الجامعة اللبنانية الأميركية
Lebanese American University

FALL 2013

# PHY 201

# Electricity and Magnetism

Dr. J. Romanos

# SYLLABUS

## LAU BYBLOS CAMPUS

*Office:* ***BA 403D***

*Office Hours:* ***MWF (10:30 am – 12:30 pm) or by appointment***

## LAU BEIRUT CAMPUS

*Office:* ***Nicol Hall 308C***

*Office Hours:* ***Tu-Th (11 am – 1 pm) or by appointment***

A student completing this course should be able to:

a) Grab the physical and mathematical aspects of the material covered in the course.

b) Develop skills and use techniques for solving problems addressed in the course.

c) Acquire Scientific and intellectual abilities to think critically about physical systems that surround us.

# COURSE GRADING AND PERFORMANCE CRITERIA

| | |
|---|---|
| The first exam will cover chapter 21-25 | 20% of the total grade |
| The second exam cover chapter 26-30 | 20% of the total grade |
| Final exam will consider whole material | 30% of the total grade |
| The lab work (report, attendance) | 20% of the total grade |
| Homework (2-4 problems for each chapter) | 10% of the total grade |

- The final grading will take 10 out of the total 13 homework.
- Homework will be collected, but not graded. You will receive points for attempting to do the homework.

## TEXTBOOK

Principles of Physics.by Halliday/ Resnick/ Jearl Walker,(Wiley 9th Edition).

# BEIRUT SECTION

**Mainly, every week one chapter will be introduced in the order shown in the following table (tentative schedule).**

| LECTURE | DATE | CHAPTERS |
|---|---|---|
| 1,2 | SEP 24, 26 | Chapter 21: Electric Charge |
| 3,4 | OCT 1,3 | Chapter 22: Electric Fields |
| 5,6 | OCT 8,10 | Chapter 23: Gauss' Law |
| 7,8 | OCT 17,22,24 | Chapter 24: Electric Potential |
| 9,10 | OCT 29, 31 | Chapter 25: Capacitance |
| EXAM I (Chapter 21-25) | | |
| 11,12 | NOV 5,7 | Chapter 26: Current and Resistance |
| 13,14 | NOV 12,14 | Chapter 27: Circuits |
| 15,16 | NOV 19,21 | Chapter 28: Magnetic Fields |
| 17,18 | NOV 26,28 | Chapter 29: Magnetic Fields Due to Current |
| 19,20 | DEC 3,5 | Chapter 30: Induction and Inductance |
| EXAM II (Chapter 26-30) | | |
| 20,21 | DEC10, 12 | Chapter 31: Electromagnetic Oscillations and Alternating Current |
| 22,23 | DEC 17,19 | Chapter 32: Maxwell's Equations |
| 24,26 | JAN 7, 9, 14,16,21 | Chapter 33-34: Electromagnetic Waves - Images |
| FINAL EXAM (Chapter 21-34) | | |

# BYBLOS SECTION

**Mainly, every week one chapter will be introduced in the order shown in the following table (tentative schedule).**

| LECTURE | DATE | CHAPTERS |
|---|---|---|
| 1,2,3 | SEP 23,25,27 | Chapter 21: Electric Charge |
| 4,5,6 | SEP 30, OCT 2,4 | Chapter 22: Electric Fields |
| 7,8,9 | OCT 7,9,11 | Chapter 23: Gauss' Law |
| 10,11,12,13 | OCT 16,18,21,23 | Chapter 24: Electric Potential |
| 14,15,16 | OCT 25,28,30 | Chapter 25: Capacitance |
| EXAM I (Chapter 21-25) | | |
| 17,18,19 | NOV 1,6,8 | Chapter 26: Current and Resistance |
| 20,21 | NOV 11,15 | Chapter 27: Circuits |
| 22,23 | NOV 18,20 | Chapter 28: Magnetic Fields |
| 24,25,26 | NOV 25,27,29 | Chapter 29: Magnetic Fields Due to Current |
| 27,28,29 | DEC 2,4,6 | Chapter 30: Induction and Inductance |
| EXAM II (Chapter 26-30) | | |
| 30,31,32 | DEC 9,11,13 | Chapter 31: Electromagnetic Oscillations and Alternating Current |
| 33,34,35,36 | DEC 16,18,20, 23 | Chapter 32: Maxwell's Equations |
| 37,38,39,40,41 | JAN 8,10,15,17,20 | Chapter 33-34: Electromagnetic Waves - Images |
| FINAL EXAM (Chapter 21-34) | | |

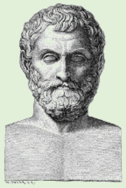
CHAPTER 21

# Electric Charge

# Brief History: Electric Charge

**600 BC**

Ancient Greek philosopher Thales of Miletus reported the attractive properties of amber when rubbed



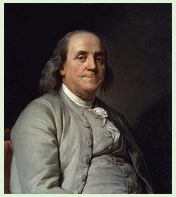
Thales of Miletus

**17th Century**

1675 AD, Robert Boyle: Electric attraction and repulsion in vacuum

**18th Century**

1729 AD, Stephen Gray: Materials are classified as conductors and insulators
1733 AD, du Fay: Two distinct types of electricity
1750 AD, Benjamin Franklin: positive and negative label
1770 AD, Coulomb: Inverse Square Law

