Analytical Physics IIa – Physics 227
Electricity and Magnetism

WELCOME

Lecturer: Professor Jolie Cizewski
E-mail: cizewski AT physics.rutgers.edu
Office phone: 848-445-8773
Office hours: Wednesdays, 2:00-3:00 PM
Office: Serin Physics & Astro 210W

Teaching Assistant: Rostyslav (Ross) Ersteniuk
E-mail: re168 AT scarletmail.rutgers.edu
Office hour: Wednesdays, 3:30-4:30 PM
ARC 332 (MSLC)

Course web page:
http://www.physics.rutgers.edu/ugrad/227spring/Electricity-and-magnetism.html
and SAKAI
Lectures

- Every Monday & Wednesday 6th period: 5:15 to 6:10 pm
- Expected to come prepared for lecture
  - Read material in the relevant sections of the text
  - Review lectures including I-clickers on web page before class
  - Be prepared to ask questions

I clickers

- Expected to come prepared to participate in I-clickers
  - 4% of your grade
  - Please register your I clicker as soon as possible.
• Take homework seriously: You will learn physics best by solving problems.

• Start doing homework early, a few hours every day, starting right after lecture in which material was presented rather than the last few hours before the assignment is due.

• Work on homework in groups

• No extensions for late completion, no excuse accepted for missed work. Lowest 2 scores dropped.

• Questions about Mastering Physics? – ask your recitation instructor Ross Ersteniuk
  E-mail: re168 AT scarletmail.rutgers.edu
Electric Charge, Coulomb's Law
Today we begin our study of electromagnetism, one of the four fundamental forces.

We start with electric charge and look at electric fields.

- WHY??

A large fraction of the phenomena in our lives – and the basis of the devices we use “all of the time” – are based on electro-magnetic phenomena.
Learning Goals for Chapter 21

• How objects become electrically charged.
• How we know that electric charge is conserved.
• How to use Coulomb’s law to calculate the electric force between charges.
• The distinction between electric force and electric field.
• How to use the idea of electric field lines to visualize and interpret electric fields.
• How to calculate the properties of electric charge distributions, including electric dipoles.
Properties of electric charge

- Atom made of electrons going around the nucleus.
  - Orbit of electron $\approx 10^{-10}$ m
  - Radius of nucleus $\approx 10^{-15}$ m

- Two types of charge
  - Negative, e.g., electron
  - Positive, e.g., proton in atom’s nucleus

- Electric charge of electron is negative unit of charge $e$

- All known charges are integer multiples of $e$

- Charge on proton = $-\text{charge on electron}$
  - $e=1.6 \cdot 10^{-19}$ Coulombs

- Coulomb of charge is a lot of charge!

- Electric charge is conserved
  - Net charge of universe does not change
  - If take away an electron from atom, same amount of positive charge left behind

Also fun
https://www.youtube.com/watch?v=tuZxFL9cGkI
Types of materials: Insulators and Conductors

• Insulators
  • Example: transparent materials such as Nylon
  • Demo+PHET: could add/subtract charges by rubbing

• Conductors
  • Example: Metals such as Copper
  • Most electrons bound to their parent nuclei except for one electron is “free” – bound to the conductor as a whole, can wander through the material
  • PHET: cartoon of induction
Properties of electric charges

- Like charges REPEL
- Unlike charges ATTRACT
  - Demonstrated in PHET with balloon(s)
- Charging by induction
  - In PHET saw how charges close to charged balloon moved
    - Negatively charge balloon INDUCED separation of charges on the wall
      - Negative charges moved away from balloon
  - In demo saw how strong the repulsive electrostatic force can be
- More examples in Textbook
  Figures 21.6, 21.7 and 21.8
Quantitative:
Force between charged particles?

Remember force of gravity
Newton’s law of gravitation = force of gravity

Law of gravitation: Every particle of matter attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them, where $G$=constant

\[
F_g = \frac{G m_1 m_2}{r^2}
\]

Any two particles attract each other through gravitational forces.

Even if the particles have very different masses, the gravitational forces they exert on each other are equal in strength:

\[
F_g (1 \text{ on } 2) = F_g (2 \text{ on } 1)
\]
Coulomb’s Law: The magnitude of the electric force between two point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them, where \( k = \text{constant} = \frac{1}{4\pi\varepsilon_0} \)

\[
F_E = \frac{kq_1q_2}{r^2} ; \quad k = \frac{1}{4\pi\varepsilon_0}
\]

Charges can be positive or negative
- Charges of same sign REPEL
- Charges of opposite sign ATTRACT

\[
\frac{1}{4\pi\varepsilon_0} = k = 9.0 \times 10^9 \ \text{N-m}^2/\text{C}^2 \quad \varepsilon_0 = 8.85 \times 10^{-12} \ \frac{\text{C}^2}{\text{N-m}^2}
\]
I clicker question

Three point charges lie on the x-axis. All three charges have the same magnitude +1C. The positions of the charges are shown on the plot. **Find the force exerted on #3 by #1 and #2.**

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

A. \( F = -\frac{k}{2} \text{N} \)

B. \( F = +2k \text{N} \)

C. \( F = +\frac{k}{2} \text{N} \)

D. \( F = +\frac{5k}{4} \text{N} \)

E. \( F = -\frac{3k}{4} \text{N} \)
Three point charges lie on the x-axis. All three charges have the same magnitude +1C. The positions of the charges are shown on the plot. Find the force exerted on #3 by #1 and #2.

