Part I: Electricity

Chapter 23

Electric Fields

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LECTURE OUTLINE

- **23.1** Properties of Electric Charges
- **23.3** Coulomb's Law
- **23.4** Analysis Model: Particle in a Field (Electric)
- **23.6** Electric Field Lines

23.1 Properties of 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

Like charges **repel** and **unlike** charges **attract** one another

❖ تتجاذب الشحنات المختلفة في النوع ، وتتنافر الشحنات المتشابهة.

❖ تكون شحنة الجسيمات الأولية إما صفرا مثل النيترونات، أو أعدادا صحيحة لشحنة الإلكترون.

23.1 Properties of Electric Charges

The smallest unit of free charge *e* known in nature, the charge on an electron (-*e*) or a proton (+*e*), has a magnitude $e = 1.602\times 10^{-19}$ C

تعتبر شحنة الإلكترون أصغر شحنة سالبة، وشحنة البروتون أصغر شحنة موجبة

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	$1.674\,93 \times 10^{-27}$

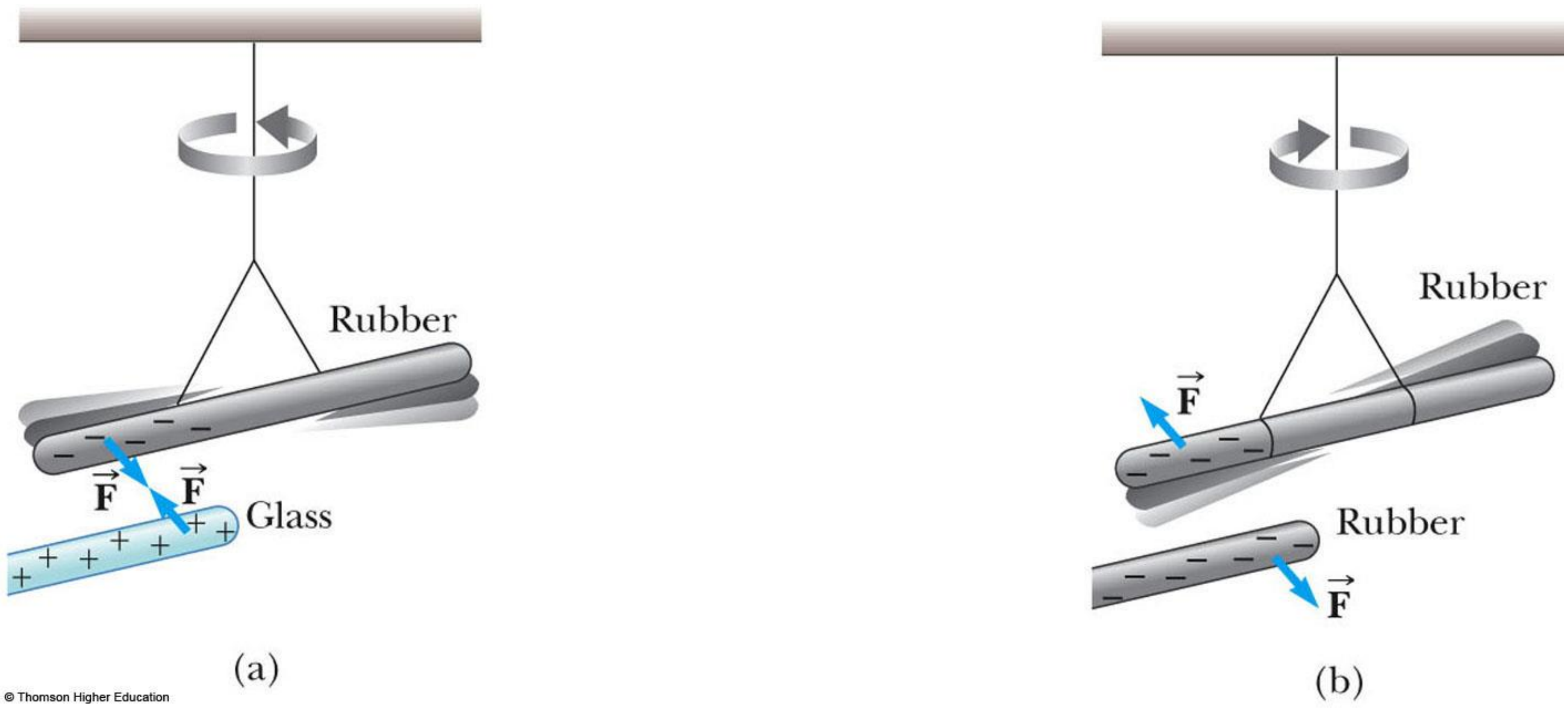
23.1 Properties of Electric Charges

- Nature's basic carrier of positive charge is the proton
  - Protons do not move from one material to another because they are held firmly in the nucleus