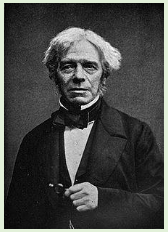


B. Franklin

Coulomb

**19th Century**

1839 AD, Michael Faraday: Electricity with different polarities
1890 AD J.J. Thompson: Quantization of electric charge



Faraday

# System of Units

We will use the SI system – SI ≡ International System of Units

## Fundamental Quantities

Length ➔ meter [m]
Mass ➔ kilogram [kg]
Time ➔ second [s]

## Other Units

Current ➔ ampere [A]

## Derived Quantities

| | | |
|---|---|---|
| Force ➔ | newton | $1\ N = 1\ kg\ m / s^2$ |
| Energy ➔ | joule | $1\ J = 1\ N\ m$ |
| Charge ➔ | coulomb | $1\ C = 1\ A\ s$ |
| Electric Potential ➔ | volt | $1\ V = 1\ J / C$ |
| Resistance ➔ | ohm | $1\ \Omega = 1\ V / A$ |

# Learning Objectives

**21.01** Distinguish between being electrically neutral, negatively charged, and positively charged and identify excess charge.

**21.02** Distinguish between conductors, nonconductors (insulators), semiconductors, and superconductors.

21.03 Describe the electrical properties of the particles inside an atom.

**21.04** Identify conduction electrons and explain their role in making a conducting object negatively or positively charged.

**21.05** Identify what is meant by "electrically isolated" and by "grounding."

**21.06** Explain how a charged object can set up induced charge in a second object.

**21.07** Identify that charges with the same electrical sign repel each other and those with opposite electrical signs attract each other.

# Learning Objectives

**21.08** For either of the particles in a pair of charged particles, draw a free-body diagram, showing the electrostatic force (Coulomb force) on it and anchoring the tail of the force vector on that particle.

**21.09** For either of the particles in a pair of charged particles, apply Coulomb's law to relate the magnitude of the electro- static force, the charge magnitudes of the particles, and the separation between the particles.

**21.10** Identify that Coulomb's law applies only to (point-like) particles and objects that can be treated as particles.

**21.11** If more than one force acts on a particle, find the net force by adding all the forces as vectors, not scalars.

**21.12** Identify that a shell of uniform charge attracts or repels a charged particle that is outside the shell as if all the shell's charge were concentrated as a particle at the shell's center.

# Learning Objectives

**21.13** Identify that if a charged particle is located inside a shell of uniform charge, there is no net electrostatic force on the particle from the shell.

**21.14** Identify that if excess charge is put on a spherical conductor, it spreads out uniformly over the external surface area.

**21.15** Identify that if two identical spherical conductors touch or are connected by conducting wire, any excess charge will be shared equally.

**21.16** Identify that a non-conducting object can have any given distribution of charge, including charge at interior points.

**21.17** Identify current as the rate at which charge moves through a point.

**21.18** For current through a point, apply the relationship between the current, a time interval, and the amount of charge that moves through the point in that time interval.

# Learning Objectives

**21.19** Identify the elementary charge.

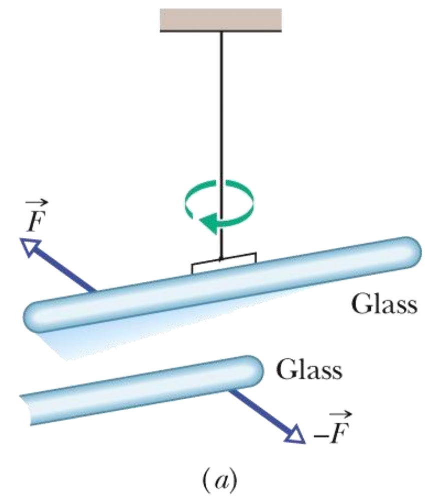
**21.20** Identify that the charge of a particle or object must be a positive or negative integer times the elementary charge.

# Learning Objectives

**21.21** Identify that in any isolated physical process, the net charge cannot change (the net charge is always conserved).

**21.22** Identify an annihilation process of particles and a pair production of particles.

**21.23** Identify mass number and atomic number in terms of the number of protons, neutrons, and electrons.

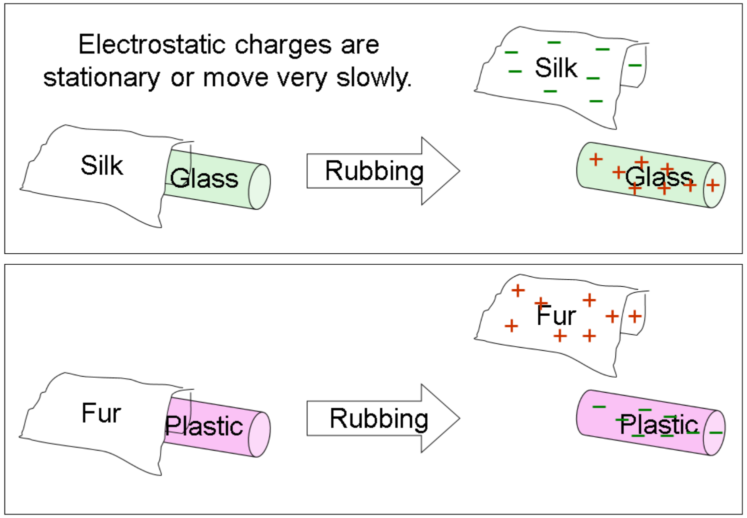





(a) The two glass rods were each rubbed with a silk cloth and one was suspended by thread. When they are close to each other, they repel each other.

