PHYS 221

Electromagnetism (1)
2^{nd} semester 1446

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Lecture 1

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List of topics

- Vector and Scalar
- Electrostatics Fields, Electrostatics Force
- Gauss Law and its application,
- Electric potential Charge Dipoles
- Conductors and Insulators
- Capacitors
- The magnetic field of conductors with different shapes
- Ampere's law and its applications.
- Magnetic Force Induced electromotive force,
- Faraday's law, Lenz's law, magnetic properties of matter
- Analysis of AC circuits, resonance in series and parallel circuits.

توزيع الدرجات:

الإختبار الفصلي الأول 15 درجة

الإختبار الفصلي الثاني 15 درجة

العملي 30 درجة: 10 درجة على التقارير و 20 درجة على الاختبار

الإختبارالنهائي 40 درجة.

Physics For Scientists And Engineers 10E By Serway And Jewett

Units and Dimensions

Some Prefixes for Powers Used with “Metric” (SI and cgs) Units

Power	Prefix	Abbreviation
10^{18}	Exa	**E**
10^{15}	Peta	**P**
10^{12}	Tera or Viga	**T or V**
10^{9}	Giga	**G**
10^{6}	Mega	**M**
10^{3}	Kilo	**K**
10^{1}	Deca	**D**
10^{-1}	deci	**d**
10^{-2}	centi	**c**
10^{-3}	milli	**m**
10^{-6}	micro	**μ**
10^{-9}	nano	**n**
10^{-12}	pico	**p**
10^{-15}	femto	**f**
10^{-18}	atto	**a**

- **DIMENSIONAL ANALYSIS**
- In physics, the word ***dimension*** *denotes the physical nature of a quantity.*
- **In 1960, an international committee agreed on a standard system of units for the fundamental quantities of science, called SI**

  (Système International). Its units of length (meter), mass (kilogram) and time are the meter (second):(mks units).
- For example, *The* distance between two points, can be measured in feet and meters.

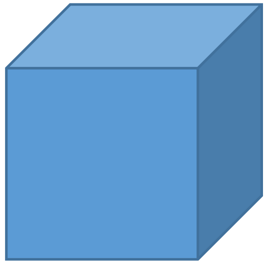
Standard system of units for the fundamental quantities of science, called SI (Système International). Its units of length (meter), mass (kilogram) and time are the meter (second):(mks units).

Quantity	Abbreviation	Unit	
Length or Distance	l, x, d, r, h	m	
Mass	m	kg	
time	t	s	
Force	F= mg	Newton	kg m/s^2
Capacitance	C	Farad	
Charge	Q, q	Coulomb	
Temperature	T	**K**,^oC, ^oF	
Energy	K (KE), U (PE)	Joule	kg m^2/s^2

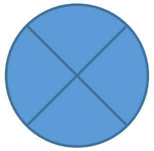

m
kg
s
SI
cd
mol
K
A

Volume of

- (Cube of side L) = L^3

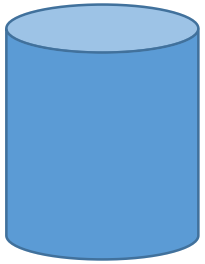


- (Sphere of Radius r) = $\frac{4}{3}\pi r^3$



- (Cylinder of Radius L and Height H)

= $\pi r^2 H$



الكثافةDensity

- في الكميات الصغيرة من المائع يمكن كتابة الصيغة الرياضية في الصورة التالية:

$$\rho = \frac{\Delta m}{\Delta V}$$

- وحدة قياس الكثافة

$$Kg / m^3$$

$$gm / cm^3$$

3.2 Vector and Scalar Quantities

- A **scalar quantity** is completely specified by a single value with an appropriate unit and has no direction.

Examples: volume, mass, speed, and time intervals.

- A **vector quantity** is completely specified by a number and appropriate units plus a direction.

Examples: displacement, velocity, and force.

3.3 Some Properties of Vectors

❑ **Equality of Two Vectors:**

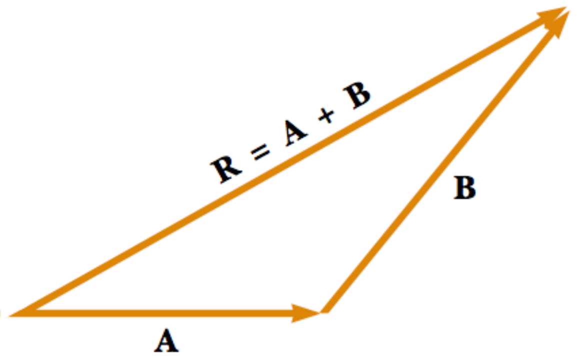
A = **B** only if *A* = *B* and if **A** and **B** point in the same direction along parallel lines.

❑ **Adding Vectors**

- The **resultant vector R** = **A** + **B** is the vector drawn from the tail of **A** to the tip of **B**.

The **commutative law of addition: A+B=B+A**

The **associative law of addition: A+(B+C)=(A+B)+C**



❑ **Negative of a Vector**

A+(-**A**)=0. The vectors **A** and -**A** have the same magnitude but point in opposite directions.

❑ **Subtracting Vectors**

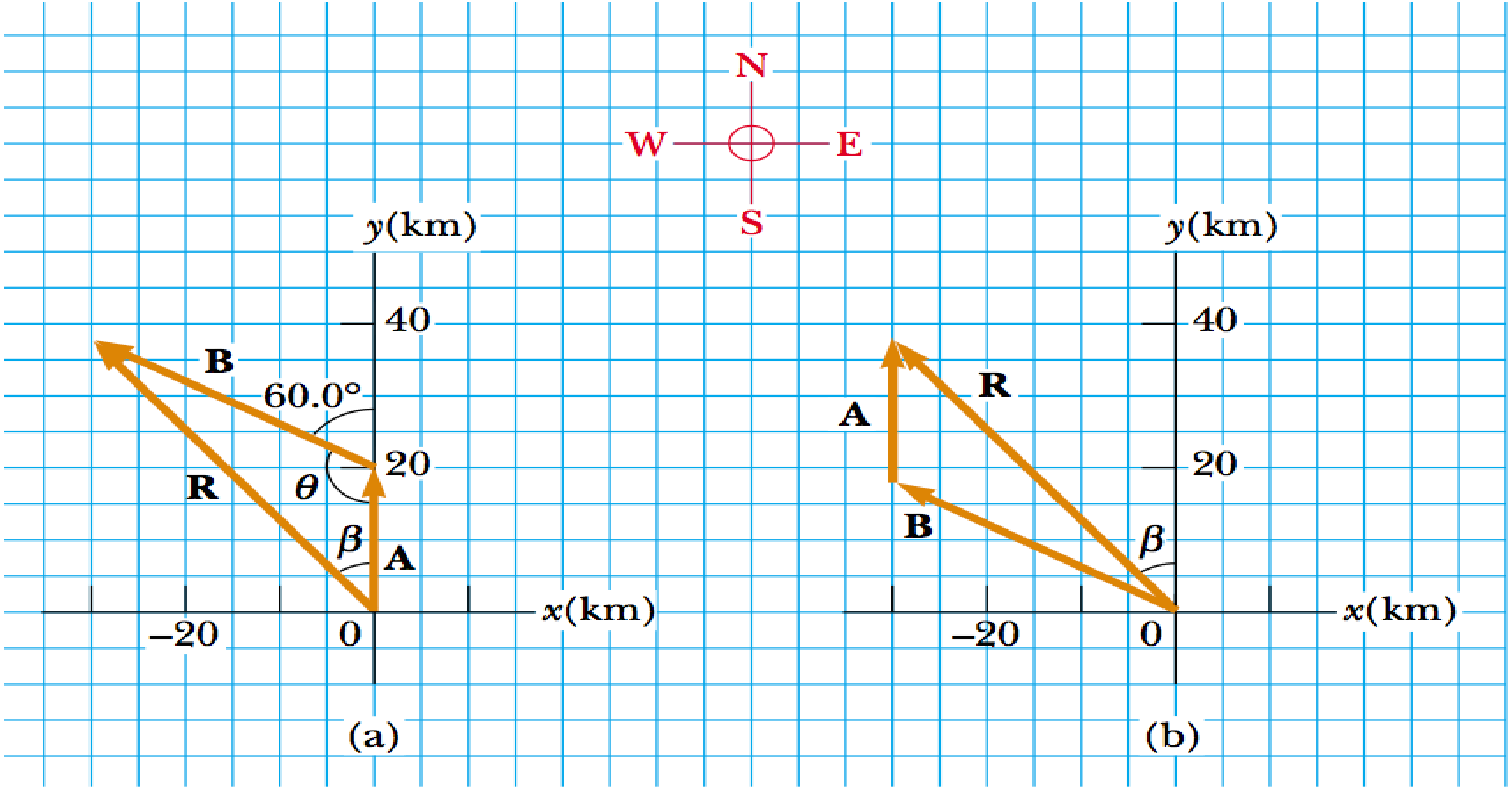
- **A-B=A+**(-**B**)