- Nature's basic carrier of negative charge is the electron
  - Gaining or losing electrons is how an object becomes charged
- Electric charge is always conserved
  - Charge is not created, only exchanged
  - Objects become charged because negative charge is transferred from one object to another

23.1 Properties of Electric Charges

- Charge is quantized
  - All charge is a multiple of a fundamental unit of charge, symbolized by e ($q=Ne$ where N: number of charge)
    - Quarks are the exception
  - Electrons have a charge of –e
  - Protons have a charge of +e
  - The SI unit of charge is the Coulomb (C)

23.1 Properties of Electric Charges

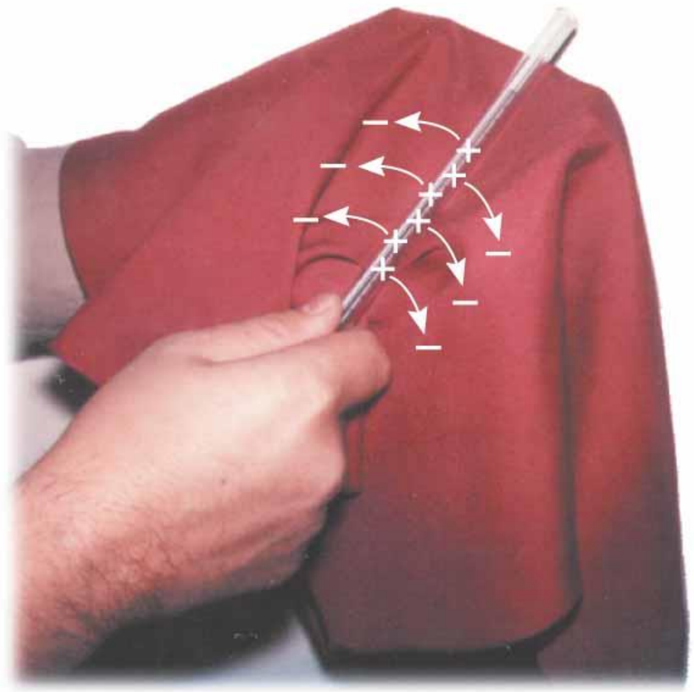


- The rubber rod is negatively charged
- The glass rod is positively charged
- The two rods will **attract**

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

23.1 Properties 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



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

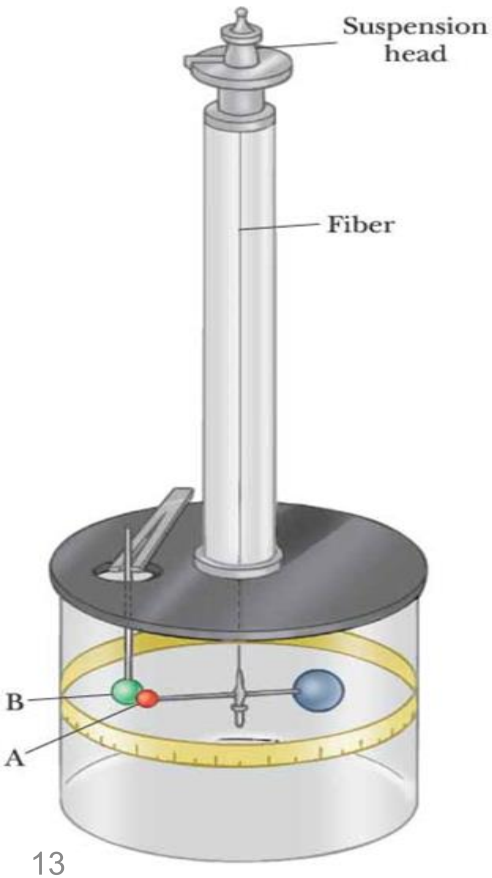
- The electrical properties of semiconductors are somewhere between those of insulators and conductors
- Examples of semiconductor materials include silicon and germanium

