Electric Charge

Chapter 21

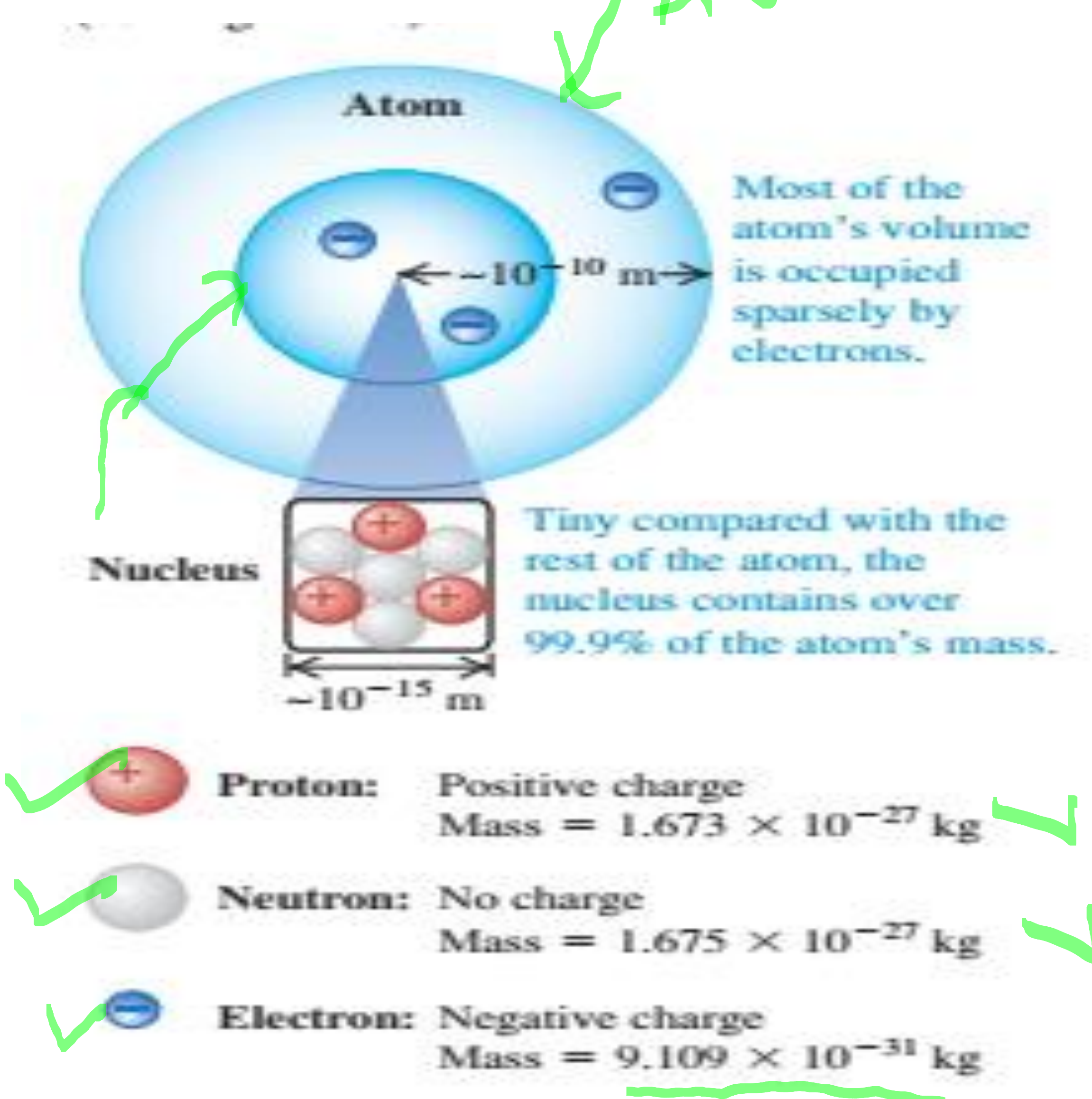
Major Topics of Chapter 21

- What holds our world together?
- Electric Charge
- Conductors & Insulators
- Coulomb's Law

↳ Several Examples

Structure of Atom

Atom



Moon-Earth Facts

Mass of Earth 5.9736 x 10^{24} kg

Mass of Moon
7.349 x 10^{22} kg

Inter-distance 384,401 Km on average

G ≈ 6.674 x 10^{-11} $N(m/kg)^2$

Charge and Mass of the Electron, Proton, and Neutron

Particle	Charge (C)	Mass(Kg)
Electron (e)	$-1.6021917 \times 10^{-19}$	9.1095×10^{-31}
Proton (p)	$+1.6021917 \times 10^{-19}$	1.67261×10^{-27}
Neutron (n)	0	1.67492×10^{-27}

Electrostatics

- Electrostatics emphasizes that, relative to each other, the charges are either stationary or moving only very slowly

− +

point charges

Electromagnetism

- Electric Charges
- Electric Field
- Gauss's Law

ELECTROSTATICS

Forces

- By the early 19th century, physicists had classified the apparent myriad of forces in nature to just 3 kinds:
  - ***Gravitational*** force
  - ***Electric*** force
  - ***Magnetic*** force

By the end of 19th century

Electromagnetic Force

Forces

- By the end of the 19th century, they had narrowed the list to just 2 forces:
  - *Gravitational* force
  - *Electromagnetic* force
  - Weak force
  - Strong Force

20th Century
4 forces

Forces

- The 20th century first added two new forces to this list that are observed only inside the atomic nucleus:
  - *Gravitational* force
  - *Electromagnetic* force
  - *Weak* force
  - *Strong* force

Electric Force?