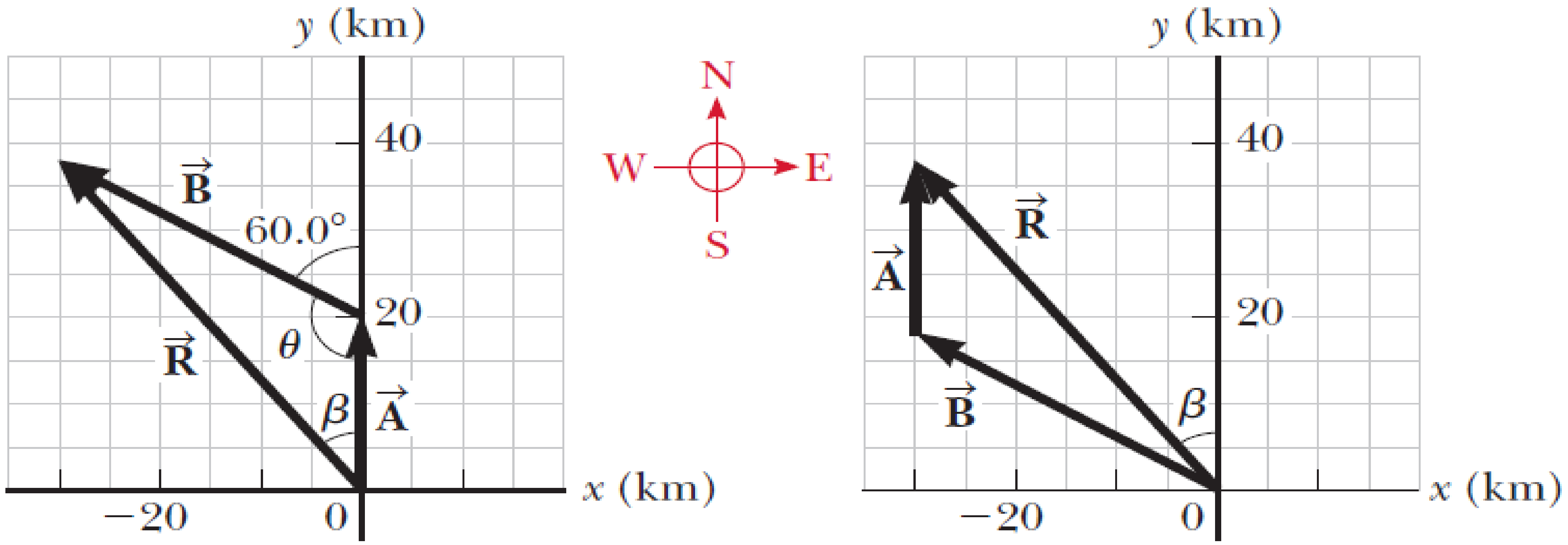
❑ **Multiplying a Vector by a Scalar**

The product *m***A** is a vector that has the same direction as **A** and magnitude *mA*.

Example 3.2: A Vacation Trip

- A car travels 20.0 km due north and then 35.0 km in a direction 60.0° west of north, as shown in Figure 3.12a. Find the magnitude and direction of the car’s resultant displacement.





$$R = \sqrt{A^2 + B^2 - 2AB\cos\theta}$$

$$R = \sqrt{(20.0\text{ km})^2 + (35.0\text{ km})^2 - 2(20.0\text{ km})(35.0\text{ km})\cos 120^\circ}$$

$$= \boxed{48.2\text{ km}}$$

$$\frac{\sin\beta}{B} = \frac{\sin\theta}{R}$$

$$\sin\beta = \frac{B}{R}\sin\theta = \frac{35.0\text{ km}}{48.2\text{ km}}\sin 120^\circ = 0.629$$

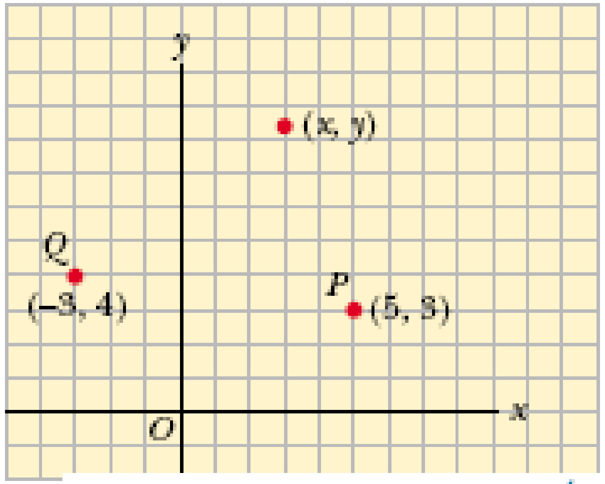
$$\beta = \boxed{38.9^\circ}$$

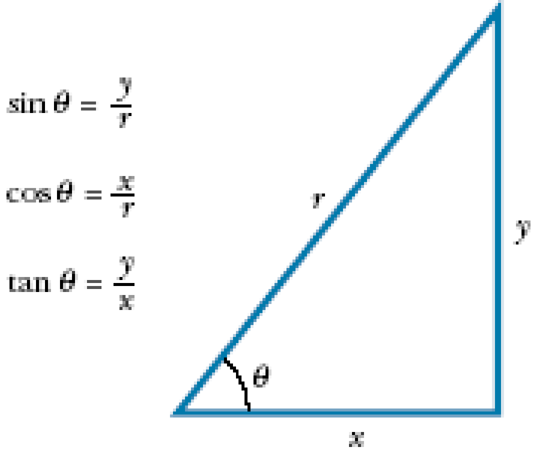
- المتجهات : (Vectors)

- نظم الإحداثيات (Coordinate Systems)

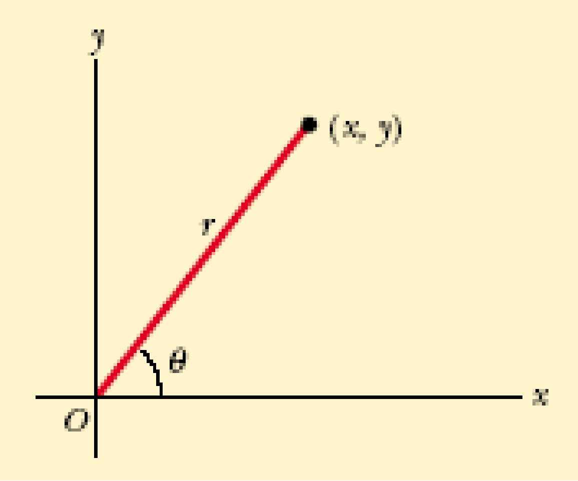
نحتاج في حياتنا العملية إلى تحديد موقع جسم ما في الفراغ سواءً كان ساكناً أم متحركاً، ولتحديد موقع هذا الجسم فإننا نستعين بما يعرف بالإحداثيات ***Coordinates***، وهناك نوعان من الإحداثيات التي سوف نستخدمها وهما ***Rectangular coordinates*** و *polar coordinates*.

الإحداثيات الكارتيزية (X,Y)





الإحداثيات القطبية (r,θ)



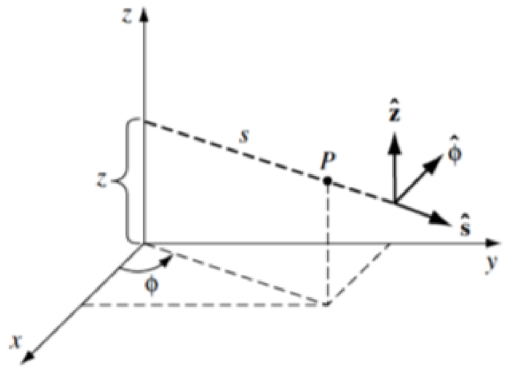
$\tan \theta = y/x$

$x = r \cos \theta$

$r = \sqrt{x^2 + y^2}$

$y = r \sin \theta$

The cylindrical coordinates (s, ϕ , z) of a point P are defined in the following figure.



Notice that ϕ has the same meaning as in spherical coordinates, and z is the same as Cartesian; s is the distance to P from the z axis, whereas the spherical coordinate r is the distance from the origin.