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

A. \( F = -\frac{k}{2} \text{N} \)
B. \( F = +2k \text{N} \)
C. \( F = +\frac{k}{2} \text{N} \)
D. \( F = +\frac{5k}{4} \text{N} \)
E. \( F = -\frac{3k}{4} \text{N} \)
Consider two point-like charges of the same mass: #1 has a charge $+q$, and #2 has a charge $Q = +10q$. You hang them from threads near each other. The angle between the thread supporting #1 and the vertical is $\alpha_1$, the angle between the thread supporting #2 and the vertical is $\alpha_2$. Choose the statement with which you agree:

A. $\alpha_1 > \alpha_2$
B. $\alpha_1 < \alpha_2$
C. $\alpha_1 = \alpha_2$
D. You need to know the mass to answer this question.
Consider two point-like charges of the same mass: #1 has a charge \(+q\), and #2 has a charge \(Q = +10q\). You hang them from threads near each other. The angle between the thread supporting #1 and the vertical is \(\alpha_1\), the angle between the thread supporting #2 and the vertical is \(\alpha_2\). Choose the statement with which you agree:

A. \(\alpha_1 > \alpha_2\)
B. \(\alpha_1 < \alpha_2\)
C. \(\alpha_1 = \alpha_2\)
D. You need to know the mass to answer this question.
Electric fields
Gravitational field

Gravitational field: Gravitational force on a test mass due to other masses
For example: gravitational field “g” on the surface of the earth tells us about the force on a “test” object of mass m

\[ F_g = m \left( \frac{Gm_{\text{earth}}}{r_{\text{earth}}^2} \right) = m \text{Field}_g = mg \]

\[ \text{Field}_g = \frac{F_g}{m} = g \]

The gravitational field = Force per unit mass
In general, don’t need to know where the Field comes from to calculate the Force on test mass

\[ F_g = m \text{Field}_g \]
Electrical field

Electrical force on a **positive** test charge $q_0$ due to other charges $Q$

Example: Force between 2 charges to determine field $E$ from charge $Q$

\[
F_E = q_0 \left( \frac{kQ}{r^2} \right) = q_0E
\]

\[
E = \frac{F_E}{q_0}
\]

Electric field $E = \text{Force per unit positive test charge}$

Units: Newton/Coulomb

In general, don’t need to know where the **Field** comes from to calculate the **Force** on test mass

\[
F_E = q_0E
\]
Electric field in pictures

$A$ and $B$ exert electric forces on each other.

- Mutual repulsion of two positively charged bodies $A$ and $B$. 

\[ \vec{F}_0 \]
Next consider body $A$ on its own. Remove body $B$ ...

... and label its former position as $P$.

Body $A$ modifies the properties of the space at point $P$. 
Electric field in pictures

- Can measure the electric field produced by $A$ with a positive test charge.  
  Body $A$ sets up an electric field $\vec{E}$ at point $P$.

\[
\vec{E} = \frac{\vec{F}_0}{q_0}
\]

$\vec{E}$ is the force per unit charge exerted by $A$ on a test charge at $P$.

Remember:
Electric field (force) is a vector – it has magnitude AND direction
Two charges are placed a certain distance apart. The probe charge is at some point on a line connecting the charges but not between them. The force exerted on the probe charge is 0. **What is the most general thing we can say about the charges?**

A. They have the same sign and magnitude.
B. They have opposite signs but the same magnitude.
C. They have the same sign and they must have different magnitudes.
D. They have opposite signs and they must have different magnitudes.
E. Both charges must have zero magnitude.
Two charges are placed a certain distance apart. The probe charge is at some point on a line connecting the charges but *not* between them. The force exerted on the probe charge is 0. What is the *most general* thing we can say about the charges?

A. They have the same sign and magnitude.

B. They have opposite signs but the same magnitude.

C. They have the same sign and they must have different magnitudes.

D. They have opposite signs and they must have different magnitudes.

E. Both charges must have zero magnitude.
Electric Field Lines
Field lines from Van de Graaff

https://tedkinsman.photoshelter.com/image/I0000LzBEmGfjEFk
Properties of electric field lines

- Start on positive charges
- End on negative charges
- Direction of field line gives direction of E field at that point (force on positive test charge)
- Closeness of lines can be measure of strength of the electric field (force)
  - If diverge => weaker electric field
  - If converge => stronger electric field
- Always continuous, never cross
Superposition of electric fields

The total electric field at a point is the vector sum of the fields due to all the charges present.

The total electric field $\vec{E}$ at point $P$ is the vector sum of $\vec{E}_1$ and $\vec{E}_2$. 
Superposition => Simple configurations

Example: Electric field due to a charged rod of Length $L$, distance $a$ away from point $P$
Summary from Lecture 1

- How objects become electrically charged.
- Coulomb’s law to calculate the electric force between charges.

\[ F_E = \frac{kq_1q_2}{r^2}; \quad k = \frac{1}{4\pi\varepsilon_0} \]

- Intro to electric fields = Force per unit (positive) charge \( E = \frac{F_E}{q_0} \)

Topics for Monday

- How to use the idea of electric field lines to visualize and interpret electric fields.
- How to calculate the properties of electric charge distributions, including electric dipoles.
- Remember: Recitation on Friday January 25! With pre-recitation assignment