Coulomb's

The Electric Force

− +

F_e

- We will turn our attention to the ***electric force***, which is a force between objects with ***charge***, just as the gravitational force is a force between objects with mass.

F_g

m_1 m_2

Electrostatics

- ***Electrostatics*** is the study of ***electric charge at rest***.
  - (Or more or less at rest, in contrast with current electricity.)

Electrical Charges

- ***Electric charge*** is a ***fundamental property*** of matter.
  - ***Two types*** of electric charges
    - ***Positive*** charge - every proton has a single positive charge.
    - ***Negative*** charge - every electron has a single negative charge.

Electrical Charge

- An object with an ***excess of electrons*** is ***negatively charged***.
- An object with ***too few electrons*** (too many protons) is ***positively charged***.
- An object with the ***same number*** of electrons and protons is ***neutral***.

Electrical Forces

- ***Like*** charges ***repel***.
- ***Opposite*** charges ***attract***.

Elementary Charges

- ***Protons*** carry the smallest positive charge.
- Protons and uncharged neutrons generally reside in an atom's ***nucleus***.
- Protons are held in the nucleus by the ***strong force***.

· Electrons → weak force

Elementary Charges

- The smallest negative charge is the charge on the ***electron***.
- In normal atoms, electrons orbit the nucleus.
- The ***electric force*** between electrons and protons supplies the centripetal force to keep electrons in the atom.

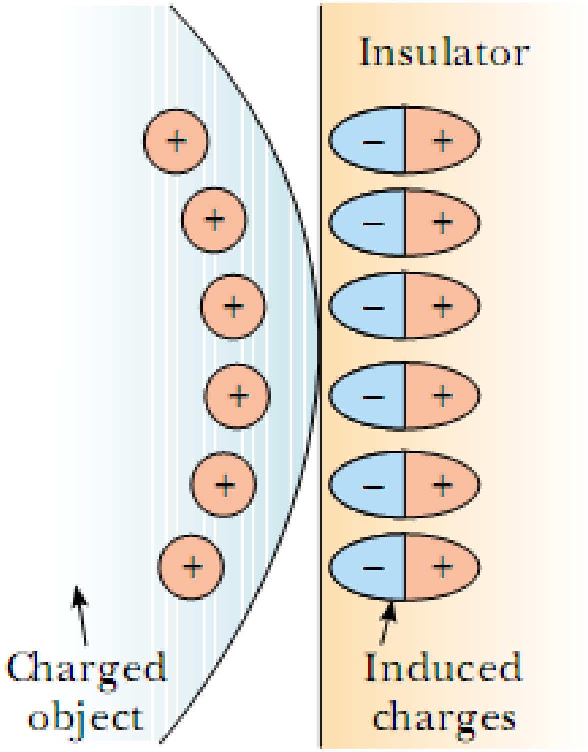
Elementary Charges

- The ***charges*** carried by the proton and electron are ***equal in size***.
- The ***mass*** of the proton is about ***2000 times*** the mass of the electron.

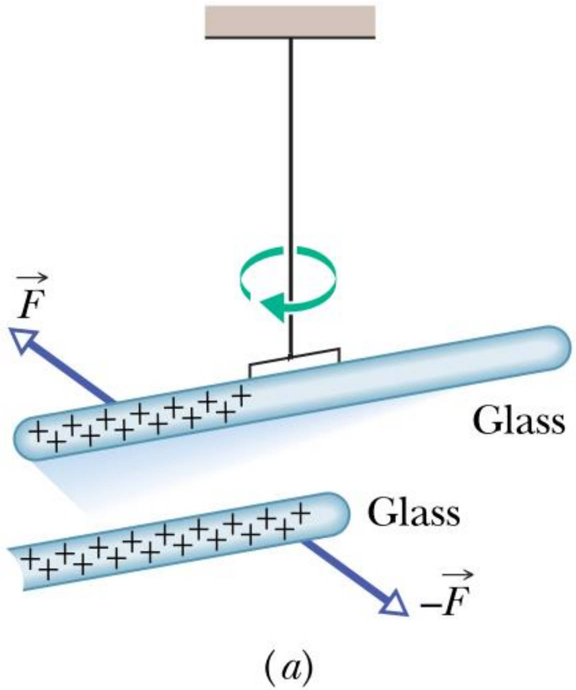
Benjamin Franklin

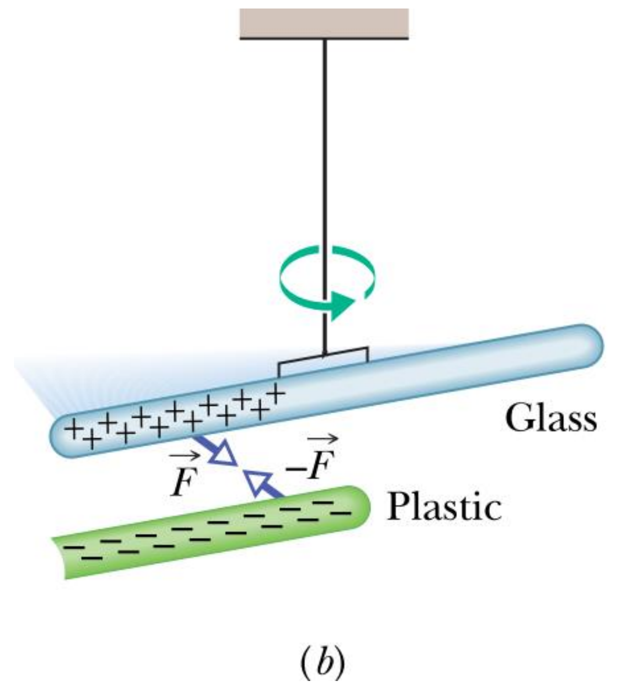
- American *all-rounder* (1706 – 1790)
- A leading author, printer, political theorist, politician, postmaster, scientist, musician, inventor, satirist, civic activist, statesman, and diplomat
- Invented the lightning rod, bifocals, the Franklin stove, a carriage odometer, and the glass harmonica
- In the field of Electrostatics
  - Labeled the charges as positive & negative
  - Principle of conservation of charge