The relations to Cartesian coordinates are

$$x = s\cos\phi, \qquad y = s\sin\phi, \qquad z = z.$$

The infinitesimal displacements are

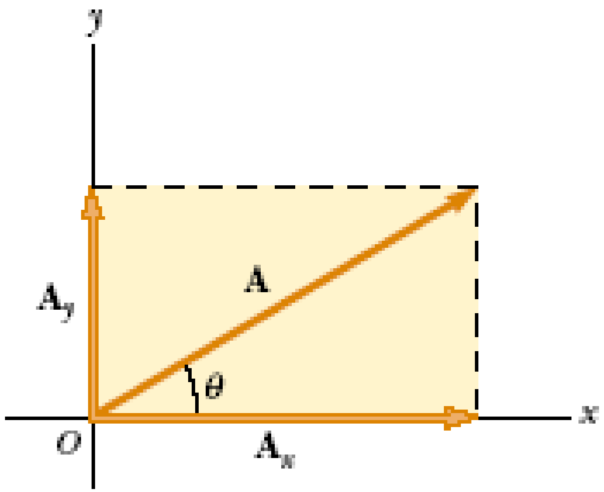
$$dl_s = ds, \qquad dl_\phi = s\,d\phi, \qquad dl_z = dz,$$

so

$$d\mathbf{l} = ds\,\hat{\mathbf{s}} + s\,d\phi\,\hat{\boldsymbol{\phi}} + dz\,\hat{\mathbf{z}},$$

- مكونات (مركبات) المتجه ومتجه الوحدة:

Components of a vector and unit vector

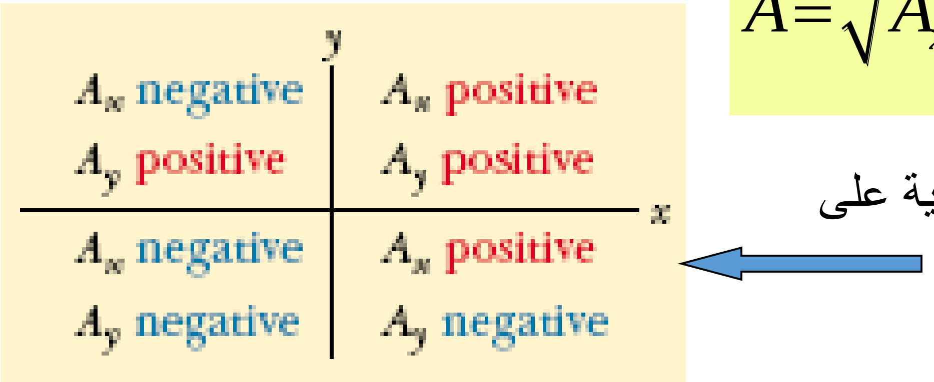


- يمكن تحليل أي متجه (A) إلى مركبة سينية (A_x) على المحور السيني (x) ومركبة صادية (A_y) على المحور الصادي (y) حيث؛

$$A_x = A\cos\theta \;\; \& \;\; A_y = A\sin\theta$$

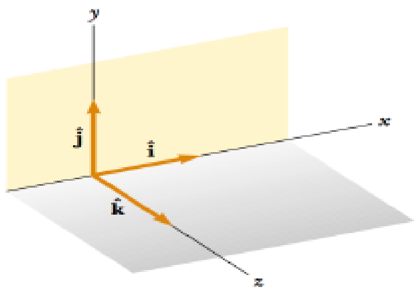
$$A = \sqrt{A_x^2 + A_y^2} \quad \& \quad \theta = \tan^{-1}\frac{A_y}{A_x}$$

- تعتمد أشارة المركبات السينية والصادية على الزاوية θ، كما هو موضح بالرسم



- ملحوظة هامة: للتعويض بالمعادلات السابقة لحساب المركبة السينية أو الصادية دائما تؤخذ قيمة الزاوية بين المتجه والمحور السيني الموجب

3.4 Components of a Vector and Unit Vectors

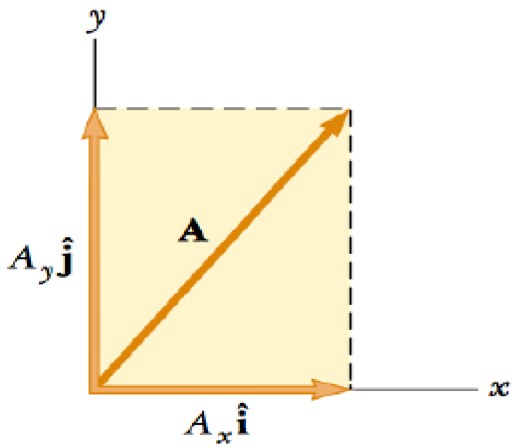


- **Unit Vectors**

$$|\hat{\mathbf{i}}| = |\hat{\mathbf{j}}| = |\hat{\mathbf{k}}| = 1.$$

- The unit vector notation for the vector **A** is

$$\mathbf{A} = A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}$$



- The resultant vector **R=A+B** is

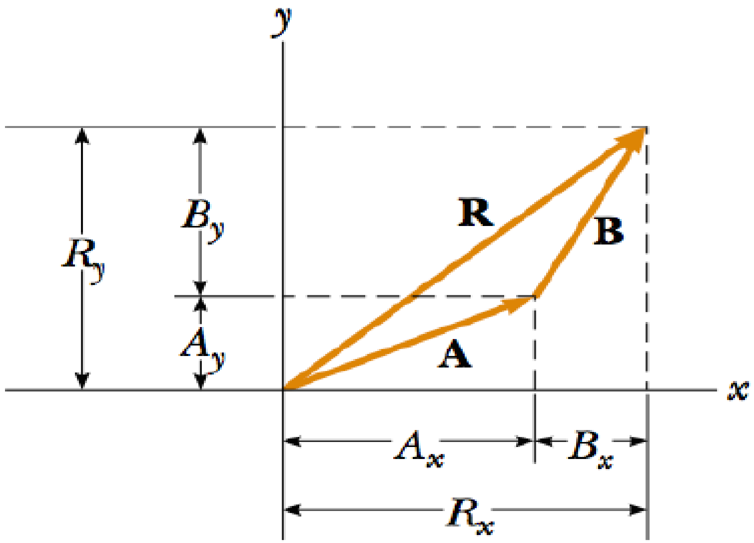
$$\mathbf{R} = (A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}) + (B_x\hat{\mathbf{i}} + B_y\hat{\mathbf{j}})$$

$$\mathbf{R} = (A_x + B_x)\hat{\mathbf{i}} + (A_y + B_y)\hat{\mathbf{j}}$$

- The magnitude of **R** and the angle

$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{(A_x + B_x)^2 + (A_y + B_y)^2}$$

$$\tan\theta = \frac{R_y}{R_x} = \frac{A_y + B_y}{A_x + B_x}$$



Example 3.3 **The Sum of Two Vectors**

Find the sum of two displacement vectors $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ lying in the *xy* plane and given by

$$\vec{\mathbf{A}} = (2.0\hat{\mathbf{i}} + 2.0\hat{\mathbf{j}})\text{ m} \quad \text{and} \quad \vec{\mathbf{B}} = (2.0\hat{\mathbf{i}} - 4.0\hat{\mathbf{j}})\text{ m}$$

$$\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}} = (2.0 + 2.0)\hat{\mathbf{i}}\text{ m} + (2.0 - 4.0)\hat{\mathbf{j}}\text{ m}$$

$$R_x = 4.0\text{ m} \qquad R_y = -2.0\text{ m}$$

$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{(4.0\text{ m})^2 + (-2.0\text{ m})^2} = \sqrt{20}\text{ m} = \boxed{4.5\text{ m}}$$

$$\tan\theta = \frac{R_y}{R_x} = \frac{-2.0\text{ m}}{4.0\text{ m}} = -0.50$$

Example 3.4 **The Resultant Displacement**

A particle undergoes three consecutive displacements: $\mathbf{d}_1 = (15\hat{\mathbf{i}} + 30\hat{\mathbf{j}} + 12\hat{\mathbf{k}})$ cm, $\mathbf{d}_2 = (23\hat{\mathbf{i}} - 14\hat{\mathbf{j}} - 5.0\hat{\mathbf{k}})$ cm and $\mathbf{d}_3 = (-13\hat{\mathbf{i}} + 15\hat{\mathbf{j}})$ cm. Find the components of the resultant displacement and its magnitude.