(a) The plastic rod was rubbed with fur. When brought close to the glass rod, the rods attract each other.

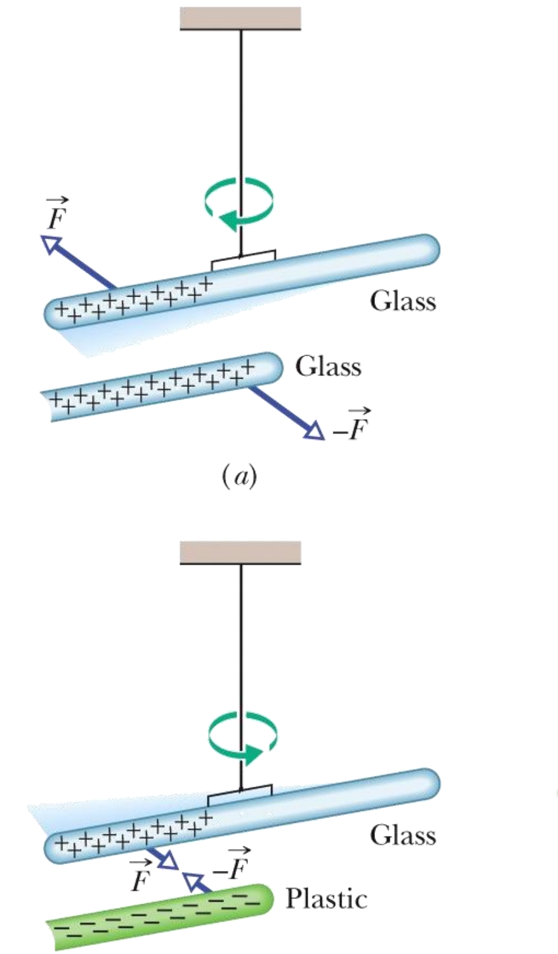
**Charging by rubbing**




**Glass rubbed with silk cloth: glass + and silk -**

**Plastic rubbed with fur: plastic - and fur +**

# Electric Charge






(a) Two charged rods of the same sign repel each other.

(b) Two charged rods of opposite signs attract each other. Plus signs indicate a positive net charge, and minus signs indicate a negative net charge.

Particles with the same sign of electrical charge repel each other, and particles with opposite signs attract each other.

# Materials classified based on their ability to move charge

- **Conductors** are materials in which a significant number of electrons are free to move. Examples include metals.
- The charged particles in nonconductors (**insulators**) are not free to move. Examples include rubber, plastic, glass.
- **Semiconductors** are materials that are intermediate between conductors and insulators; examples include silicon and germanium in computer chips.
- **Superconductors** are materials that are perfect conductors, allowing charge to move without any hindrance.

- **Charged Particles.** The properties of conductors and insulators are due to the structure and electrical nature of atoms. Atoms consist of positively charged *protons*, negatively charged *electrons*, and electrically neutral *neutrons*. The protons and neutrons are packed tightly together in a central nucleus and do not move.

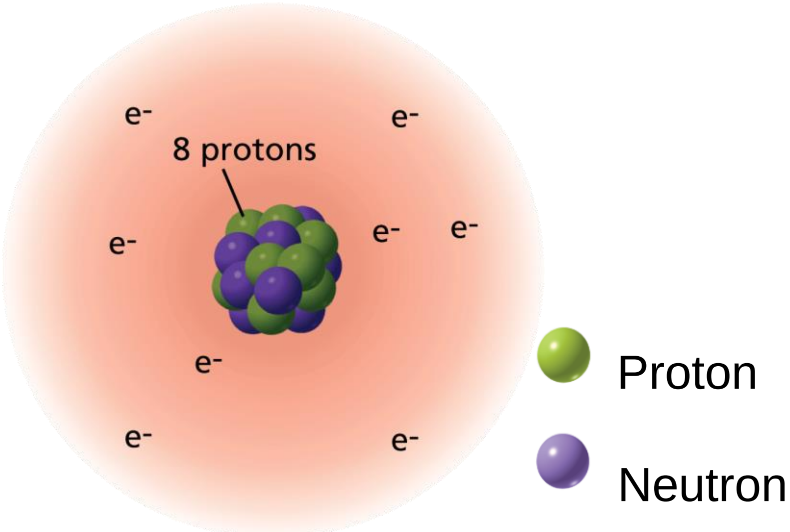



**Table 21-1 The Charges of Three Particles**

| Particle | Symbol | Charge |
| --- | --- | --- |
| Electron | e or $e^-$ | $-e$ |
| Proton | p | $+e$ |
| Neutron | n | 0 |

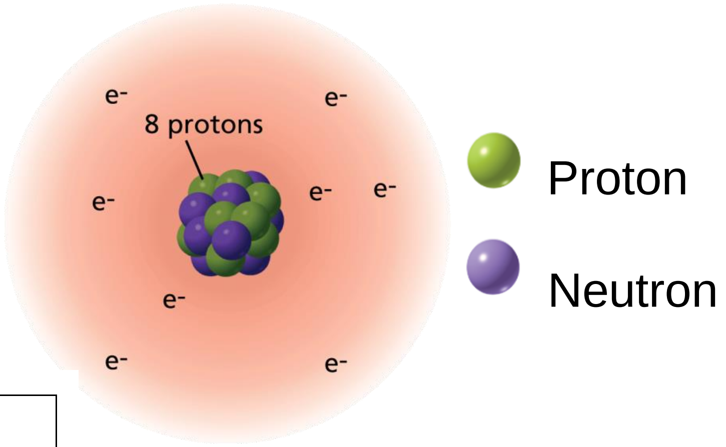


A neutral atom has equal numbers of protons and electrons.