Static Cling – Charged and Neutral Body



Charged Bodies & Their Interaction





Two charged rods of the same sign repel each other

Two charged rods of opposite signs attract each other

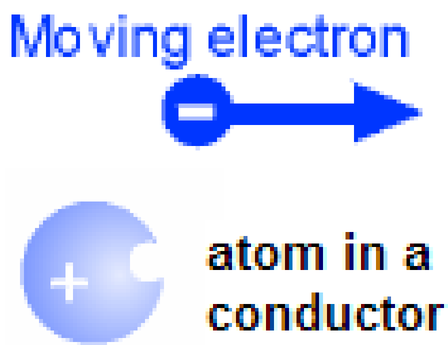
Plus signs indicate a positive net charge, and minus signs indicate a negative net charge

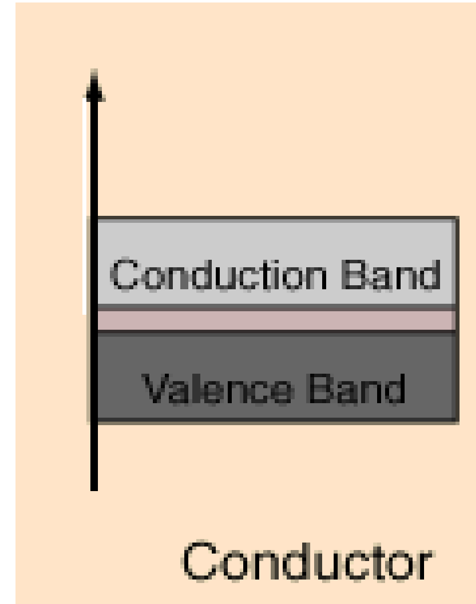
Conductors and Insulators

- **Conductors** are materials through which charge can move rather freely; *examples include metals (such as copper in common lamp wire), the human body, and tap water*
- **Nonconductors** — also called **insulators** — are materials through which charge cannot move freely; *examples include rubber (such as the insulation on common lamp wire), plastic, glass, and chemically pure water*
- **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; *examples include Niobium-Tin, and Lanthanum-Barium-Copper Oxide*

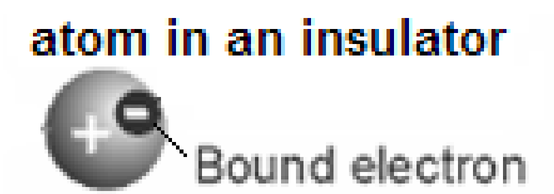
Conductors and insulators

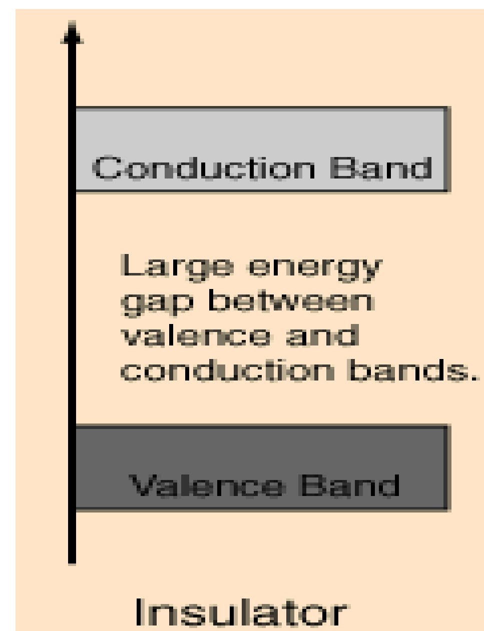
- All materials contain electrons.
- The electrons are what carry the current in a conductor.