$$= (15 + 23 - 13)\hat{\mathbf{i}}\text{ cm} + (30 - 14 + 15)\hat{\mathbf{j}}\text{ cm} + (12 - 5.0 + 0)\hat{\mathbf{k}}\text{ cm}$$

$$= (25\hat{\mathbf{i}} + 31\hat{\mathbf{j}} + 7.0\hat{\mathbf{k}})\text{ cm}$$

$$R = \sqrt{R_x{}^2 + R_y{}^2 + R_z{}^2}$$

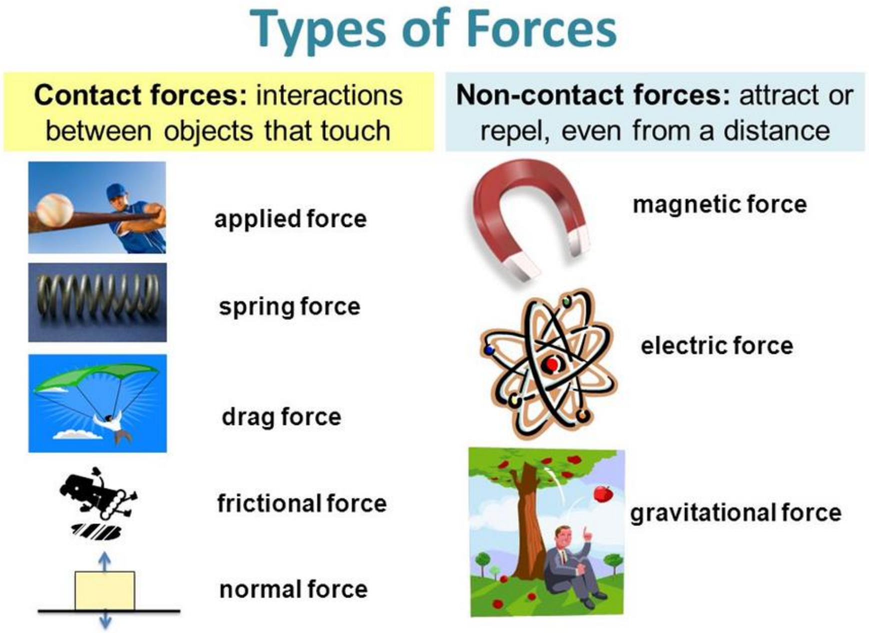
$$= \sqrt{(25\text{ cm})^2 + (31\text{ cm})^2 + (7.0\text{ cm})^2} = 40\text{ cm}$$

Electricity and Magnetism

- The laws of electricity and magnetism play a central role in the operation of many modern devices.
- The interatomic and intermolecular forces responsible for the formation of solids and liquids are electric in nature.

Electricity and Magnetism – Forces

- The concept of force links the study of electromagnetism to previous study.
- The electromagnetic force between charged particles is one of the fundamental forces of nature.

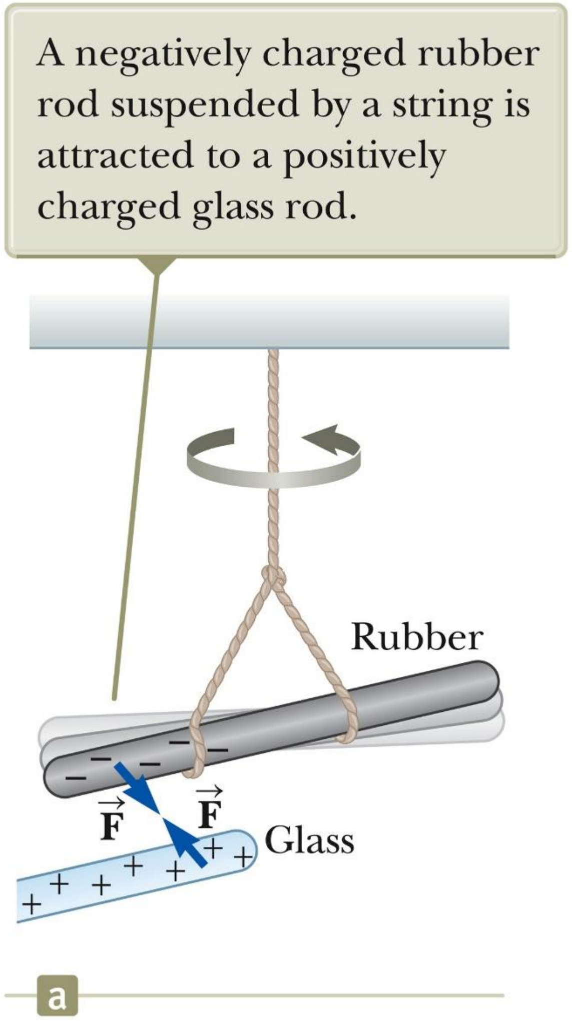


Electric Charges

- There are two kinds of electric charges
  - Called positive and negative
    - Negative charges are the type possessed by electrons.
    - Positive charges are the type possessed by protons.
- Charges of the same sign repel one another and charges with opposite signs attract one another.

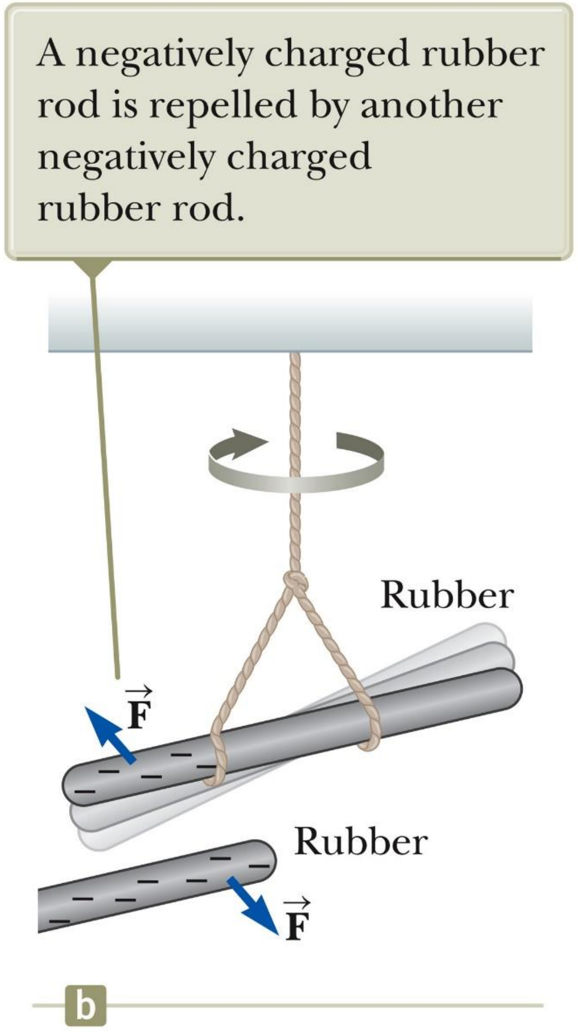
Electric Charges, 2

- The rubber rod is negatively charged.
- The glass rod is positively charged.
- The two rods will attract.



Electric Charges, 3

- The rubber rod is negatively charged.
- The second rubber rod is also negatively charged.
- The two rods will repel.

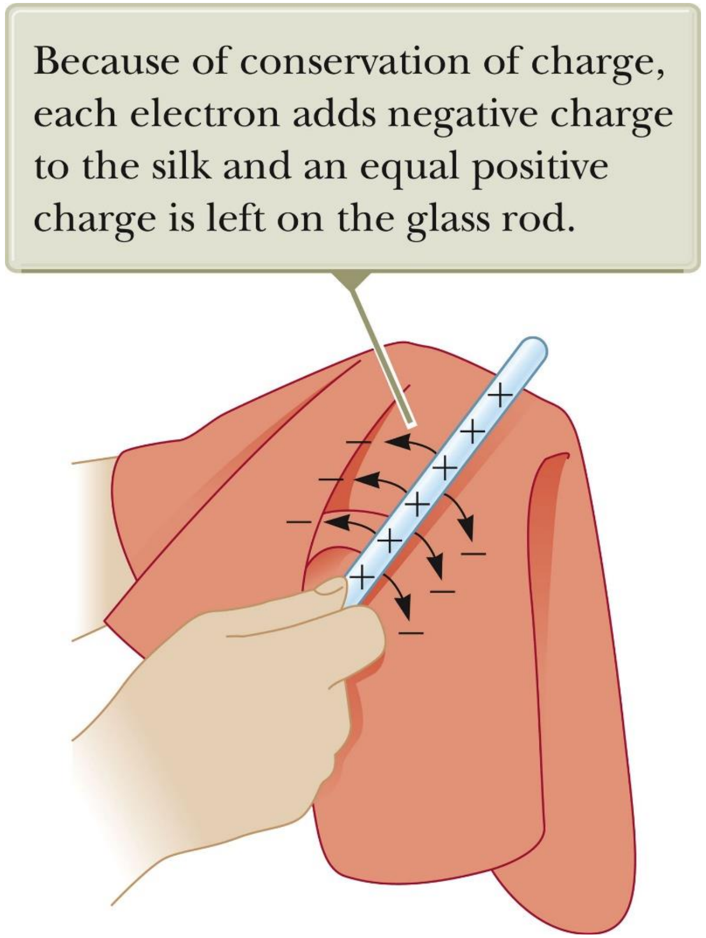


More About Electric Charges

- Electric charge is always conserved in an isolated system.
  - For example, charge is not created in the process of rubbing two objects together.
  - The electrification is due to a transfer of charge from one object to another.

Conservation of Electric Charges

- A glass rod is rubbed with silk.
- Electrons are transferred from the glass to the silk.
- Each electron adds a negative charge to the silk.
- An equal positive charge is left on the rod.



