• Class webpage: http://www.physics.rutgers.edu/ugrad/204sum2/

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# Physics 204 - General Physics II

## Summer 2019

Students are expected to read the relevant textbook sections before each lecture.

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**Sunday 7/28 Exam 1** 2:00PM-3:20PM.

**Sunday 8/11 Exam 2** 2:00 - 3:20 PM.
Required Materials

• iClicker Remote

• Book: College Physics (Openstax)

• A calculator
Lecture

• Review: Gravity
• Electric Charge and Its Conservation
• Insulators and Conductors
• Induced Charge
• Coulomb’s Law
• The Electric Field
Electric Charge and Electric Field
Static Electricity; Electric Charge

Observation: Objects can be charged by rubbing
Static Electricity; Electric Charge

Observation: Two identical object charged the same way will repel.

Observation: 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.
Conservation of Electric Charge

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 electric 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.
Can an object carry a charge of $2.4 \times 10^{-19}$ C?

a) Yes, if the object is a conductor.

b) Yes, if the object has electrons or protons.

c) Yes, if the object is an insulator.

d) No, because objects do not have charge.

e) No, because charge is quantized.
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 (e.g. Metals)

• **Insulators**: Almost no charge flows (e.g. Most other materials)

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

- Metal objects (conductors) can be charged by conduction.
- 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:
Coulomb’s Law

Observation: 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).
Coulomb’s Law

Observation: If the absolute value of the product of the charges increases, the magnitude of the electric force increases proportionally.

• 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).

\[ |\vec{F}_{12}| \propto |q_1 q_2| \]
Coulomb’s Law

Observation: The electric force between two charged objects weakens as the distance between the objects increases.

• Furthermore if we are careful we would measure:

  ➢ \( \frac{1}{4} \) of the force if we double the distance between the objects \((r \rightarrow 2r)\)

  ➢ \( \frac{1}{9} \) of the force if we triple the distance between the objects \((r \rightarrow 3r)\),

  ➢ ...

\[ |\vec{F}_{12}| \propto \frac{1}{r^2} \]
Coulomb’s Law

Conclusion: The magnitude of the electric force between two objects 1 and 2, of charges $q_1$ and $q_2$, respectively is:

$$\left| \vec{F}_{12} \right| = k \frac{|q_1 q_2|}{r^2}$$

- The equation above is known as Coulomb’s Law.
- $k$ is a proportionality constant
  $$k = 8.988 \times 10^9 \, N \cdot m^2/C^2$$
Two point charges are stationary and separated by a distance $R$. Which one of the following pairs of charges would result in the largest repulsive force?

- a) $-2q$ and $+4q$
- b) $-3q$ and $-3q$
- c) $+3q$ and $-3q$
- d) $+2q$ and $+4q$
- e) Either b) or c)
Coulomb’s Law

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

**Coulomb’s Law**  \[ \vec{F}_{12} = k \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12} \]

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:

$$|\vec{F}_{12}| = \frac{1}{4\pi \varepsilon_0} \frac{|Q_1 Q_2|}{r_{12}^2}$$

$$\varepsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \text{ } \text{C}^2/\text{N} \cdot \text{m}^2.$$
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 using Coulomb’s Law and then added (as vectors).
The electric field is the electric force \( \vec{F}_{el} \) on a test charge, divided by the charge:

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

For a point charge:

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

Notice that the electric field (E-Field) is itself 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:
The electric field between two closely spaced, oppositely charged parallel plates is constant.
Example: Hanging charged masses.

Two identical charged spheres of equal charge \( (q_1 = q_2) \) and mass \( m = 3.0 \times 10^{-2} \text{ kg} \), hang in equilibrium by two strings of equal length \( \ell = 0.15 \text{ m} \). Each hanging sphere makes an angle \( \theta = 5^\circ \) \( (i.e. \theta_1 = \theta_2 = 5^\circ) \) with the vertical. Find the magnitude of the charge on each sphere.

How would the angles \( (\theta_1 \text{ and } \theta_2) \) compare if the charges \( q_1 \text{ and } q_2 \) are NOT equal?
How would the angles $\theta_1$ and $\theta_2$ compare?

- a) $\theta_1 = \theta_2$
- b) $\theta_1 > \theta_2$
- c) $\theta_1 < \theta_2$

$m_1 = m_2, q_1 > q_2$