.

• What do we already know about the qualities of this new Electric force we are looking for?
  ‣ Oppositely charged objects attract, like charged objects repel.
  ‣ The more vigorously we charge an object, the stronger it interacts with other charged objects.
  ‣ The strength of attraction/repulsion diminishes the further apart the interacting objects are from each other.
Coulomb’s Law

\[ F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{K|q_1||q_2|}{r^2} \]

- \( K \) = electrostatic constant
- \( q_1 \) = charge on particle 1
- \( q_2 \) = charge on particle 2
- \( r \) = distance between particle 1 and 2

Magnitude of Electric Force
Coulomb’s Law

\[ F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{K|q_1||q_2|}{r^2} \]
Coulomb’s Law

Units of Charge are Coulombs (C)

e = fundamental unit of electric charge (charge of one proton) = \(1.60 \times 10^{-19} \text{ C}\)

How many electrons are necessary to make -1 C of charge?

\[-1 \text{ C} \cdot \left(\frac{1 \text{ electron}}{-1.6 \times 10^{-19} \text{ C}}\right) = 6.25 \times 10^{18} \text{ electrons}\]
Coulomb’s Law

Electrostatic constant: $K$

$$K = \text{electrostatic constant} = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$$
Coulomb’s Law

Electrostatic constant: $K$

$K = \text{electrostatic constant} = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$

$\varepsilon_0 \equiv \frac{1}{4\pi K} = 8.85 \times 10^{-12} \text{ C}^2/\text{N m}^2$

$F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{1}{4\pi \varepsilon_0} \frac{|q_1||q_2|}{r^2}$
Coulomb’s Law

Let’s compare Electricity and Gravity

\[ F_{\text{Electric}} = \frac{K|q_1||q_2|}{r^2} \quad F_{\text{Gravity}} = \frac{Gm_1m_2}{r^2} \]
Coulomb’s Law

Let’s compare Electricity and Gravity

\[ F_{\text{Electric}} = \frac{K|q_1||q_2|}{r^2} \quad F_{\text{Gravity}} = \frac{Gm_1m_2}{r^2} \]

\[ \frac{F_{\text{Electric}}}{F_{\text{Gravity}}} = \frac{K|q_1||q_2|}{Gm_1m_2} = 1.2 \times 10^{36} \text{ for two protons!} \]
Coulomb’s Law

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Electric force is HUGE!
Coulomb used a torsion balance to experimentally study electric forces.
Coulomb’s Law

The net electric force on a charge is the vector sum of the force due to all the other charges:

\[ \vec{F}_{\text{net}} = \vec{F}_1 \text{ on } j + \vec{F}_2 \text{ on } j + \vec{F}_3 \text{ on } j + \cdots \]
Clicker Question #2

Two identical charges are arranged as shown. Where (A,B,C,D,E) could a third charge be placed in the picture below so that it experienced no net force?
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\[
\begin{align*}
A & \quad B \\
D & \quad q_1 \\
E & \quad q_2 \\
C
\end{align*}
\]
Clicker Question #2

Two identical charges are arranged as shown. Where (A,B,C,D,E) could a third charge be placed in the picture below so that it experienced no net force?

Anywhere else that would work?
Coulomb’s Law

What is the electric force on the 1.0 nC charge?

\[
|F_{11}| = k \frac{q_1 q_2}{r_{12}^2} = \left(8.99 \times 10^9 \, \text{N} \cdot \text{m}^2 / \text{C}^2\right) \times \frac{(1 \times 10^{-9} \, \text{C}) (2 \times 10^{-9} \, \text{C})}{(0.01 \, \text{m})^2}
\]
\[
= 1.8 \times 10^{-4} \, \text{N}
\]

\[
|F_{13}| = k \frac{q_1 q_3}{r_{13}^2} = \left(8.99 \times 10^9 \, \text{N} \cdot \text{m}^2 / \text{C}^2\right) \times \frac{(1 \times 10^{-9} \, \text{C}) (2 \times 10^{-9} \, \text{C})}{(0.01 \, \text{m})^2}
\]
\[
= 1.8 \times 10^{-4} \, \text{N}
\]

\[
|F_1| = |F_{11}| + |F_{13}| = 3.6 \times 10^{-4} \, \text{N}
\]

VECTORS!

\[F_x = F_{1x} - F_{3x} = F_{21} \cos 60^\circ - F_{31} \cos 60^\circ = 0 \, \text{N}\]

\[F_y = F_{1y} + F_{3y} = F_{21} \sin 60^\circ + F_{31} \sin 60^\circ = 3.1 \times 10^{-4} \, \text{N} \, \text{upwards}\]

or \[3.1 \times 10^{-4} \, \text{N} \, \uparrow\]
Electric Field

What would happen if I had two point charges on opposite ends of the universe, and I jiggled one of the charges? Does the other charge know immediately?
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Michael Faraday suggested that an electric charge alters the space around it. Other charges interact with the field surrounding the original charge.
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Electric Field

\[ \vec{E}(x, y, z) \equiv \frac{\vec{F}_{\text{on } q \text{ at } (x, y, z)}}{q} \]

- source charge creates the electric field, \( \vec{E} \)
- probe charge \( q \) within this electric field experiences a force, \( \vec{F} \).
- Electric field exists everywhere in space, regardless of whether there is a probe charge or not.
- Units: N/C
The field really does exist at all points in space.
Electric Field

Electric field of a point charge

\[ \vec{E} = \frac{1}{4\pi \varepsilon_0} \frac{q}{r^2} \hat{r} \]

3. The electric field is \( \vec{E} = \vec{F}_{\text{on } q'}/q' \). It is a vector in the direction of \( \vec{F}_{\text{on } q'} \).
Electric Field

Refresher: unit vectors

Dimensionless vectors with magnitude = 1

The unit vectors specify the directions to the points.
Electric Field

Electric field diagrams

Electric field points away from a positive source charge.

Electric field points towards a negative source charge.
What is the electric field at the location of the 1.0 nC charge?

\[ \vec{E} = \frac{F_{21}}{q_1} \]

Using \( q_1 = 1.0 \text{nC} \) from previous example

\[ E = \frac{(3.1 \times 10^{-4} \text{N})}{(1.0 \times 10^{-9} \text{C})} = 3.1 \times 10^5 \frac{\text{N}}{\text{C}} \]
Clicker Question #3

At which point (a, b, c, d) is the Electric field strongest?
Clicker Question #3

At which point (a, b, c, d) is the Electric field strongest?
Reminders

• You should be finished reading Ch. 25. Read through 26.4 by next Tue. lecture.
• HW1 due Tuesday at 9am (Mastering Physics).
• Bring clickers every day. Don’t pass up on easy extra credit!