Quantization of Electric Charges

- The electric charge, q, is said to be quantized.
  - q is the standard symbol used for charge as a variable.
  - Electric charge exists as discrete packets.
  - $q = \pm Ne$
    - N is an integer
    - e is the fundamental unit of charge
    - $|e| = 1.6 \times 10^{-19}$ C
    - Electron: $q = -e$
    - Proton: $q = +e$

Conductors

- Electrical conductors are materials in which some of the electrons are free electrons.
  - Free electrons are not bound to the atoms.
  - These electrons can move relatively freely through the material.
  - Examples of good conductors include copper, aluminum and silver.
  - When a good conductor is charged in a small region, the charge readily distributes itself over the entire surface of the material.

Insulators

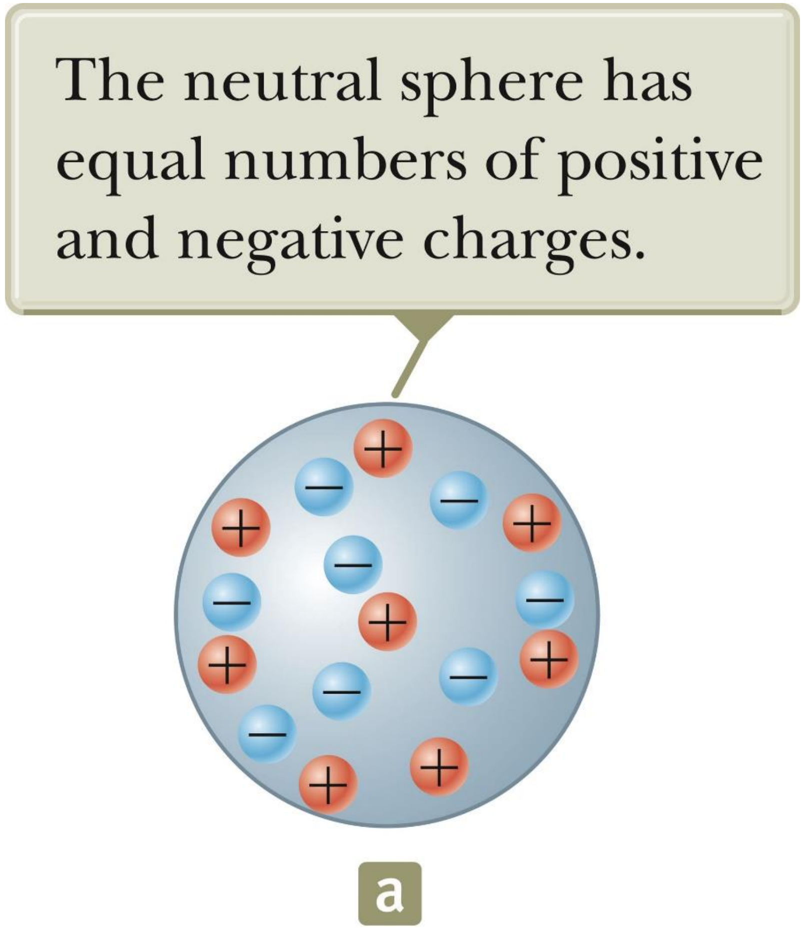
- Electrical insulators are materials in which all of the electrons are bound to atoms.
  - These electrons can not move relatively freely through the material.
  - Examples of good insulators include glass, rubber and wood.
  - When a good insulator is charged in a small region, the charge is unable to move to other regions of the material.

Semiconductors

- The electrical properties of semiconductors are somewhere between those of insulators and conductors.
- Examples of semiconductor materials include silicon and germanium.
  - Semiconductors made from these materials are commonly used in making electronic chips.
- The electrical properties of semiconductors can be changed by the addition of controlled amounts of certain atoms to the material.

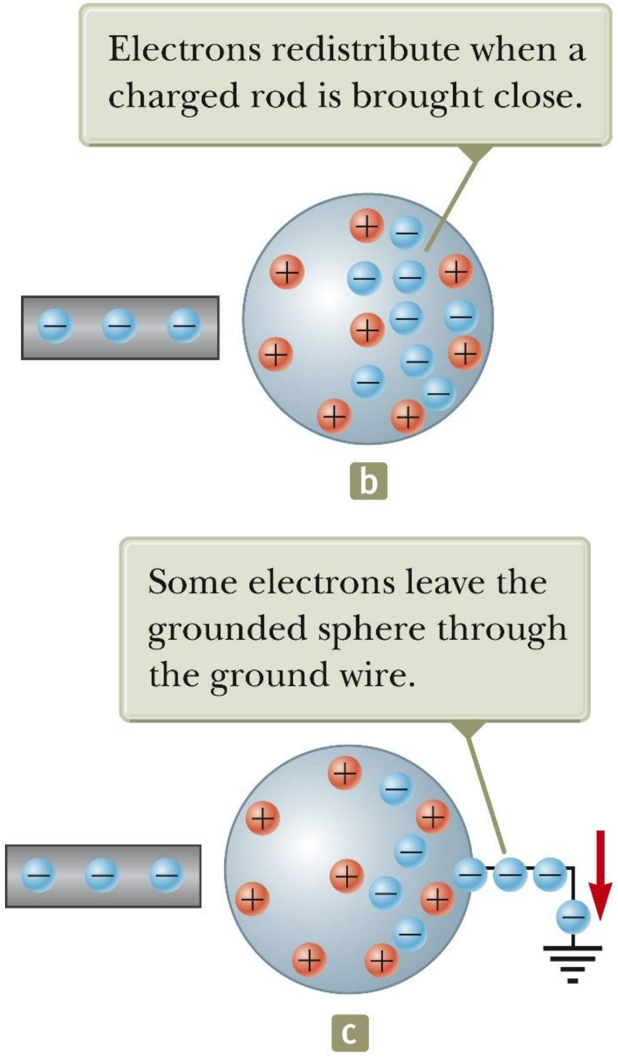
Charging by Induction

- Charging by induction requires no contact with the object inducing the charge.
- Assume we start with a neutral metallic sphere.
    - The sphere has the same number of positive and negative charges.



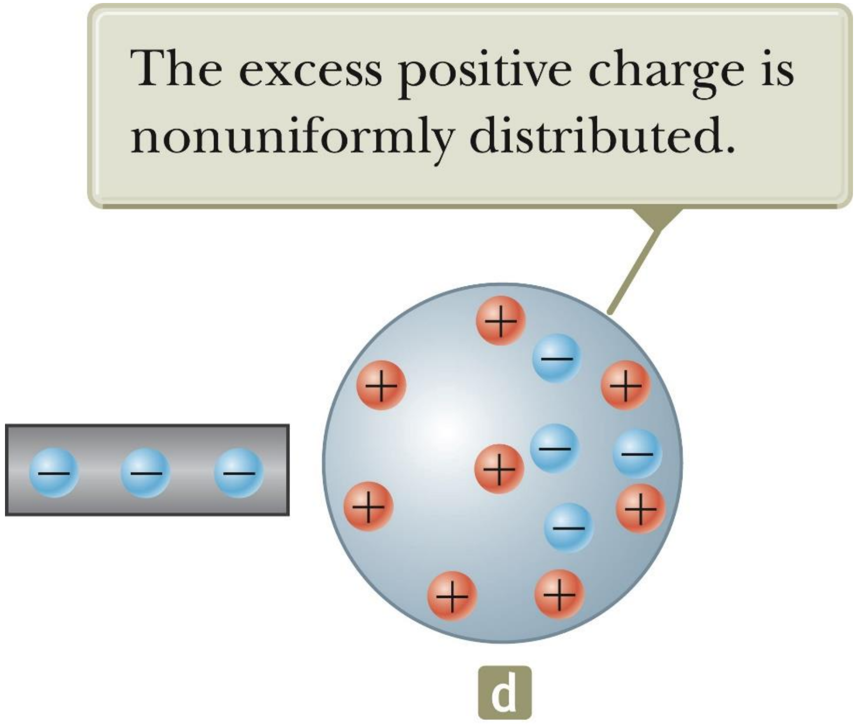
Charging by Induction, 2

- B:
- A charged rubber rod is placed near the sphere.
    - It does **not** touch the sphere.
- The electrons in the neutral sphere are redistributed.
- C:
- The sphere is grounded.
- Some electrons can leave the sphere through the ground wire.



