Lecture 1, 7/10/2017

- Electric Charge and Its Conservation, the Atom, Insulators and Conductors
- Induced Charge
- Coulomb’s Law
- The Electric Field and Electric Field Lines
Electric Charge and Electric Field
Observation: Objects can be charged by rubbing
Observation 1: Two identical objects charged the same way will repel.

Observation 2: Two objects made of different materials (e.g. plastic and glass) will attract when charged.

Conclusions:

- Charge comes in two types. We name these two types, positive and negative.
- Like charges repel and opposite charges attract.
Electric charge is conserved—the arithmetic sum of the total charge cannot change in any interaction.

“It is now discovered and demonstrated, both here and in Europe, that the Electrical Fire is a real Element, or Species of Matter, not created by the Friction, but collected only.”

— Benjamin Franklin, Letter to Cadwallader Colden, 5 June 1747
Electric Charge in the Atom

Atom:

Nucleus (small, massive, positive charge)

Electron cloud (large, very low density, negative charge)
Electric Charge in the Atom

Atoms are electrically neutral.

Rubbing charges objects by moving electrons from one to the other (conservation of charge).
The Coulomb

Unit of charge: coulomb, C

Charges produced by rubbing are typically around a microcoulomb:

\[ 1 \mu C = 10^{-6} C \]

Electric charge on a single electron:

\[ e = 1.602 \times 10^{-19} C \]

Electric charge is quantized in units of the electron charge.
Electric Charge in the Atom

Polar molecule: neutral overall, but charge not evenly distributed
Insulators and Conductors

We will mostly concentrate in 2 types of materials:

**Conductors**: Charge flows freely (Metals)

**Insulators**: Almost no charge flows (Most other materials)

Some materials are **semiconductors**: Can act as either conductors or insulators.
Induced Charge

Metal objects (conductors) can be charged by conduction:

(a) Neutral metal rod

(b) Metal rod acquires charge by contact
Induced Charge

They can also be charged by induction:
Induced Charge

Nonconductors (insulators) won’t become charged by conduction or induction, but will experience charge separation (polarization):
The Electroscope

The electroscope can be used for detecting charge:
The Electroscope

The electroscope can be charged either by conduction or by induction.
The Electroscope

The charged electroscope can then be used to determine the sign of an unknown charge.
Coulomb’s Law

Observation 1: Two charged objects exert forces on each other (i.e. they either attract or repel). We call this force the electric force between object 1 and object 2 (of charge $q_1$ and $q_2$, respectively).

Observation 2: The magnitude of the electric force is proportional to the product of the charges (i.e. if $q_1 \times q_2$ increases so does the electric force).

Observation 3: The electric force between two charged objects weakens as the distance between the objects increases. Furthermore if we are careful we would measure a $1/4$ of the force if we double the distance between the objects ($r_{12}$).
Coulomb’s Law

Conclusion:
The magnitude of the electric force between objects 1 and 2 is

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

The equation above is known as **Coulomb’s Law**

Where \( k \) is a proportionality constant

\[ k = 8.988 \times 10^9 \, N \cdot m^2/C^2 \]
Coulomb’s Law

Observation: The electric force is along the line connecting the charges.

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

where \( \hat{r}_{12} \) is a unit vector in the direction along the line connecting charges \( q_1 \) and \( q_2 \).
Coulomb’s Law

The proportionality constant $k$ can also be written in terms of $\varepsilon_0$, the permittivity of free space:

$$F = \frac{1}{4\pi\varepsilon_0} \frac{Q_1 Q_2}{r^2},$$

$$\varepsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2.$$
Notes on Coulomb’s Law

Coulomb’s law strictly applies only to point charges.

Superposition: for multiple point charges, the forces on each charge from every other charge can be calculated and then added as vectors.
The electric field is the force on a small charge, divided by the charge:

\[ \vec{E} = \frac{\vec{F}}{q}. \]
Electric field of a Point Charge of Charge “Q”

For a point charge:

\[ E = \frac{F}{q} = \frac{kqQ}{r^2} \]

\[ E = k \frac{Q}{r^2}; \quad \text{[single point charge]} \]
The Electric Field

Notice that the electric field (E-Field) is a vector quantity.

Force on a point charge in an electric field: \( \vec{F} = q\vec{E} \).

Superposition principle for electric fields: \( \vec{E} = \vec{E}_1 + \vec{E}_2 + \cdots \).
Electric Field Lines

The electric field can be represented by field lines. These lines start on a positive charge and end on a negative charge.

The number of field lines starting (ending) on a positive (negative) charge is proportional to the magnitude of the charge. So the electric field is stronger where the field lines are closer together.
The Electric Dipole

Electric dipole: two equal magnitude charges of opposite in sign separated by a small distance:
Uniform Electric Field

The electric field between two closely spaced, oppositely charged parallel plates is constant.