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

23.3 Coulomb's Law

ميزان الإلتواء لكولوم لتحقيق قانون التربيع العكسي لقوة كهربية بين شحنتين



- 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

$$F \alpha \frac{q_1 q_2}{r^2}$$

$$F = K_e \frac{q_1 q_2}{r^2}$$

23.3 Coulomb's Law

- Mathematically,

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

- The SI unit of charge is the **coulomb** (C)
- k_e is called the **Coulomb constant**
  - $k_e = 8.9876 \times 10^9\ N{\cdot}m^2/C^2 = 1/(4\pi e_o)$
  - ε_o is the **permittivity of free space** سماحية الفراغ
  - $e_o = 8.8542 \times 10^{-12}\ C^2 / N{\cdot}m^2$
- Typical charges can be in the µC range
  - Remember, Coulombs must be used in the equation
- Remember that force is a *vector* quantity
- Applies only to point charges

23.3 Coulomb's Law

- The electrical force between two stationary point charges is given by Coulomb's Law
- 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 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

23.3 Coulomb's Law

- 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

Electric force & the gravitational force between the two particles.

مقارنة بين القوة الكهربية والقوة الميكانيكية

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

- يدور إلكترون واحد حول البروتون في ذرة الهيدروجين وذلك في مدار دائري نصف قطره $5.29 \mathrm{x} 10^{-11}$ متر. قارن بين قوتي الجذب الكهربية (الكولومية) والميكانيكية (النيوتونية) بينهما؟

Electric force & the gravitational force between the two particles.

مقارنة بين القوة الكهربية والقوة الميكانيكية

- القوة الكهربية

$$F_e = K_e \frac{q_e q_p}{r^2} = 9\times10^9 \frac{\left(1.6\times10^{-19}\right)^2}{\left(5.29\times10^{-11}\right)^2} = 8.2\times10^{-8}\,N$$

- القوة الميكانيكية

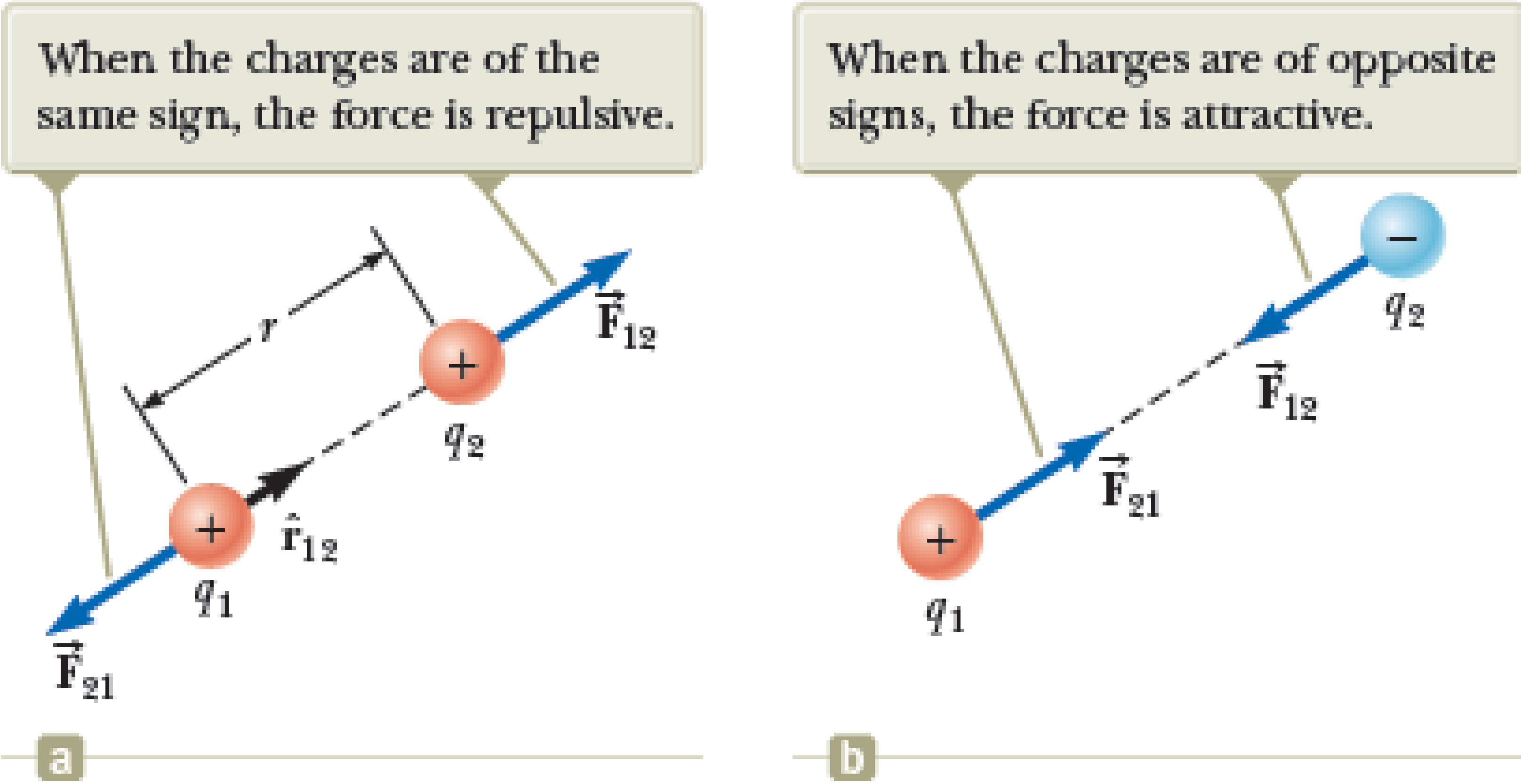
$$F_m = G\frac{m_e m_p}{r^2} = 6.67\times10^{-11}\frac{\left(9.1095\times10^{-31}\right)\left(1.67261\times10^{-27}\right)}{\left(5.29\times10^{-11}\right)^2} = 3.7\times10^{-47}\,N$$