$$^{A}_{Z}\mathrm{X}$$

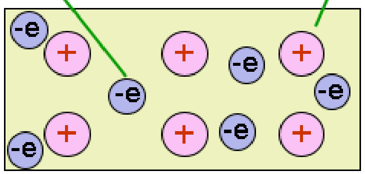
Z: Atomic number (number of protons)
N: Number of neutrons
A: Mass number (A = Z + N)
For neutral atoms, Z is also the number of electrons

- A neutral atom has equal numbers of protons and electrons
- An atom becomes a **positive ion** when it loses electrons and a **negative ion** when it gains electrons




Electrons can move freely

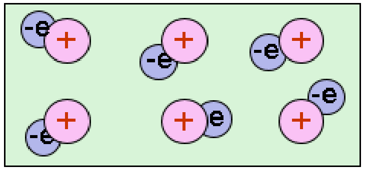
Ions are fixed (solid) or move very slowly (liquid)




Conductors

metals
human body
tap water

Electrons held to ions and cannot move freely



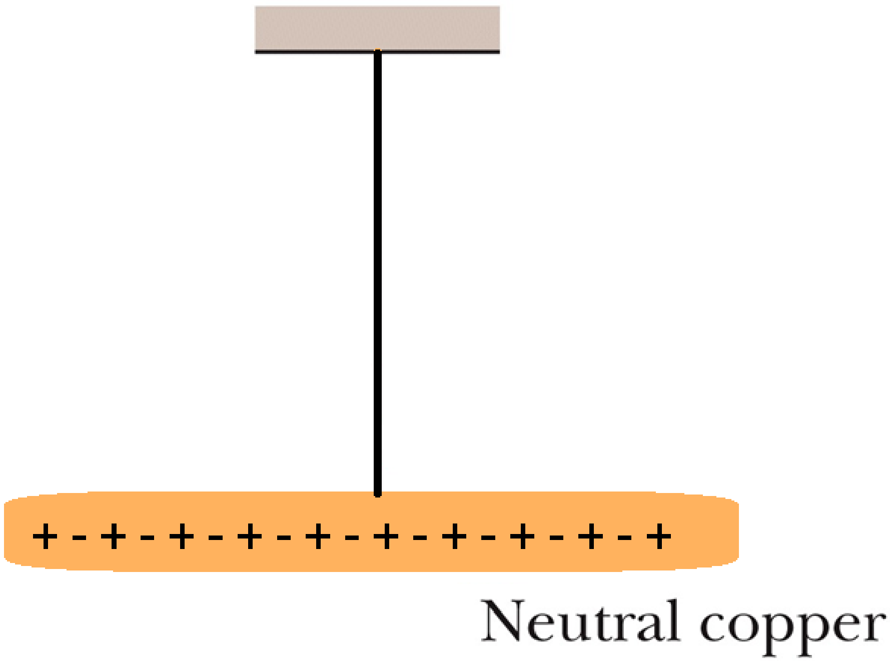

Insulators

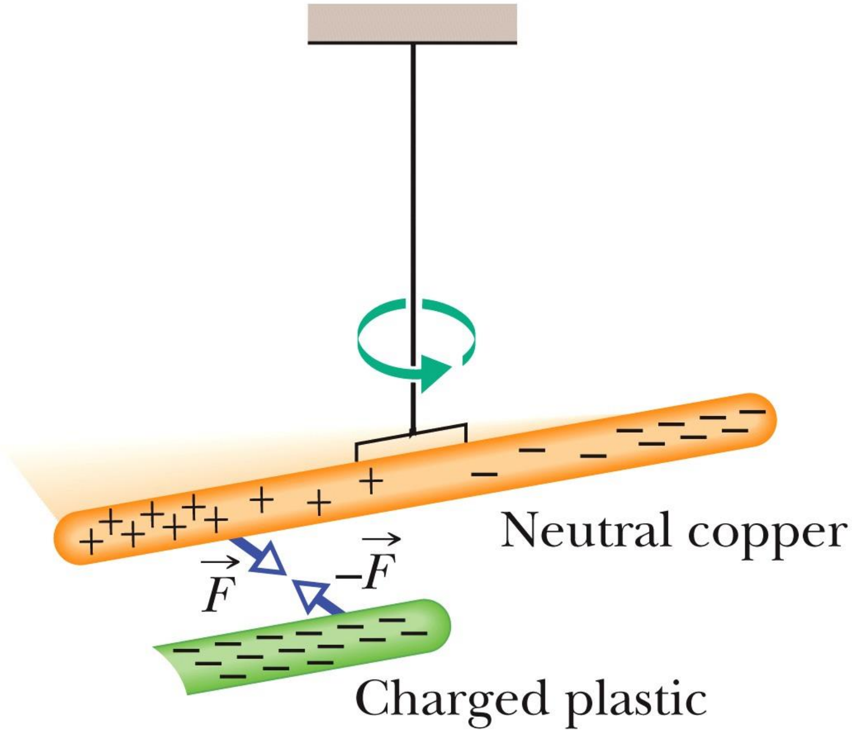
glass
plastic
pure water

- For **conductors**, outermost electrons are loosely held by nucleus
- For **insulators**, outermost electrons are tightly held by nucleus