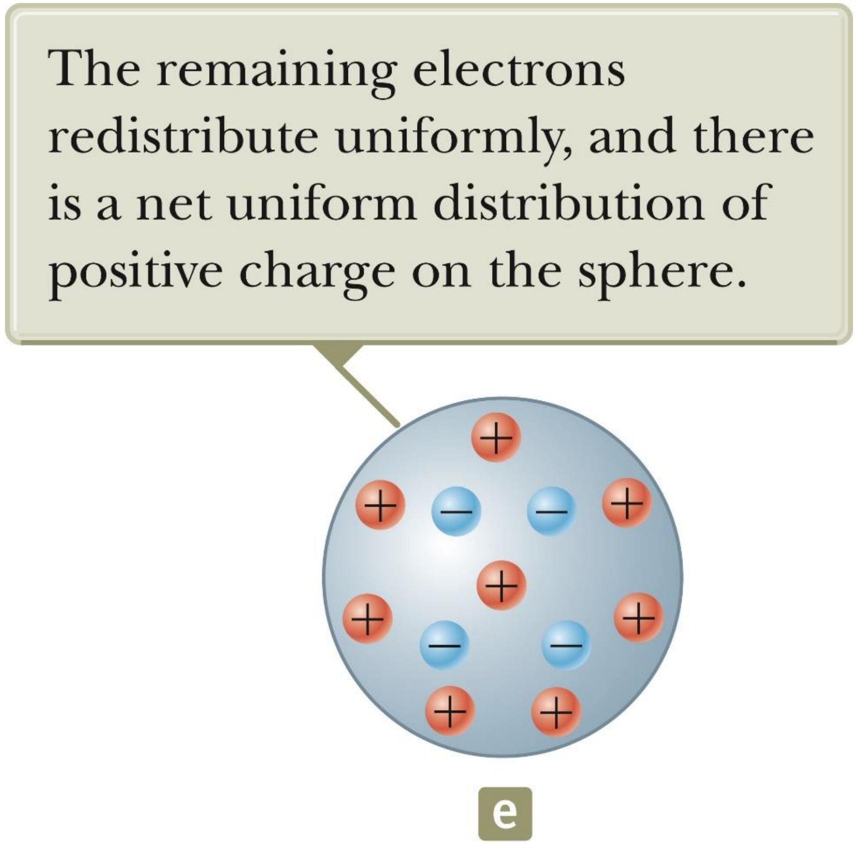
Charging by Induction, 3

- The ground wire is removed.
- There will now be more positive charges.
- The charges are not uniformly distributed.
- The positive charge has been ***induced*** in the sphere.



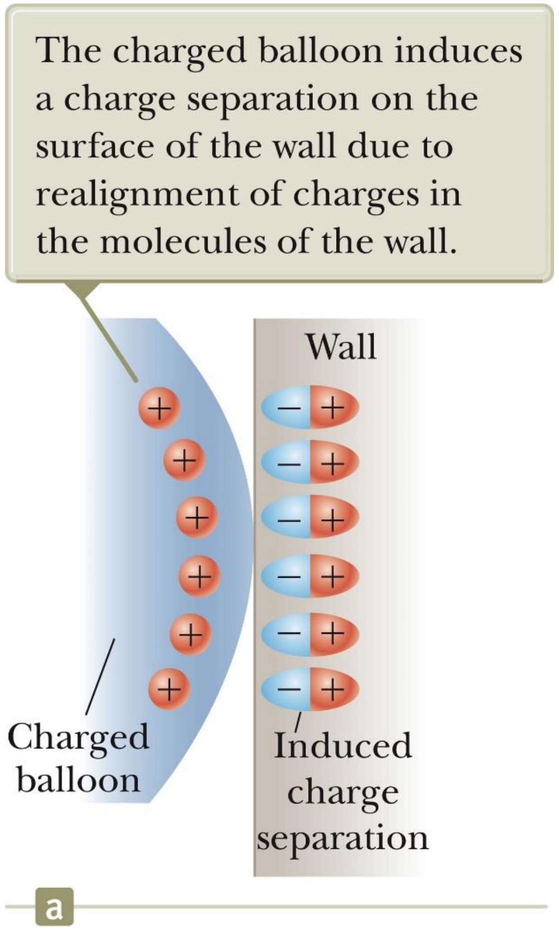
Charging by Induction, 4

- The rod is removed.
- The electrons remaining on the sphere redistribute themselves.
- There is still a net positive charge on the sphere.
- The charge is now uniformly distributed.
- Note the rod lost none of its negative charge during this process.



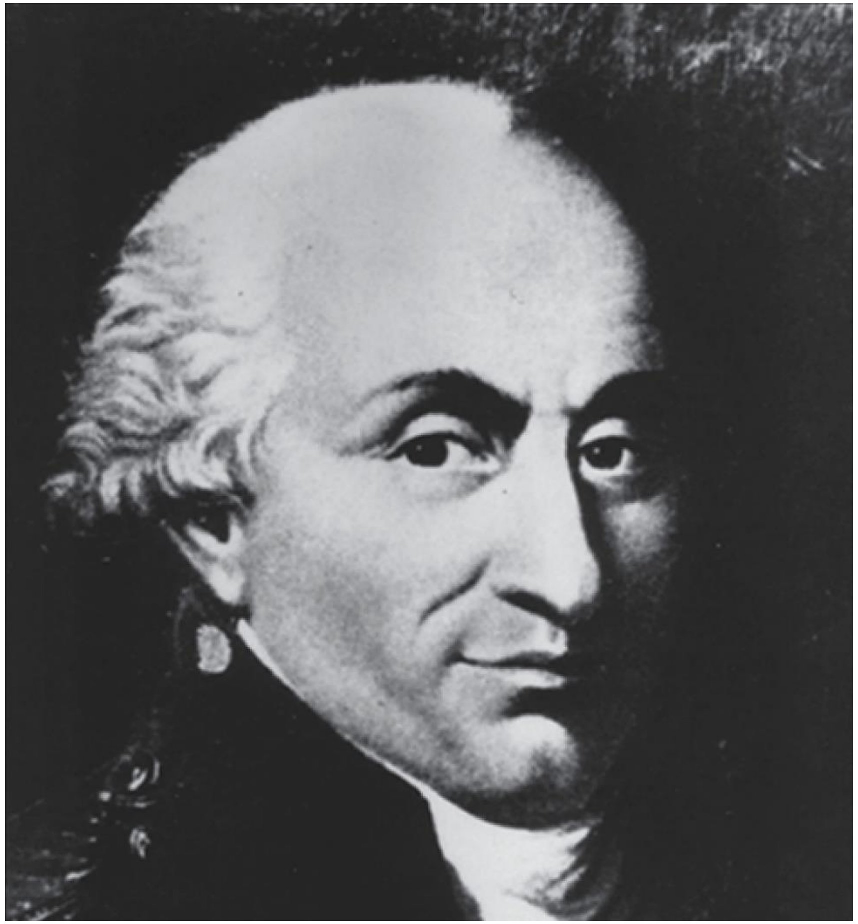
Charge Rearrangement in Insulators

- A process similar to induction can take place in insulators.
- The charges within the molecules of the material are rearranged.
- The proximity of the positive charges on the surface of the object and the negative charges on the surface of the insulator results in an attractive force between the object and the insulator.



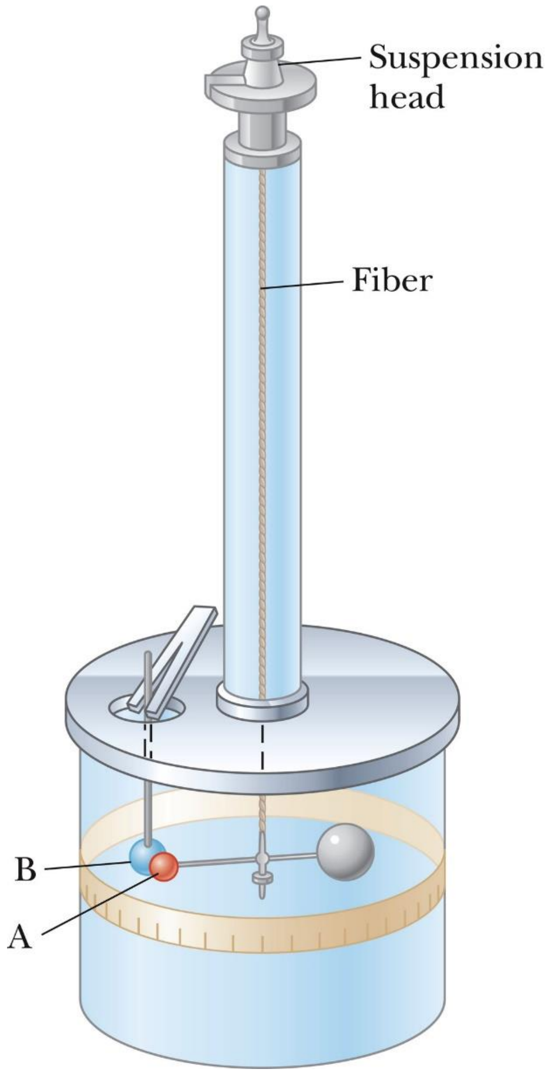
Charles Coulomb

- 1736 – 1806
- French physicist
- Major contributions were in areas of electrostatics and magnetism
- Also investigated in areas of
  - Strengths of materials
  - Structural mechanics
  - Ergonomics



Coulomb's Law

- Charles Coulomb measured the magnitudes of electric forces between two small charged spheres.
- The force is inversely proportional to the square of the separation r between the charges and directed along the line joining them.
- The force is proportional to the product of the charges, q_1 and q_2, on the two particles.
- The electrical force between two stationary point charges is given by Coulomb's Law.