Therefore, the gravitational force between charged atomic particles is negligible when compared with the electric force.

وهذا فرق كبير جدا بين القوتين، لذا من الممكن إهمال قوة الجذب النيوتونية في الفيزياء الذرية

23.3 Coulomb’s Law

قوى تنافر بين شحنتين   قوى تجاذب بين شحنتين

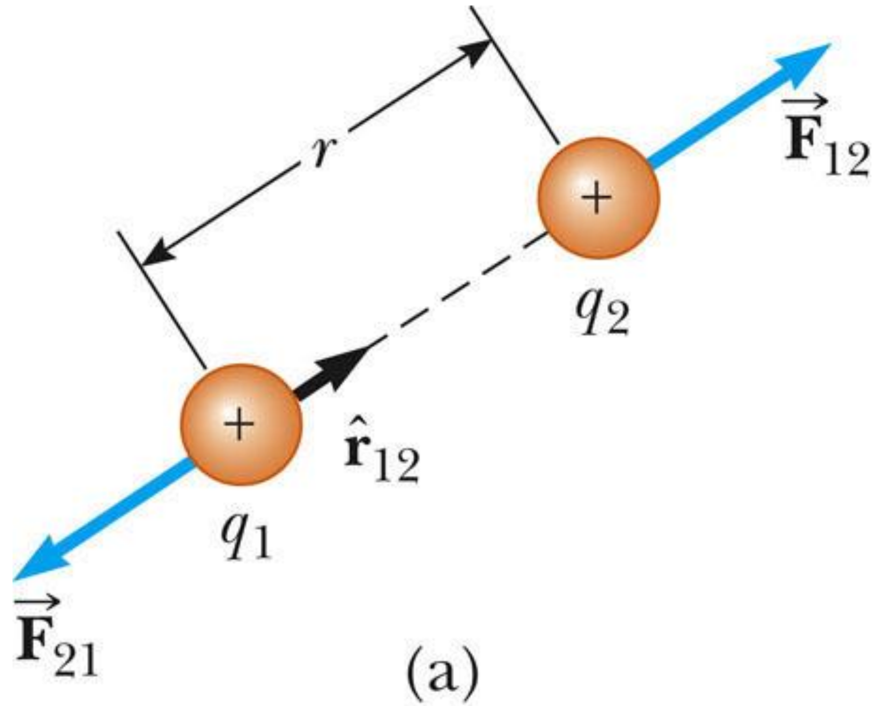


Vector Nature of Electric Forces, 1

- In vector form,

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

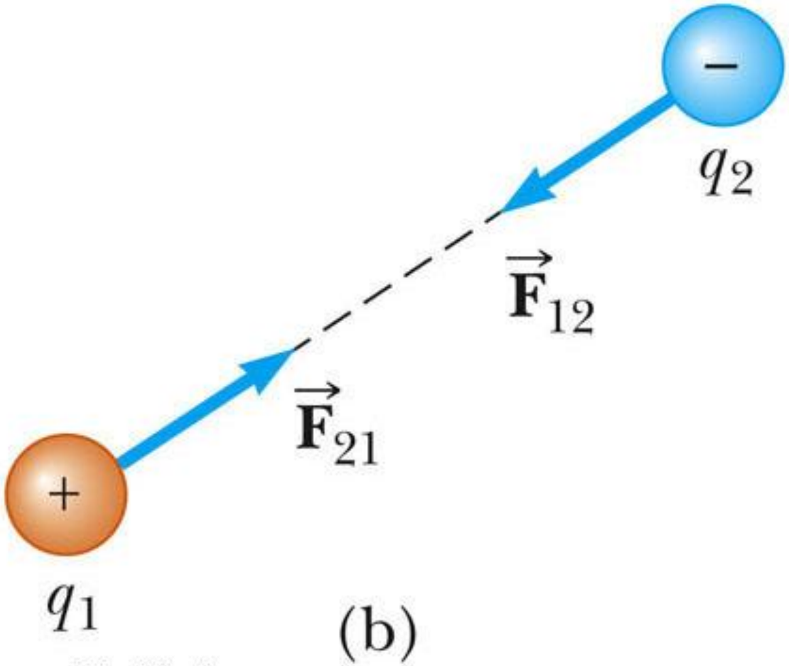
- Two point charges are separated by a distance r
- $\hat{\mathbf{r}}_{12}$ is a unit vector directed from q_1 to q_2
- The like charges produce a repulsive force between them
- Use the active figure to move the charges and observe the force



- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2

Vector Nature of Electrical Forces, 2

- 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
  - Use the active figure to investigate the force for different positions



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- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2

Vector Nature of Electrical Forces, 3

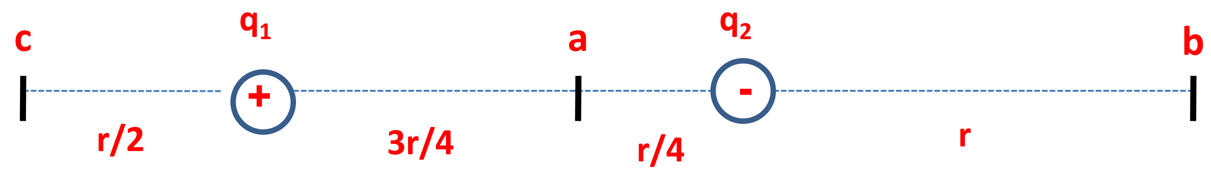
- Electrical forces obey Newton's Third Law
- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2 $\vec{\mathbf{F}}_{21} = -\vec{\mathbf{F}}_{12}$
- With like signs for the charges, the product $q_1 q_2$ is positive and the force is repulsive
- The sign of the product of $q_1 q_2$ 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

Electric forces: Examples

Tow point charges lie along the *x* axis as shown in Figure. Calculate the net force acting on q_3? If the **$q_1=q_2=0.64\ \mu C$, $q_3=0.32\ \mu C$, $r=8$ cm**

