

Lecture 8 - Electricity & magnetism I

Classical Physics - Continued Electricity & Magnetism

Franklin

Two signs of electric charge

Faraday

Announcements

- **Today:** Start Electricity and Magnetism March (Ch 6) Homework 3 due
- **Mon., Sept 29:** Review before Exam 1 Homework 4 due
- **Wed., Oct. 1: Exam 1** Covers material through the Review Chapters 1 – 5 of March; Ch. 1-2 of Lightman
- **Mon. Oct. 6:** Solutions to Exam 1 Electromagnetism and waves March (Ch 6)

Timeline

- See Timeline description of lives of various scientists on WWW pages.

The state of science around 1700

- **The Newtonian Paradigm (or World View):**
 - What is the world made of?
 - **Particles - objects that have mass.**
 - What Happens in the World?
 - **Forces cause particles to move in accordance with Newton's Laws of Motion.**
- **Determinism**
 - **Everything is determined !**
 - Universe acts like a giant machine, a giant clock with every part obeying precise laws
- (The second law of thermodynamics was not yet formulated)

What forces do we know about?

- **Force of gravity:**
 - Force = $G m_1 m_2 / R^2$
 - Force on mass m near surface of earth $F = G m m_{\text{earth}} / R_{\text{earth}}^2 = m g$ $g = G m_{\text{earth}} / R_{\text{earth}}^2$
- **Force of due to a spring:**
 - Force $F = - K x$
- **Force of due to contact**
 - What transmits the force? This was an open question in the 1700's. What do you think?
- **Other?**

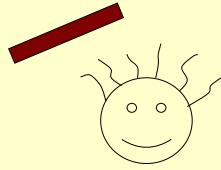
What was not understood around 1700?

- What is ordinary matter around us?
 - Made up of particles? Atoms?
- What is light?
 - Newton viewed light as particles?
 - Huygens, others said light acts as waves.
- What is the source of energy for the sun?
- What is electricity, magnetism?
- Other?

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Electrical Forces

- Known long ago in Greece
 - "Electret" (like rod rubbed with fur) causes forces known in ancient Greece
 - "Electron" is word invented in ancient Greece



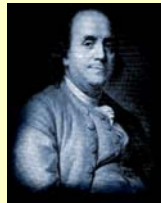
- Studied by scientists with new approaches (scientific method; Newton's laws; concept of fundamental forces) starting in the 1700's

Metals and Insulators

- Two types of materials
 - Metals conduct electricity
 - Electric charge moves through material
 - Examples: Copper, Gold
 - Insulators do not conduct electricity
 - Electric charges stay can be induced by contact friction, but do not move through material unless there is "breakdown" that leads to sparks and lightening.
 - Examples: Glass rod, Rubber, paper, air
- Known long ago in Greece

Benjamin Franklin 1706 - 1790

- Regarded as the **First Great American Scientist**
- 10th of 17 children, Left school at age of 10
Learned Craft of Publishing as apprentice
- Became **Businessman, Author, Inventor, Scientist, Statesman**
 - Discoveries on electricity were in advance of European Scientists.
 - Famous kite experiments established electrical nature of lightening
 - Invented "Lightening Rod" at time when Europe had medieval view of lightening - rang church bells to ward off lightening
- Statesman representing the Colonies and the United States in Europe

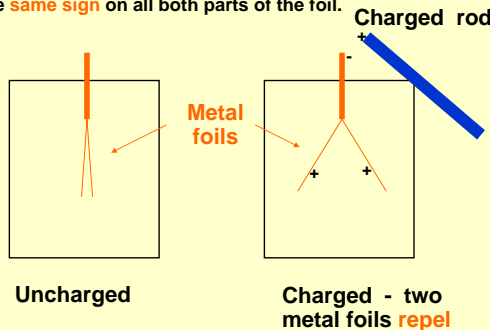


Electrostatics

- A kind of force. Does it fit in the Newtonian picture?
 - Charge electroscope with rubber rod which has been rubbed with fur. Gold leaves separate.
 - Bring same rubber rod close to top of electroscope. observe leaves separate further.
 - Bring glass rod (rubbed with silk) close to top of electroscope. observe leaves approach each other.
 - Now repeat experiment, but charge with glass rod. Gold leaves still separate.
 - Now rubber rod causes leaves to approach each other.
 - Glass rod causes leaves to separate.
- Similar Experiments with insulating "Pith Balls"
- Explanation?
 - There exist two kinds of charge. (Ben Franklin, 1751)
 - Unlike charges attract Like charges repel

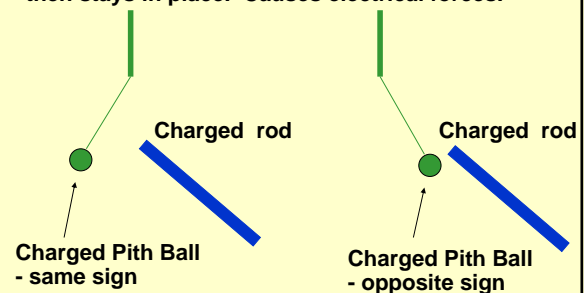
Forces between Charges - Demo

- Charge moves in a metal. Like charge repelled. Makes charge of the same sign on all both parts of the foil.



Forces between Charges - Demo

- Charge can be transferred between insulators and then stays in place. Causes electrical forces.