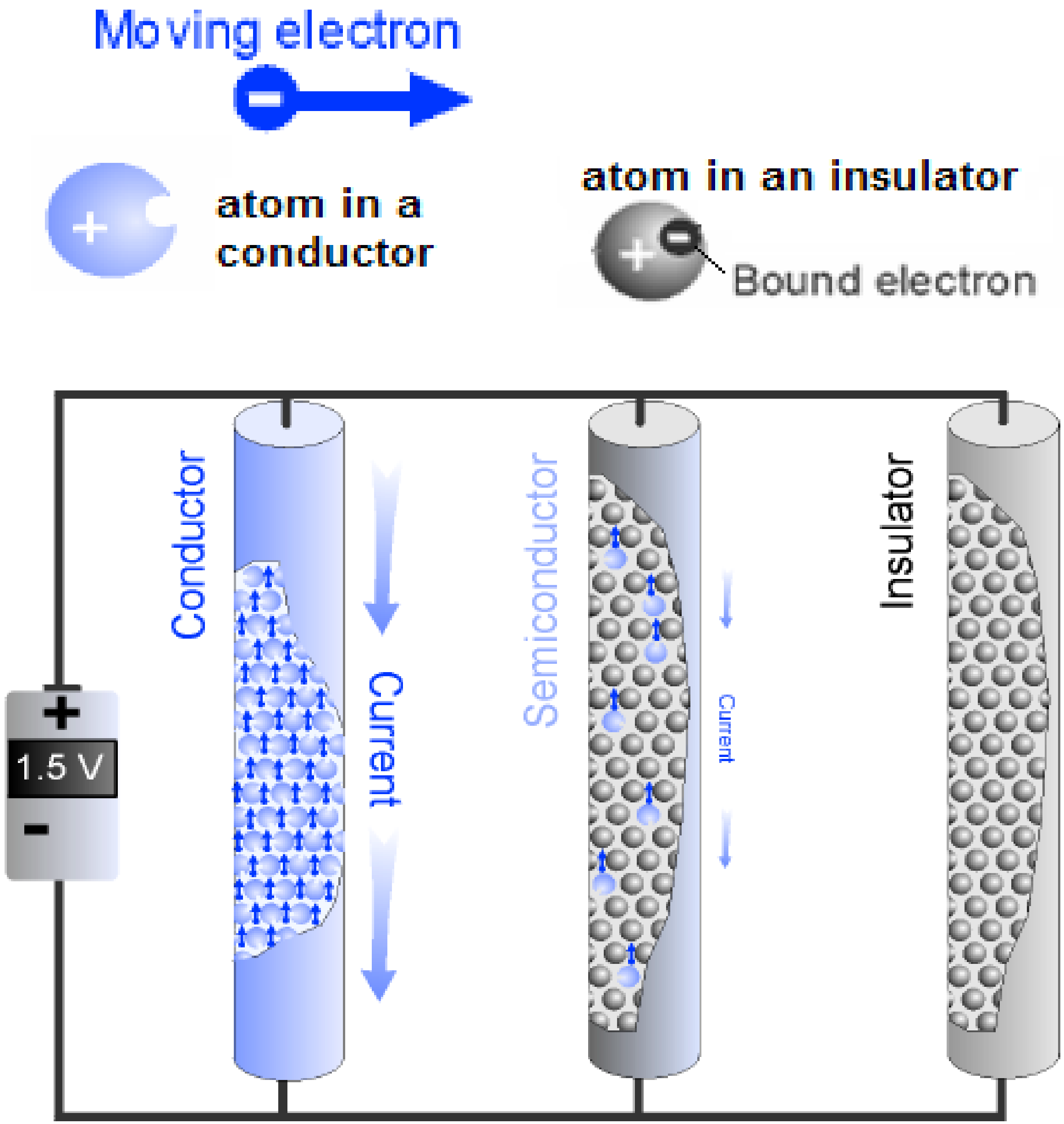


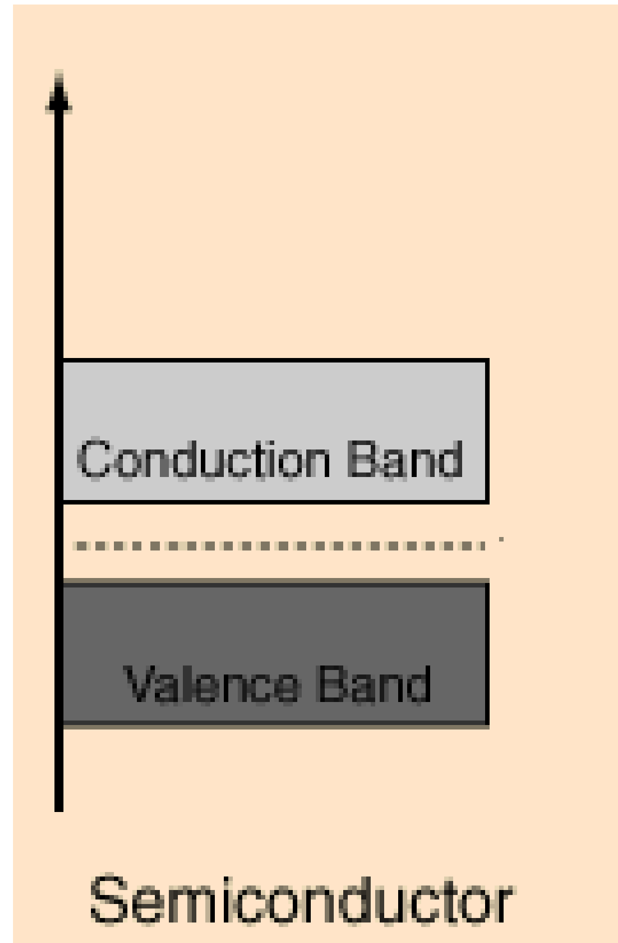
- The electrons in insulators are <u>not</u> free to move—they are tightly bound inside atoms.





- A **semiconductor** has a few free electrons and atoms with bound electrons that act as insulators.