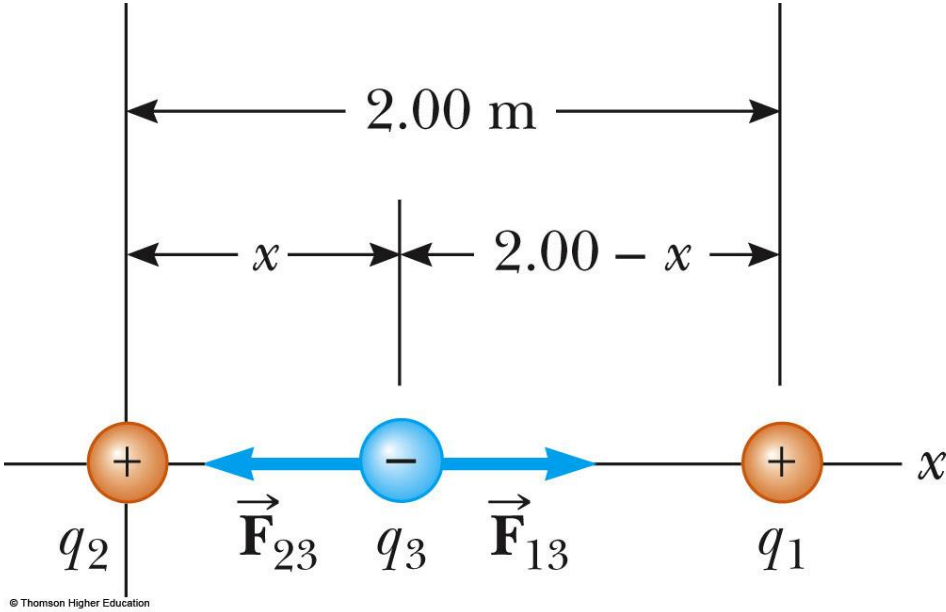
شحنتان نقطيتان متساويتان هما q_1 q_2 إحداهما موجبة والأخرى سالبة، تفصلهما مسافة مقدارها r. احسب القوة المؤثرة على شحنة ثالثة موجبة q_3 إذا وقعت عند النقاط c, b, a إذا علمت أن:

$q_1=q_2=0.64\ \mu C$, $q_3=0.32\ \mu C$, $r=8$ cm



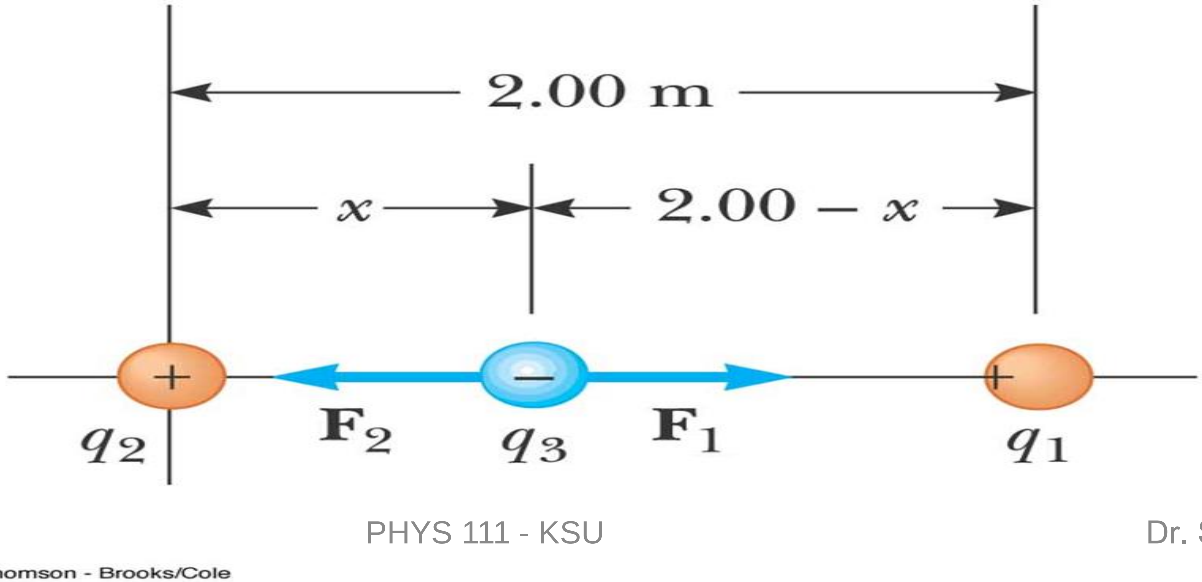
Zero Resultant Force, Example

- 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



Zero Resultant Force, Example

Three point charges lie along the *x* axis as shown in Figure. The positive charge q_1=15µC is at x=2m, the positive charge q_2=6 µC is at the origin, and the net force acting on q_3 is zero. What is the *x* coordinate of q_3?