# Conduction Electrons

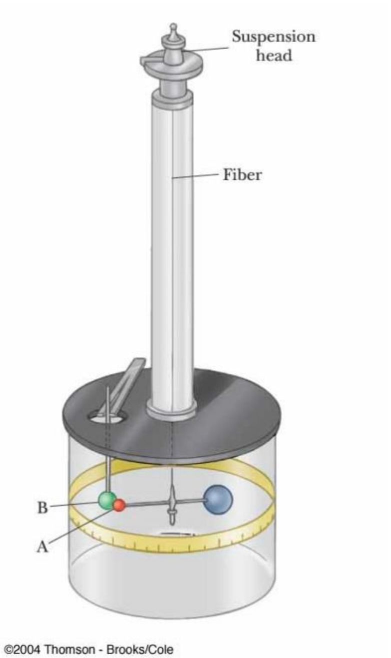
- When atoms of a conductor like copper come together to form the solid, some of their outermost—and so most loosely held—electrons become free to wander about within the solid, leaving behind positively charged atoms ( positive ions).
- We call the mobile electrons **conduction electrons**. There are few (if any) free electrons in a nonconductor.
- Only conduction electrons can move

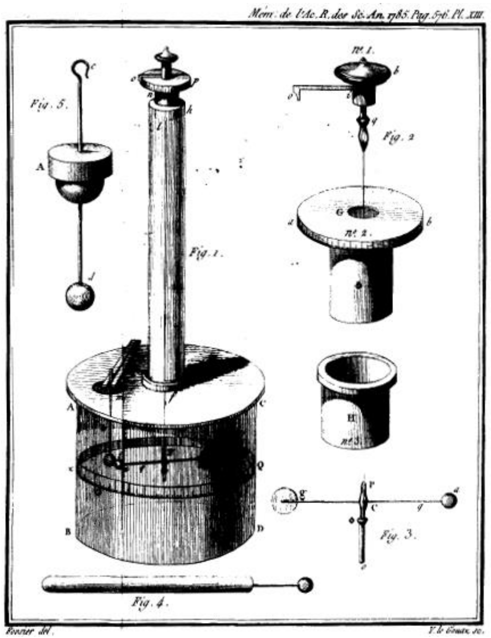



**Induced Charge.** A neutral copper rod is electrically isolated from its surroundings by being suspended on a non-conducting thread. Either end of the copper rod will be attracted by a charged rod. Here, conduction electrons in the copper rod are repelled to the far end of that rod by the negative charge on the plastic rod. Then that negative charge attracts the remaining positive charge on the near end of the copper rod, rotating the copper rod to bring that near end closer to the plastic rod.

# Coulomb's law



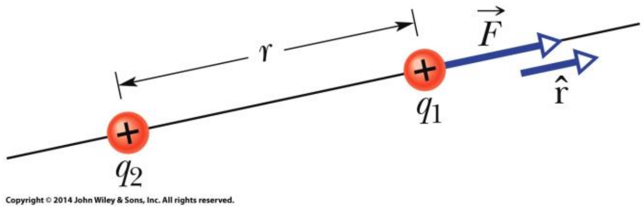
- Charles Coulomb measured the magnitudes of electric forces between two small charged spheres
- He found the force depended on the charges and the distance between them

$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$$

# Coulomb's law

Coulomb's law describes the **electrostatic force** (or electric force) between two charged particles. If the particles have charges $q_1$ and $q_2$, are separated by distance $r$, and are at rest (or moving only slowly) relative to each other, then the magnitude of the force acting on each due to the other is given by

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1|\,|q_2|}{r^2} \quad \text{(Coulomb's law)},$$

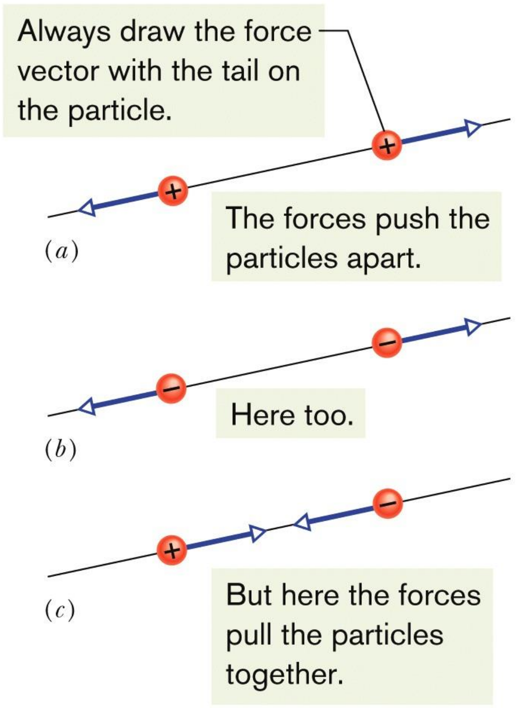



The electrostatic force on particle 1 can be described in terms of a unit vector ***r*** along an axis through the two particles, radially away from particle 2.

where $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/N.m^2$ is the permittivity constant. The ratio $1/4\pi\varepsilon_0$ is often replaced with the electrostatic constant (or Coulomb constant) $k = 8.99 \times 10^9\ N.m^2/C^2$. Thus k = $1/4\pi\varepsilon_0$.