Point Charge

- The term **point charge** refers to a particle of zero size that carries an electric charge.
  - The electrical behavior of electrons and protons is well described by modeling them as point charges.

Coulomb’s Law, cont.

- The force is attractive if the charges are of opposite sign.
- The force is repulsive if the charges are of like sign.
- The force is a conservative force.

Coulomb's Law, Equation

- Mathematically,

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

- The SI unit of charge is the **coulomb** ©.
- k_e is called the **Coulomb constant.**
  - k_e = 8.9876 x 10^9 N·m^2/C^2 = $1/(4\pi\varepsilon_o)$
  - ε_o is the **permittivity of free space.**
  - ε_o = 8.8542 x 10^{-12} C^2 / N·m^2

Coulomb's Law, Notes

- Remember the charges need to be in coulombs.
  - *e* is the smallest unit of charge.
    - except quarks
  - $e = 1.6 \times 10^{-19}$ C
  - So 1 C needs 6.24×10^{18} electrons or protons
- Typical charges can be in the μC range.
- Remember that force is a *vector* quantity.

Particle Summary

TABLE 23.1 *Charge and Mass of the Electron, Proton, and Neutron*

Particle	Charge (C)	Mass (kg)
Electron (e)	$-1.602\,176\,5 \times 10^{-19}$	$9.109\,4 \times 10^{-31}$
Proton (p)	$+1.602\,176\,5 \times 10^{-19}$	$1.672\,62 \times 10^{-27}$
Neutron (n)	0	$1.674\,93 \times 10^{-27}$

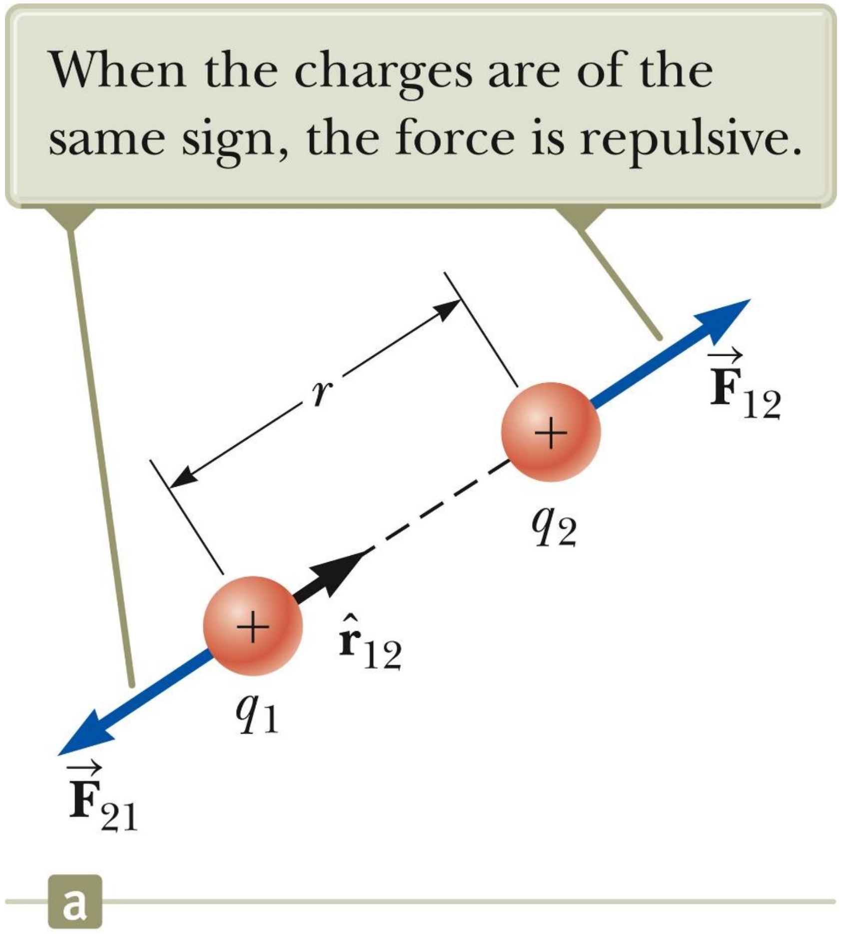
- The electron and proton are identical in the magnitude of their charge, but very different in mass.
- The proton and the neutron are similar in mass, but very different in charge.

Vector Nature of Electric Forces

- In vector form,

$$\vec{\mathbf{F}}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{12}$$

- $\hat{\mathbf{r}}_{12}$ is a unit vector directed from q_1 to q_2.
- The like charges produce a repulsive force between them.



Vector Nature of Electrical Forces, cont.

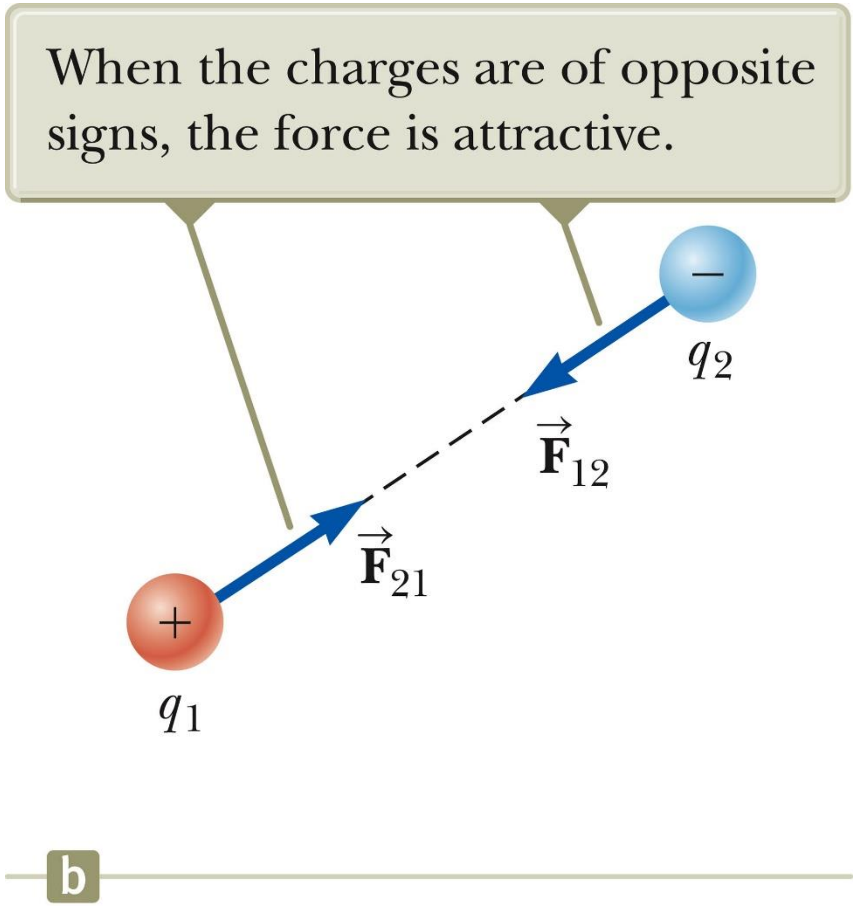
- Electrical forces obey Newton's Third Law.
- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2

$$\vec{\mathbf{F}}_{21} = -\vec{\mathbf{F}}_{12}$$

- With like signs for the charges, the product $q_1 q_2$ is positive and the force is repulsive.

Vector Nature of Electrical Forces, 3

- Two point charges are separated by a distance *r*.
- The unlike charges produce an attractive force between them.
- With unlike signs for the charges, the product $q_1 q_2$ is negative and the force is attractive.



Section 23.3

A Final Note about Directions

- The sign of the product of q_1q_2 gives the *relative* direction of the force between q_1 and $q_{2.}$
- The *absolute* direction is determined by the actual location of the charges.

Ex1. The electron and proton of a hydrogen atom are separated (on the average) by a distance of approximately 5.3 x 10^{-11} m. Find the magnitudes of the electric force and the gravitational force between the two particles.

Solution From Coulomb's law, we find that the magnitude of the electric force is

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

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

gravitational force is

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

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

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

The ratio $F_e/F_g \approx 2 \times 10^{39}$. Thus, the gravitational force between charged atomic particles is negligible when compared with the electric force. Note the similarity of form of Newton's law of universal gravitation and Coulomb's law of electric forces. Other than magnitude, what is a fundamental difference between the two forces?