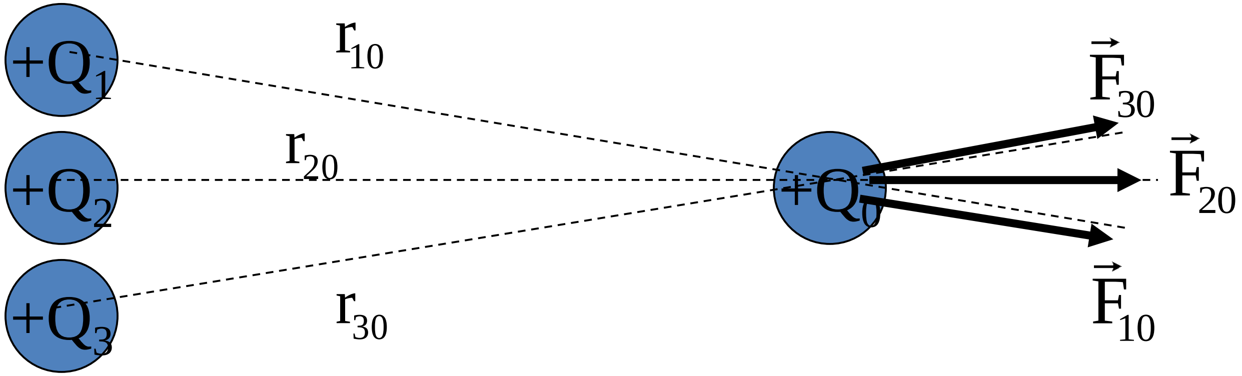
The Superposition Principle

- 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:

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

Superposition of Forces

$$\vec{F}_0 = \vec{F}_{10} + \vec{F}_{20} + \vec{F}_{30} + ...$$

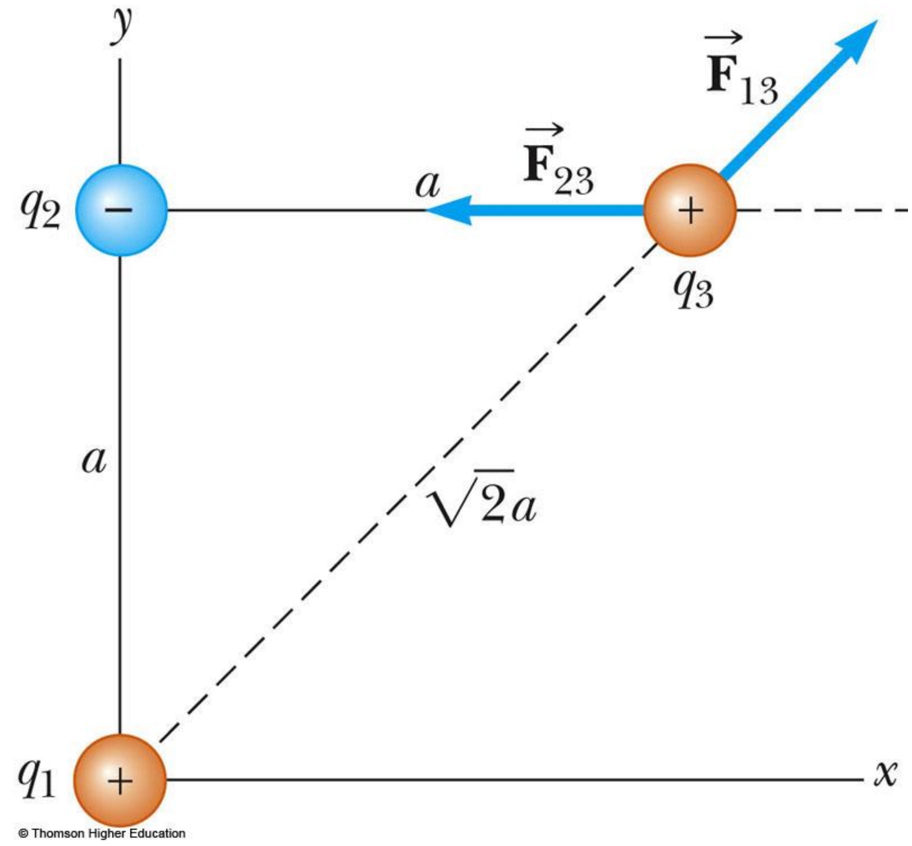


$$\vec{F}_0 = \frac{kq_0q_1}{r_{10}^2}\hat{r}_{10} + \frac{kq_0q_2}{r_{20}^2}\hat{r}_{20} + \frac{kq_0q_3}{r_{30}^2}\hat{r}_{30} + ...$$

$$\vec{F}_0 = kq_0\left(\frac{q_1}{r_{10}^2}\hat{r}_{10} + \frac{q_2}{r_{20}^2}\hat{r}_{20} + \frac{q_3}{r_{30}^2}\hat{r}_{30} + ...\right) = kq_0\sum_{i=1}^{N}\frac{q_i}{r_{i0}^2}\hat{r}_{i0}$$