- The electrostatic force vector acting on a charged particle due to a second charged particle is either directly toward the second particle (opposite signs of charge) or directly away from it (same sign of charge).

- If multiple electrostatic forces act on a particle, the net force is the vector sum (not scalar sum) of the individual forces.






Two charged particles repel each other if they have the same sign of charge, either (a) both positive or (b) both negative. (c) They attract each other if they have opposite signs of charge.

# Units

- Electric charge is measured in **Coulomb**
- Current is the rate at which charge moves past a point or through a region

$$i = \frac{dq}{dt} \qquad \text{(chapter 26)}$$

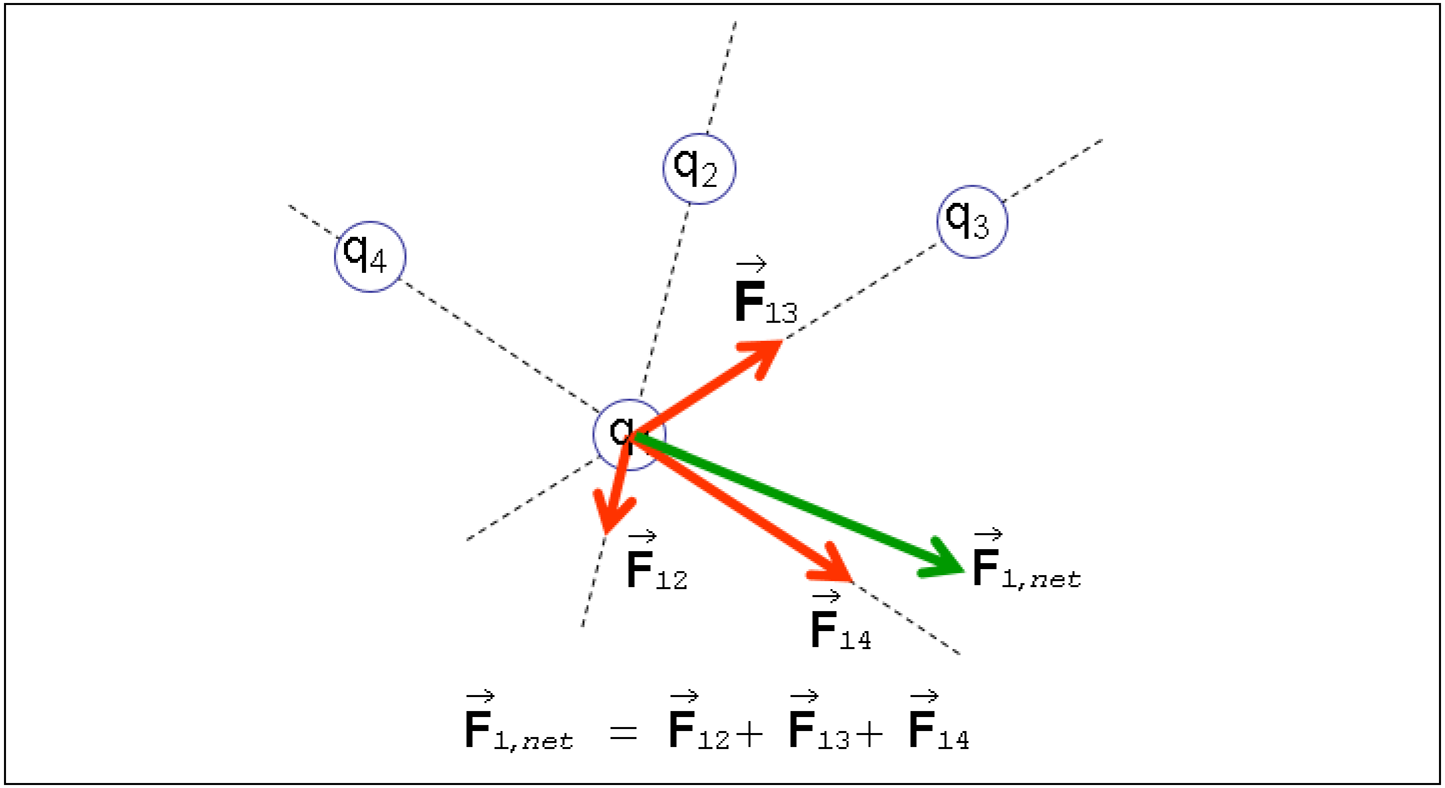
$i: current\ (in\ amperes)$

$dq: amount\ of\ charge\ (in\ coulomb)\ moving\ in\ time\ dt$

1 C = (1A) (1s)

**Multiple Forces:** If multiple electrostatic forces act on a particle, the net force is the vector sum (not scalar sum) of the individual forces.