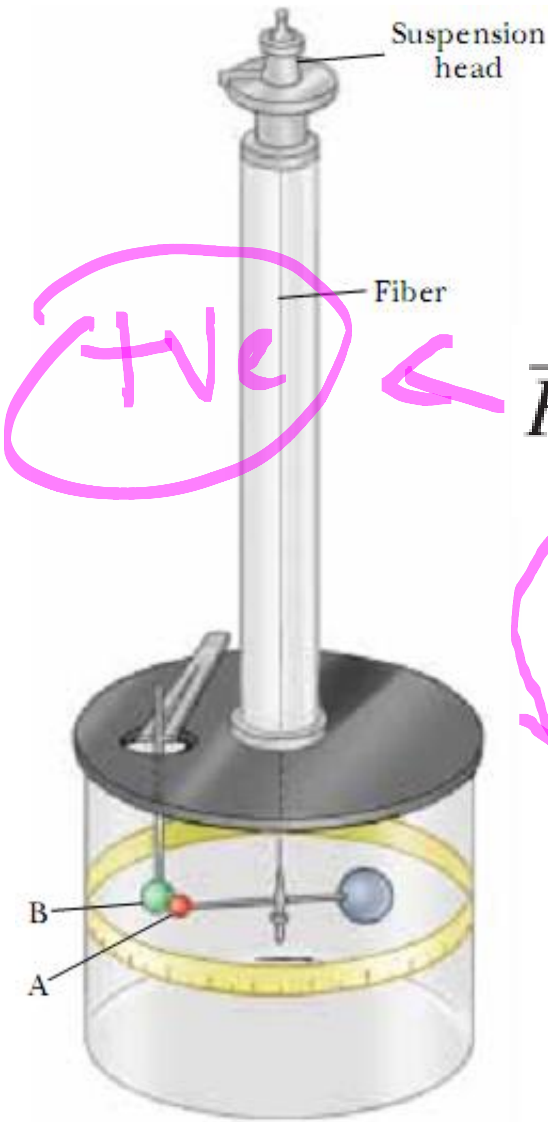


Charles Coulomb

- French physicist (1736-1806)
- Coulomb's major contribution to science was in the field of electrostatics and magnetism.
- During his lifetime, he also investigated the strengths of materials and determined the forces that affect objects on beams, thereby contributing to the field of structural mechanics.
- In the field of ergonomics, his research provided a fundamental understanding of the ways in which people and animals can best do work.

(Photo courtesy of AIP Niels Bohr Library/E. Scott Barr Collection)

Coulomb's Law

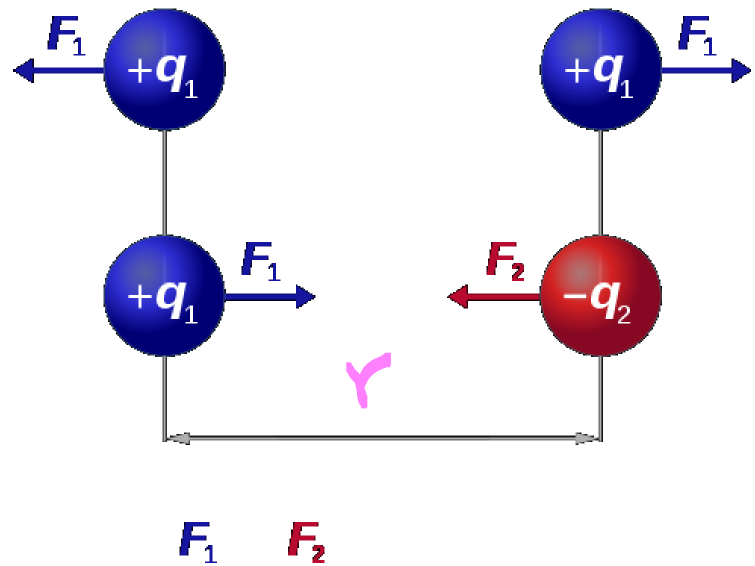


$F \propto q_1 q_2$

$F \propto \frac{1}{r^2}$

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

$F_e =$



where

$$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9\,\mathrm{N\cdot m^2/C^2}$$

here

$$F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$$ (Coulomb's law: force between two point charges) (21.2)

$\varepsilon_0 \approx 8.854 \times 10^{-12}$ F/m

Do it !!

A copper penny contains both positive and negative charges, each of a magnitude 1.37exp5 C. Suppose that these charges could be concentrated into two separate bundles, held 100m apart. What attractive force would act on each bundle?

$$F_e = \frac{K|q_1||q_2|}{r^2}$$

$F_c = ?$

Answer ??

Do it !!

A copper penny contains both positive and negative charges, each of a magnitude 1.37exp5 C. Suppose that these charges could be concentrated into two separate bundles, held 100m apart. What attractive force would act on each bundle?

Answer : F = 1.69 exp 16 N.

Solution

$(1.37 \times 10^{5})^2$

Solution From Eq. 25-4 we have

$$F = \frac{1}{4\pi\epsilon_0}\frac{|q|^2}{r^2} = \frac{(8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.37 \times 10^5\ \text{C})^2}{(100\ \text{m})^2}$$

$$= 1.69 \times 10^{16}\ \text{N}.$$

$$K = \frac{1}{4\pi\varepsilon_0}$$

2. Do it !!

The average distance r between the electron and the proton in the hydrogen atom is 5.3exp -11 m.

a. What is the magnitude of the average electrostatic force that acts between these two particles?

b. What is the magnitude of the average gravitational force that acts between these particles?

2. Do it !!

The average distance r between the electron and the proton in the hydrogen atom is 5.3exp -11 m.

a. What is the magnitude of the average electrostatic force that acts between these two particles?

   Fe=8.2 exp -8 N

b. What is the magnitude of the average gravitational force that acts between these particles?