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Forces between Charges

- How do we describe these forces within Newtonian system?
- Need expression for **forces** in terms of the **positions** of charges

- **Forces Law Coulomb (1785) Inverse square law:**

$$F = K q_1 q_2 / R^2 \quad q_1, q_2 = \text{charge (plus or minus)}$$

Like gravity, except electric force can be **attractive** or **repulsive**

Forces between Charges

- Electrostatic forces **MUCH** stronger than gravity:

- **Electrostatic:** $F_E = K q_1 q_2 / R^2$

- **Gravity:** $F_G = G m_1 m_2 / R^2$

- In meter- Kg - second system:

$$K = 9.0 \times 10^9 \quad G = 6.67 \times 10^{-11}$$

- **Force between two protons** at distance of 1 m:

$$\text{Charge} = 1.6 \times 10^{-19} \text{ Coulomb}$$

$$\text{Mass} = 1.6 \times 10^{-27} \text{ Kg}$$

$$F_E = 2.3 \times 10^{-28} \text{ Newtons}; F_G = 1.8 \times 10^{-64} \text{ Newtons}$$

Factor of 10^{36}

How can Gravitational Forces ever be important?

- **Electrostatic forces are zero** between two **neutral** objects (equal amounts of positive and negative)
- **Gravitational forces** always have the same sign (attractive) and **never cancel out**
- **Force between sun and earth** (both nearly neutral) is mainly gravitational

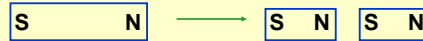
Magnetic Forces

- **Yet another kind of force**

- Known since prehistory – lodestone compasses used in China thousands of years ago
- Bar Magnets: Two poles (North & South)
- Force description: **Like poles repel; Unlike poles attract.**

- **Explanation?**

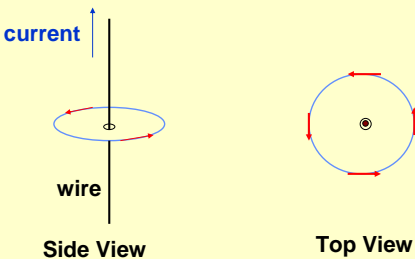
- Is there a magnetic charge (analogous to electric charge) ?
- Try to isolate the charges: cut the magnet in half:



- In fact, **no experiment to date** (and there have been many attempts) has shown evidence for the existence of magnetic charge. We believe the source of the magnetic force is not a new kind of charge, but is due to **motion of electric charge**.

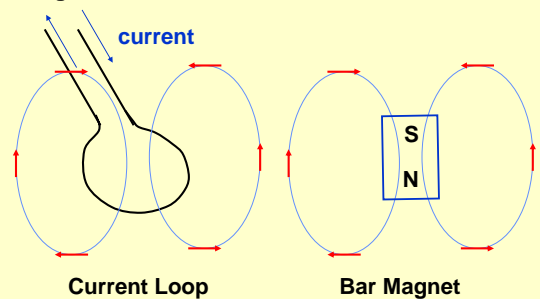
Magnetic Forces due to Electric Current

- Current is charges in motion
- Causes force on magnet
- Example: **Compass** near wire with current



Magnetic Forces due to Electric Current Loop

- Current in a loop causes magnetic forces just like a magnet

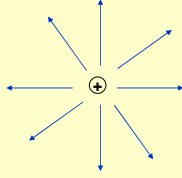


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The Field Concept

- **Michael Faraday** (1791 - 1867) had the idea that forces between bodies were caused by **Fields that fill all space and act on the bodies**

- **Electric Field E** due to positive charge



- **Faraday** (building upon Ampere's work) discovered the **interdependence of Electric & Magnetic Fields**:

- A moving or changing electric field generates a magnetic field and a moving or changing magnetic field generates an electric field.

The Field Concept (continued)

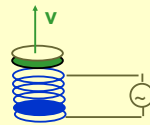
- **Electric and Magnetic Fields** at a given point in space determine the force on a "test" electric charge if it were placed at that point in space.
- **Electric field E** causes **force $F = qE$** ($q = \text{charge}$)
- **Magnetic field B** causes **force $F = qvB$** on charge moving with **speed v** perpendicular to **B**

This "harmless" equation has the **seeds of trouble** for the Newtonian picture!

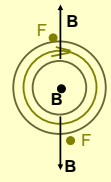
- Magnetic force depends on the **speed** of the particle.
- Force is meant to be an **absolute quantity**. The laws of physics are supposed to be the same for two different observers (people or instruments) even if they are moving at constant v with respect to one another --- **Remember Galileo, Newton!**
- But **speed is not the same** to the different observers! What is going on? Will this lead to a breakdown of the ideas of **Galileo and Newton**?

Demo E-M Cannon

- Connect solenoid to a source of alternating voltage. The flux through the area \perp to axis of solenoid therefore changes in time. A conducting ring placed on top of the solenoid will have a current induced in it opposing this change. There will then be a force on the ring since it contains a current which is circulating in the presence of a magnetic field.



side view



top view

- **Fields are real!**

Summary

- **New Forces and ideas** in the Newtonian World!

- **Electric Charge:**

- **Property of particles... Determines new Coulomb Force: $F = K q_1 q_2 / R^2$**

- **Fields – new idea in Newtonian physics:**

- **Extend through space**

- **Electric Fields: created by electric charges**

- **Magnetic Fields: created by electric charges in motion**

- **Principles used in electric generators,**

- **Electric Fields and Magnetic Fields are not independent of each other.** A changing magnetic field generates an electric field and a changing electric field generates a magnetic field. **Maxwell realized the full significance of this interrelationship** --- next time.