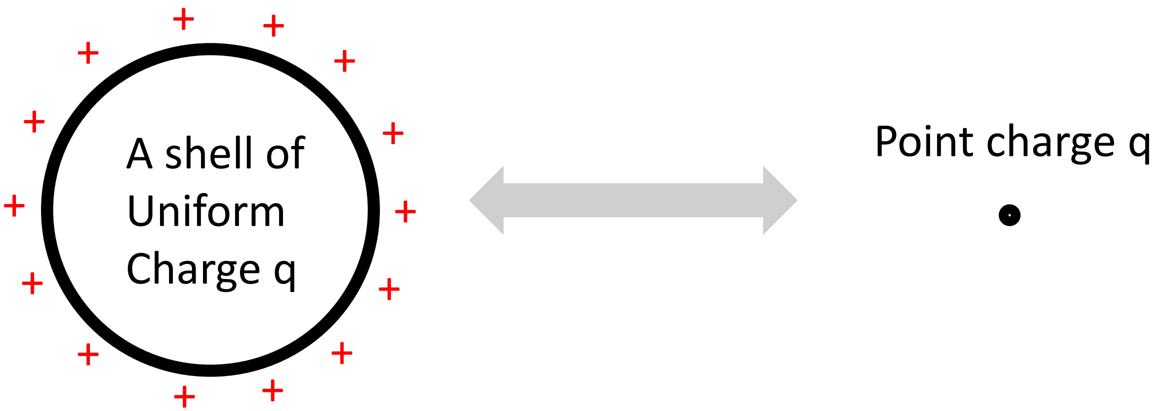
$$\vec{F}_{1,\text{net}} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \vec{F}_{15} + \cdots + \vec{F}_{1n},$$



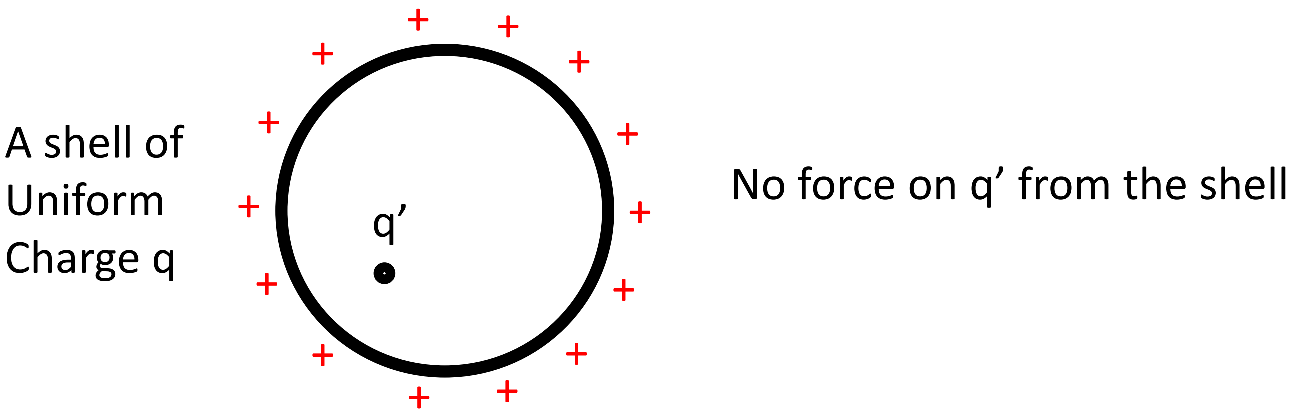

**Principle of superposition**: the net force acting on any particle is the **vector** sum of the forces acting on this particle due to individual particles

**Shell Theories:** There are two shell theories for electrostatic force

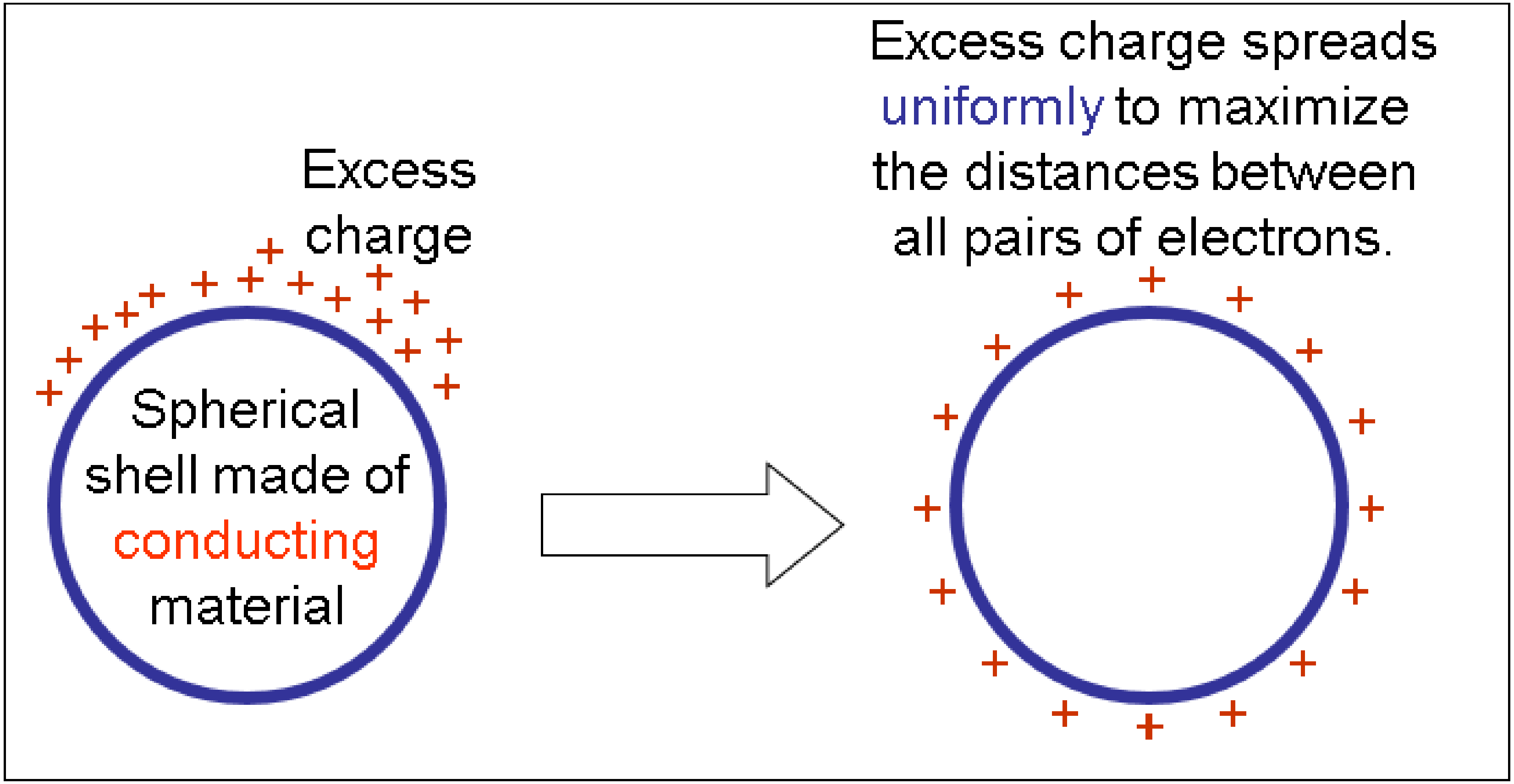
Shell theory 1. A charged particle outside a shell with charge uniformly distributed on its surface is attracted or repelled as if the shell's charge were concentrated as a particle at its center.