   Fg = 3.6 exp -47 N.

Solution

Solution (*a*) From Eq. 25-4 we have, for the electrostatic force,

$$F_e = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2} = \frac{(8.99 \times 10^9\ \mathrm{N\cdot m^2/C^2})(1.60 \times 10^{-19}\ \mathrm{C})^2}{(5.3 \times 10^{-11}\ \mathrm{m})^2}$$

$$= 8.2 \times 10^{-8}\ \mathrm{N}.$$

Although this force may seem small (it is about equal to the weight of a speck of dust), it produces an enormous acceleration of the electron within the atom, about $10^{23}\ \mathrm{m/s^2}$.

(*b*) For the gravitational force, we have

$$F_g = G\frac{m_e m_p}{r^2}$$

$$= \frac{(6.67 \times 10^{-11}\ \mathrm{N\cdot m^2/kg^2})(9.11 \times 10^{-31}\ \mathrm{kg})(1.67 \times 10^{-27}\ \mathrm{kg})}{(5.3 \times 10^{-11}\ \mathrm{m})^2}$$

$$= 3.6 \times 10^{-47}\ \mathrm{N}.$$

The nucleus in an iron atom has a radius of about 4.0×10^{-15} m and contains 26 protons.

(a) What is the magnitude of the repulsive electrostatic force between two of the protons that are separated by 4.0×10^{-15} m?

(b) What is the magnitude of the gravitational force between those same two protons?

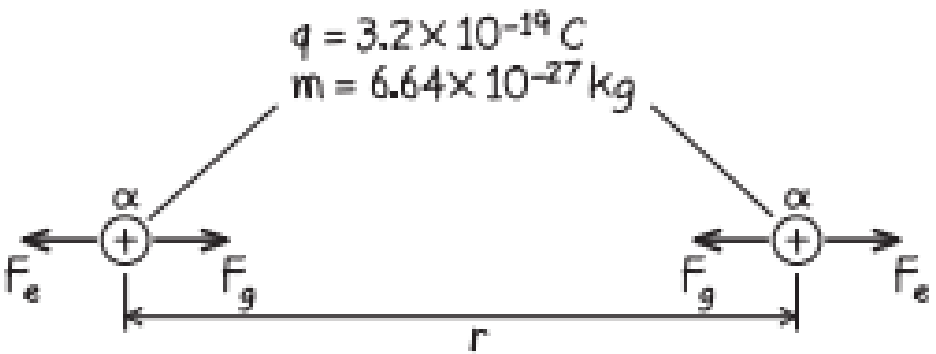
Solution

$$F = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2} = \frac{(8.99 \times 10^9\ \mathrm{N\cdot m^2/C^2})(1.60 \times 10^{-19}\ \mathrm{C})^2}{(4 \times 10^{-15}\ \mathrm{m})^2}$$

$$= 14\ \mathrm{N}.$$

Electric Force vs Gravitational Force

An α particle (the nucleus of a helium atom) has mass $m = 6.64 \times 10^{-27}$ kg and charge $q = +2e = 3.2 \times 10^{-19}$ C. Compare the magnitude of the electric repulsion between two α ("alpha") particles with that of the gravitational attraction between them.



21.11 Our sketch for this problem.

Solution

EXECUTE: Figure 21.11 shows our sketch. From Eqs. (21.2) and (13.1),

$$F_e = \frac{1}{4\pi\epsilon_0}\frac{q^2}{r^2} \qquad F_g = G\frac{m^2}{r^2}$$

These are both inverse-square forces, so the r^2 factors cancel when we take the ratio:

$$\frac{F_e}{F_g} = \frac{1}{4\pi\epsilon_0 G}\frac{q^2}{m^2}$$

$$= \frac{9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2}{6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2}\frac{(3.2 \times 10^{-19}\text{ C})^2}{(6.64 \times 10^{-27}\text{ kg})^2}$$

$$= 3.1 \times 10^{35}$$

PROBLEM

Two point charges, $q_1 = +25$ nC and $q_2 = -75$ nC, are separated by a distance $r = 3.0$ cm (Fig. 21.12a). Find the magnitude and direction of the electric force (a) that q_1 exerts on q_2 and (b) that q_2 exerts on q_1.

SOLUTION

IDENTIFY and SET UP: This problem asks for the electric forces that two charges exert on each other. We use Coulomb's law, Eq. (21.2), to calculate the magnitudes of the forces. The signs of the charges will determine the directions of the forces.

EXECUTE: (a) After converting the units of r to meters and the units of q_1 and q_2 to coulombs, Eq. (21.2) gives us

$$F_{1\text{ on }2} = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$$

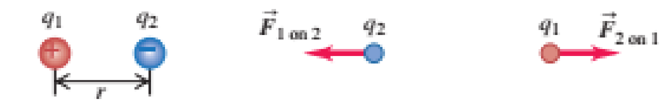
$$= (9.0 \times 10^9\ \mathrm{N \cdot m^2/C^2})\frac{|(+25 \times 10^{-9}\ \mathrm{C})(-75 \times 10^{-9}\ \mathrm{C})|}{(0.030\ \mathrm{m})^2}$$

$$= 0.019\ \mathrm{N}$$

The charges have opposite signs, so the force is attractive (to the left in Fig. 21.12b); that is, the force that acts on q_2 is directed toward q_1 along the line joining the two charges.