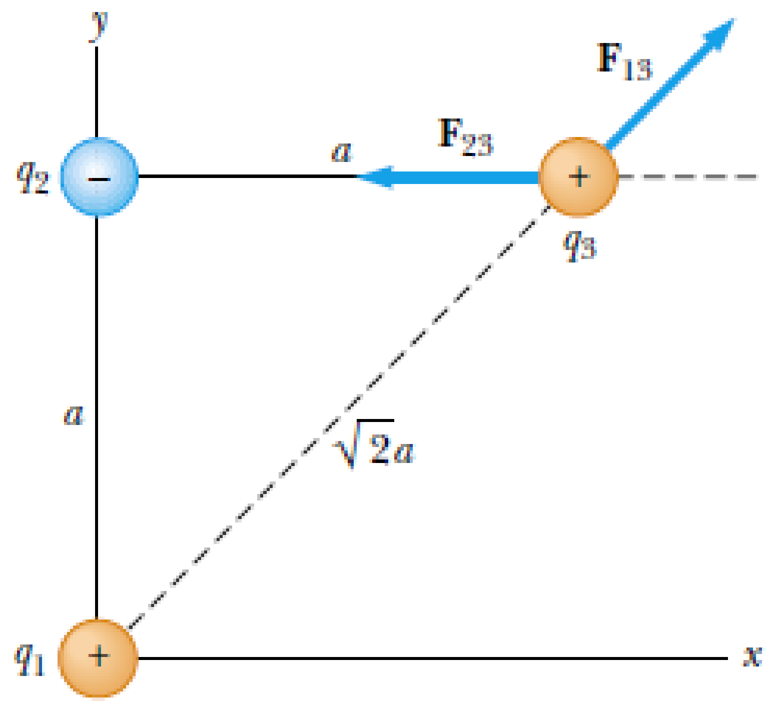
Multiple Charges

- The resultant force on any one charge equals the vector sum of the forces exerted by the other individual charges that are present.
  - Remember to add the forces *as vectors*.
- The resultant force on q_1 is the vector sum of all the forces exerted on it by other charges.

$$\vec{\mathbf{F}}_1 = \vec{\mathbf{F}}_{21} + \vec{\mathbf{F}}_{31} + \vec{\mathbf{F}}_{41}$$

- For example, if four charges are present, the resultant force on one of these equals the vector sum of the forces exerted on it by each of the other charges.

Ex.2 Consider three point charges located at the corners of a right triangle as shown in Figure, where $q1 = q3 = 5.0$ μC, q2 =- 2.0 μC, and a = 0.10 m. Find the resultant force exerted on q3.



The magnitude of $\mathbf{F}_{23}$ is

$$F_{23} = k_e \frac{|q_2||q_3|}{a^2}$$

$$= (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2})\ \frac{(2.0 \times 10^{-6}\ \mathrm{C})(5.0 \times 10^{-6}\ \mathrm{C})}{(0.10\ \mathrm{m})^2}$$

$$= 9.0\ \mathrm{N}$$

The magnitude of the force $\mathbf{F}_{13}$ exerted by q_1 on q_3 is

$$F_{13} = k_e \frac{|q_1||q_3|}{(\sqrt{2}a)^2}$$

$$= (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2})\ \frac{(5.0 \times 10^{-6}\ \mathrm{C})(5.0 \times 10^{-6}\ \mathrm{C})}{2(0.10\ \mathrm{m})^2}$$

$$= 11\ \mathrm{N}$$

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

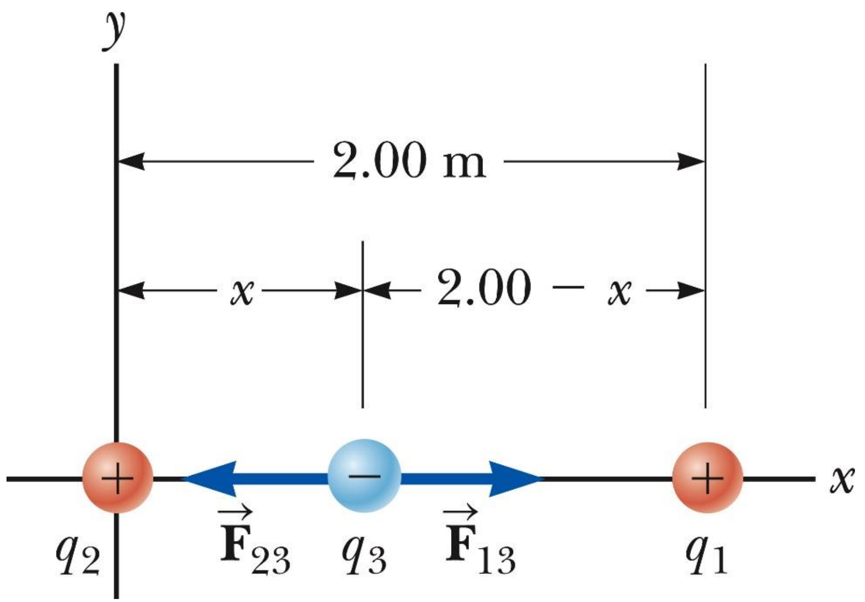
$$F_{3y} = F_{13y} + F_{23y} = 7.9\ \text{N} + 0 = 7.9\ \text{N}$$

We can also express the resultant force acting on q_3 in unit-vector form as

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

Zero Resultant Force, Example

- Where is the resultant force equal to zero?
  - The magnitudes of the individual forces will be equal.
  - Directions will be opposite.
- Will result in a quadratic
- Choose the root that gives the forces in opposite directions.



Section 23.3

$$F_{13} = k_e \frac{|q_1||q_3|}{(2.00 - x)^2} \qquad F_{23} = k_e \frac{|q_2||q_3|}{x^2}$$

For the resultant force on q_3 to be zero, $\mathbf{F}_{23}$ must be equal in magnitude and opposite in direction to $\mathbf{F}_{13}$. Setting the magnitudes of the two forces equal, we have

$$k_e \frac{|q_2||q_3|}{x^2} = k_e \frac{|q_1||q_3|}{(2.00 - x)^2}$$

Noting that k_e and $|q_3|$ are common to both sides and so can be dropped, we solve for x and find that

$$(2.00 - x)^2 |q_2| = x^2 |q_1|$$

$$(4.00 - 4.00x + x^2)(6.00 \times 10^{-6}\ \text{C}) = x^2(15.0 \times 10^{-6}\ \text{C})$$

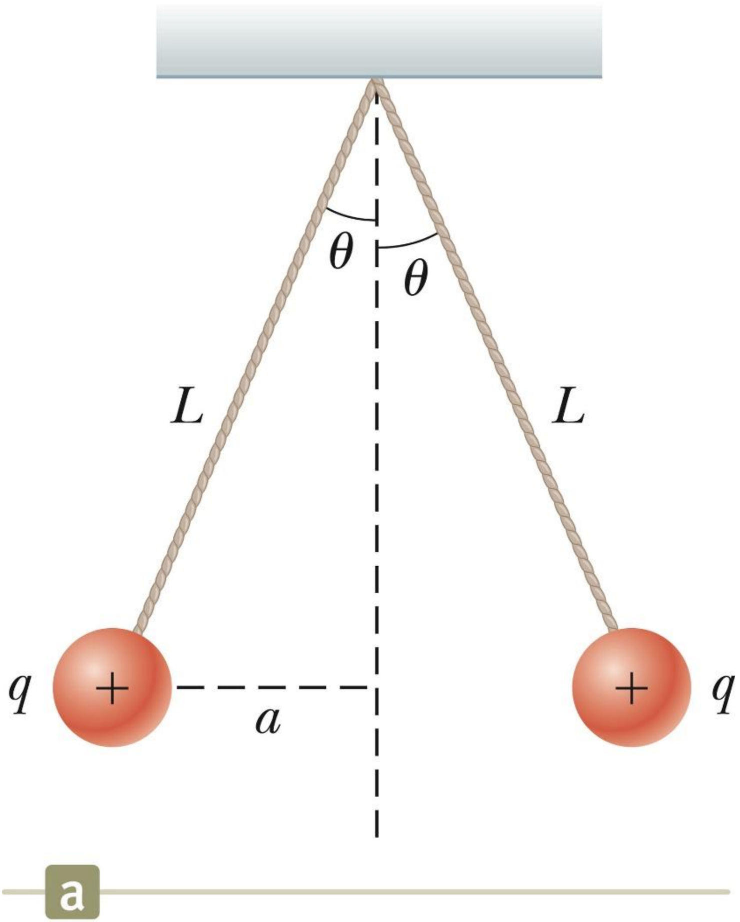
This can be reduced to the following quadratic equation:

$$3.00x^2 + 8.00x - 8.00 = 0$$

Solving this quadratic equation for x, we find that the positive root is $x =$ 0.775 m. There is also a second root, $x = -3.44$ m. This is another location at which the magnitudes of the forces on q_3 are equal, but both forces are in the same direction at this location.

Electrical Force with Other Forces, Example

- The spheres are in equilibrium.
- Since they are separated, they exert a repulsive force on each other.
  - Charges are like charges
- Model each sphere as a particle in equilibrium.
- Proceed as usual with equilibrium problems, noting one force is an electrical force.



Electrical Force with Other Forces, Example cont.

- The force diagram includes the components of the tension, the electrical force, and the weight.
- Solve for $|q|$
- If the charge of the spheres is not given, you cannot determine the sign of q, only that they both have same sign.