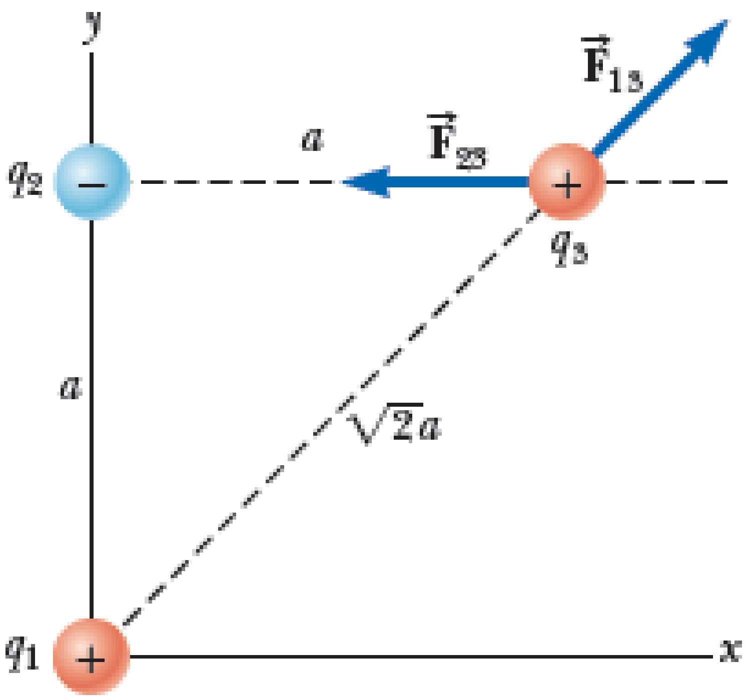
Superposition Principle, Example

- The force exerted by q_1 on q_3 is $\vec{\mathbf{F}}_{13}$
- The force exerted by q_2 on q_3 is $\vec{\mathbf{F}}_{23}$
- The *resultant force* exerted on q_3 is the vector sum of $\vec{\mathbf{F}}_{13}$ and $\vec{\mathbf{F}}_{23}$



Superposition Principle, Example

Consider three point charges located at the corners of a right triangle as shown in Figure, where $q_1 = q_3 =$ 5mC, $q_2 =$ 22mC, and $a =$ 0.100 m. Find the resultant force exerted on q_3.



Quick Quiz

Object A has a charge of 12 μC, and object B has a charge of 16μC. Which statement is true about the electric forces on the objects?

(a) $\vec{A}_{AB} = -3\,\vec{A}_{BA}$

(b) $\vec{A}_{AB} = -\,\vec{A}_{BA}$

(c) $3\vec{A}_{AB} = -\,\vec{A}_{BA}$

(d) $\vec{A}_{AB} = 3\,\vec{A}_{BA}$

(e) $\vec{A}_{AB} = \vec{A}_{BA}$

(f) $3\vec{A}_{AB} = \vec{A}_{BA}$

Quick Quiz

Quick Quiz 23.3 Object A has a charge of $+2\ \mu C$, and object B has a charge of $+6\ \mu C$. Which statement is true about the electric forces on the objects? (a) $\vec{F}_{AB} = -3\vec{F}_{BA}$ (b) $\vec{F}_{AB} = -\vec{F}_{BA}$ (c) $3\vec{F}_{AB} = -\vec{F}_{BA}$ (d) $\vec{F}_{AB} = 3\vec{F}_{BA}$ (e) $\vec{F}_{AB} = \vec{F}_{BA}$ (f) $3\vec{F}_{AB} = \vec{F}_{BA}$

Quick Quiz 23.4 A test charge of $+3\ \mu C$ is at a point P where an external electric field is directed to the right and has a magnitude of 4×10^6 N/C. If the test charge is replaced with another test charge of $-3\ \mu C$, what happens to the external electric field at P? (a) It is unaffected. (b) It reverses direction. (c) It changes in a way that cannot be determined.

Summary الخلاصة

$$F = K_e \frac{q_1 \, q_2}{r^2}$$

Coulomb's law states that the electric force exerted by a charge $\boldsymbol{q_1}$ on a second charge $\boldsymbol{q_2}$ is

- قانون كولوم

- 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

Thank You

ACKNOWLEDGEMENTS