Shell theory 2. A charged particle inside a shell with charge uniformly distributed on its surface has no net force acting on it due to the shell.



**Shell Theories:** There are two shell theories for electrostatic force




If excess charge is placed on a spherical shell that is made of a conducting material, the excess charge spreads uniformly over the surface.

# 21-2 Charge is Quantized

- Electric charge is measured in **Coulomb**

- The smallest charge you can find is $e = 1.602 \times 10^{-19}$ C.

- Electric charge is quantized (restricted to certain values). All other charges are multiple of this charge.

- The charge of a particle can be written as ne, where *n* is a positive or negative integer and *e* is the elementary charge. Any positive or negative charge *q* that can be detected can be written as

$$q = ne, \qquad n = \pm 1, \pm 2, \pm 3, \ldots,$$

in which *e*, the elementary charge, has the approximate value

$$e = 1.602 \times 10^{-19}\ \mathrm{C}.$$

**Table 21-1 The Charges of Three Particles**

| Particle | Symbol | Charge |
|---|---|---|
| Electron | e or $e^-$ | $-e$ |
| Proton | p | $+e$ |
| Neutron | n | 0 |

## **21-2** Charge is Quantized

- When a physical quantity such as charge can have only discrete values rather than any value, we say that the quantity is **quantized**.

- It is possible, for example, to find a particle that has no charge at all or a charge of *+10e* or *-6e*,

- Charge of *3.57e* is not possible

# 21-3 Charge is Conserved

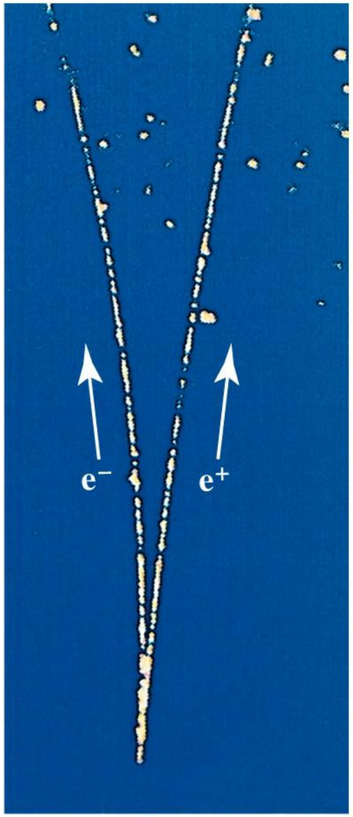
The net electric charge of any isolated system is always conserved.

If two charged particles undergo an annihilation process, they have equal and opposite signs of charge.

$$e^- + e^+ \rightarrow \gamma + \gamma$$

If two charged particles appear as a result of a pair production process, they have equal and opposite signs of charge.

$$\gamma \rightarrow e^- + e^+$$



Courtesy Lawrence Berkeley Laboratory

A photograph of trails of bubbles left in a bubble chamber by an electron and a positron. The pair of particles was produced by a gamma ray that entered the chamber directly from the bottom. Being electrically neutral, the gamma ray did not generate a telltale trail of bubbles along its path, as the electron and positron did.

# 21 Summary

## Electric Charge

- The strength of a particle's electrical interaction with objects around it depends on its electric charge, which can be either positive or negative.

## Conductors and Insulators

- Conductors are materials in which a significant number of electrons are free to move. The charged particles in nonconductors (insulators) are not free to move.

## Conservation of Charge

- The net electric charge of any isolated system is always conserved.

## Coulomb's Law

- The magnitude of the electrical force between two charged particles is proportional to the product of their charges and inversely proportional to the square of their separation distance.
- .

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1|\,|q_2|}{r^2}$$ **Eq. 21-4**

$$e = 1.602 \times 10^{-19}\,\mathrm{C}.$$ **Eq. 21-12**