21.12 What force does q_1 exert on q_2, and what force does q_2 exert on q_1? Gravitational forces are negligible.

(a) The two charges (b) Free-body diagram for charge q_2 (c) Free-body diagram for charge q_1



(b) Proceeding as in part (a), we have

$$F_{1\text{ on }2} = \frac{1}{4\pi\epsilon_0}\frac{|q_2 q_1|}{r^2} = F_{2\text{ on }1} = 0.019\ \mathrm{N}$$

The attractive force that acts on q_1 is to the right, toward q_2 (Fig. 21.12c).

Problem-Solving Strategy 21.1 Coulomb's Law

IDENTIFY *the relevant concepts:* Coulomb's law describes the electric force between charged particles.

SET UP *the problem* using the following steps:

1. Sketch the locations of the charged particles and label each particle with its charge.
2. If the charges do not all lie on a single line, set up an *xy*-coordinate system.
3. The problem will ask you to find the electric force on one or more particles. Identify which these are.

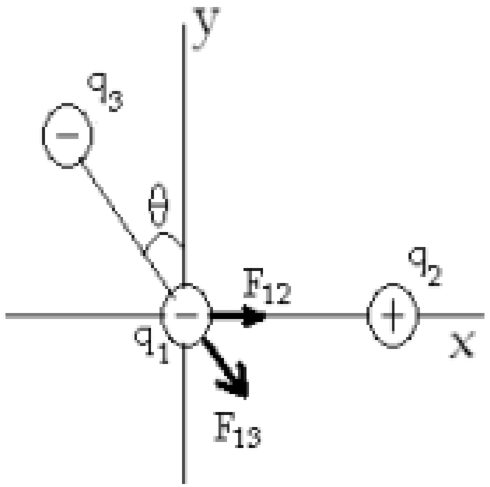
EXECUTE *the solution* as follows:

1. For each particle that exerts an electric force on a given particle of interest, use Eq. (21.2) to calculate the magnitude of that force.
2. Using those magnitudes, sketch a free-body diagram showing the electric force vectors acting on each particle of interest. The force exerted by particle 1 on particle 2 points from particle 2 toward particle 1 if the charges have opposite signs, but points from particle 2 directly away from particle 1 if the charges have the same sign.

3. Do it !!

Fig shows three charged particles, held in place by forces not shown. What electrostatic force, due to the other two charges, acts on q1 ? Take q1 = $-1.2\mu C$, q2 = $+3.7\mu C$, q3 = $-2.3\mu C$, r_{12} = 15cm, r_{13} = 10cm and Θ = 32deg.

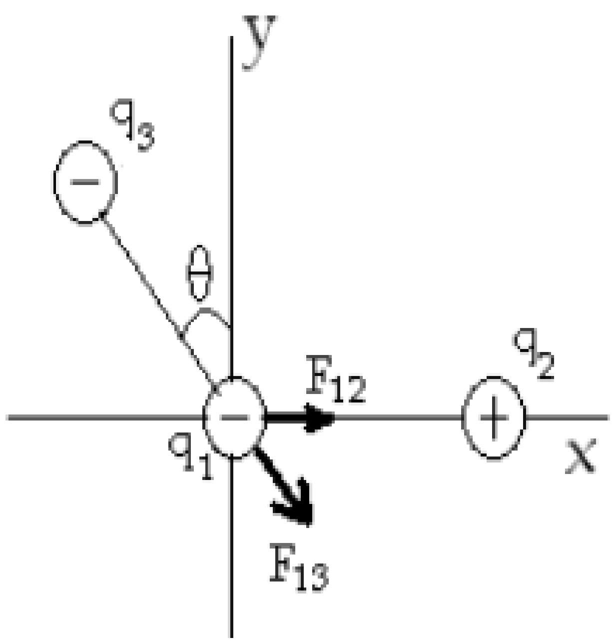
Answer ??



Solution

For solutions –see *lectures*

Answer: Vector F1 = 3.73N
with Θ = -34deg



Given

$q1 = -1.2\mu C$,

$q2 = +3.7\mu C$,

$q3 = -2.3\mu C$,

$r12 = 15cm$,

$r13 = 10cm$

$\Theta = 32deg.$

F on q1 = ?

Solution This problem calls for the use of the superposition principle. We start by computing the magnitudes of the forces that q_2 and q_3 exert on q_1. We substitute the magnitudes of the charges into Eq. 25-5:

$$F_{12} = \frac{1}{4\pi\epsilon_0}\frac{|q_1||q_2|}{r_{12}^2}$$

$$= \frac{(8.99 \times 10^9\ \mathrm{N\cdot m^2/C^2})(1.2 \times 10^{-6}\ \mathrm{C})(3.7 \times 10^{-6}\ \mathrm{C})}{(0.15\ \mathrm{m})^2}$$

$$= 1.77\ \mathrm{N}.$$

The charges q_1 and q_2 have opposite signs so that the force exerted by q_2 on q_1 is attractive. Hence $\vec{F}_{12}$ points to the right in Fig. 25-10.

We also have

$$F_{13} = \frac{(8.99 \times 10^9\ \mathrm{N\cdot m^2/C^2})(1.2 \times 10^{-6}\ \mathrm{C})(2.3 \times 10^{-6}\ \mathrm{C})}{(0.10\ \mathrm{m})^2}$$

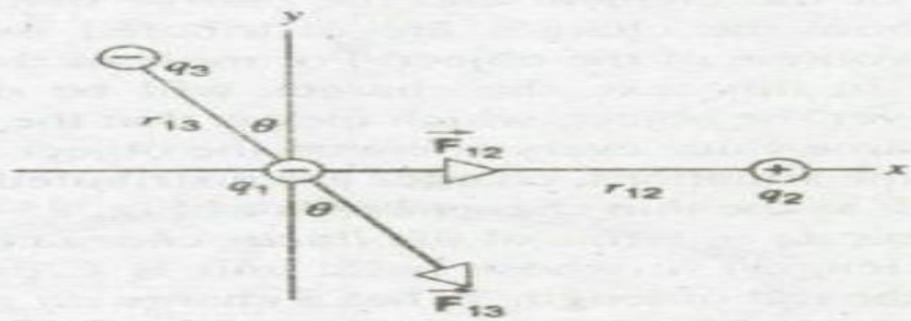
$$= 2.48\ \mathrm{N}.$$

These two charges have the same (negative) sign so that the force exerted by q_3 on q_1 is repulsive. Thus $\vec{F}_{13}$ points as shown in Fig. 25-10.

The components of the resultant force $\vec{F}_1$ acting on q_1 are determined by the corresponding components of Eq. 25-8, or

$$F_{1x} = F_{12x} + F_{13x} = F_{12} + F_{13}\sin\theta$$

$$= 1.77\ \mathrm{N} + (2.48\ \mathrm{N})(\sin 32°) = 3.08\ \mathrm{N}$$



and

$$F_{1y} = F_{12y} + F_{13y} = 0 - F_{13}\cos\theta$$

$$= -(2.48\ \mathrm{N})(\cos 32°) = -2.10\ \mathrm{N}.$$

From these components, you can show that the magnitude of $\vec{F}_1$ is 3.73 N and that this vector makes an angle of $-34°$ with the x axis.

Coulomb's Law(Homework)

2. What must be the distance between point charge $q_1 =$ 26.3 μC and point charge $q_2 = -47.1$ μC for the attractive electrical force between them to have a magnitude of 5.66 N?

Vector Addition of Electric Forces on a line ***(Homework)***

Two point charges are located on the x-axis of a coordinate system: $q_1 = 1.0\ \text{nC}$ is at $x = +2.0\ \text{cm}$, and $q_2 = -3.0\ \text{nC}$ is at $x = +4.0\ \text{cm}$. What is the total electric force exerted by q_1 and q_2 on a charge $q_3 = 5.0\ \text{nC}$ at $x = 0$?

Ans

$\vec{F}_{1\text{ on }3} = (-112\ \mu\text{N})\hat{\imath}$ and $\vec{F}_{2\text{ on }3} = (84\ \mu\text{N})\hat{\imath}$.

$$\vec{F}_3 = \vec{F}_{1\text{ on }3} + \vec{F}_{2\text{ on }3} = (-112\ \mu\text{N})\hat{\imath} + (84\ \mu\text{N})\hat{\imath} = (-28\ \mu\text{N})\hat{\imath}$$

4. Do –it !! ***Homework***

Two positive charges, each of 4.18μC and a negative charge, -6.36μC, are fixed at the vertices of an equilateral triangle of side 13.0 cm. Find the electrical force on the negative charge?

4. Do –it !!

Two positive charges, each of 4.18μC and a negative charge, -6.36μC, are fixed at the vertices of an equilateral triangle of side 13.0 cm. Find the electrical force on the negative charge?

Answer: Vector F- = 24.5N with Θ = along the bisector of angle

Calculate the Force

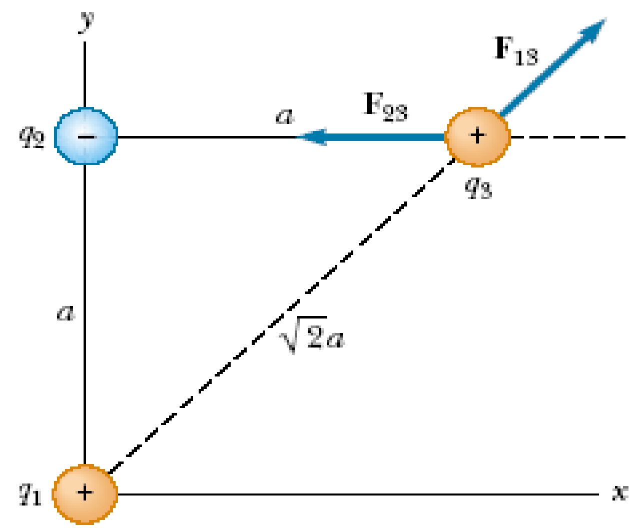
Consider three point charges located at the corners of a right triangle as shown in Figure. Find the resultant force exerted on *q3* .

$q_1 = q_3 = 5.0\ \mu C$, $q_2 = -2.0\ \mu C$, and $a = 0.10$ m.

$F_{3x} = F_{13x} + F_{23} = 7.9\ N - 9.0\ N = -1.1\ N$

$F_{3y} = F_{13y} = 7.9\ N$

$$\mathbf{F}_3 = \boxed{(-1.1\mathbf{i} + 7.9\mathbf{j})\ N}$$



Find the magnitude and direction of the resultant force $\mathbf{F}_3$

8.0 N at an angle of 98° with the x axis.

Announcement

- Sessional II is scheduled on 25/11/2020. Do not forget to submit the assignment 2 on the same day before 1.30 P.M
- Weightage(15 marks)
- Course Contents to be included are from Week 05 (After Slide 14) till Week 10
- Assignment 02/HomeWorks Included

What next??

- The electric field