Edgenuity

Warm-Up | Coulomb's Law

Lesson Question

What is Coulomb's law?

Lesson Goals

Examine the factors that affect the electrical force between two objects.

Compare electrical force with gravitational force.

Solve problems using Coulomb's law.

Words to Know

Write the letter of the definition next to the matching word as you work through the lesson. You may use the glossary to help you.

D Coulomb's law

C superposition principle

B Coulomb's constant

A Newton's third law of motion

A. the law that states for every action there is an equal and opposite reaction

B. a proportionality constant equal to $8.99 \times 10^9 \text{ N} \frac{\text{m}^2}{\text{C}^2}$ and designated by a lowercase *k*

C. the principle that states the net electrical force on a specific charge is equal to the sum of the vector components of the charges applying electrical forces on it

D. the law that states the force of attraction or repulsion between two charges is affected by the amount of charge and the square of the distance between the two charges

Warm-Up | Coulomb's Law

Electrical Force on a Charged Particle in an Electric Field

- An electrical force is a force between two charged particles, ions, or objects.
  - q = electric charge
    - It can be positive or negative.
    - SI unit is the coulomb (C).
  - E = electric field

$$F = qE$$

Instruction | Coulomb's Law

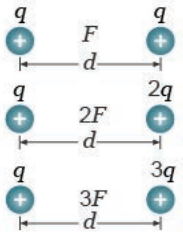
Slide 2

Direction of Electrical Force

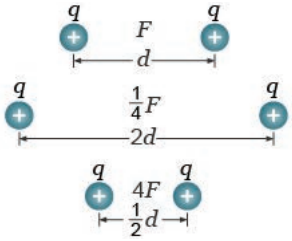
- The electrical force is a vector that has both magnitude and direction.
- The direction of electrical force is based on the facts that:
  - like charges will repel and move [away] from each other.
  - unlike charges will attract and move toward each other.
  - [neutral] charges will neither attract nor repel.

Electrical Force

- Regardless of the value of the charge, any two charges obey **Newton's third law of motion** and will exert an [equal] and opposite electrical force on each other.



The electrical force between two charges is [directly] proportional to the product of the amount of charge on the charges.



The electrical force between two charges is [inversely] proportional to the square of the distance between the charges.

Instruction | Coulomb's Law

Slide 4

Coulomb's Law

- **Coulomb's law** states that the force of attraction or repulsion between two charges is affected by the amount of [charge] and the square of the [distance] between the two charges.
  - **Coulomb's constant** (k) is $8.99 \times 10^9 \text{ N} \cdot \frac{\text{m}^2}{\text{C}^2}$
  - Electrical force in units of newtons (N)
  - Charge (q) in units of coulombs (C)
  - Distance in units of meters (m)

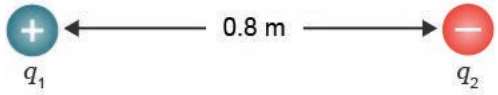
$$F_e = \text{k}\frac{q_1 q_2}{d^2}$$

Electrical Force between Two Charges

EXAMPLE

A positive charge q_1 of 5 µC is on the x-axis. A negative charge q_2 of 7 µC is 0.8 meters away. Find the force and direction applied by q_1 on q_2.

- Given:
  - $q_1 = 5 \text{ µC} = 5 \times 10^{-6} \text{ C}$
  - $q_2 = -7 \text{ µC} = 5 \times 10^{-6} \text{ C}$
  - $d = 0.8 \text{ m}$
- Unknown: F_e
- Equation to use: $F_e = \text{k}\frac{q_1 q_2}{d^2}$



Instruction | Coulomb's Law

Slide 4

Electrical Force between Two Charges

$$F_{12} = \mathrm{k}\frac{q_1 q_2}{d^2}$$

$$F_{12} = \left(8.99 \times 10^9\ \mathrm{N} \cdot \frac{\mathrm{m}^2}{\mathrm{C}^2}\right)\left(\frac{5 \times 10^{-6}\ \mathrm{C} \times (-7 \times 10^{-6}\ \mathrm{C})}{(0.8\ \mathrm{m})^2}\right)$$

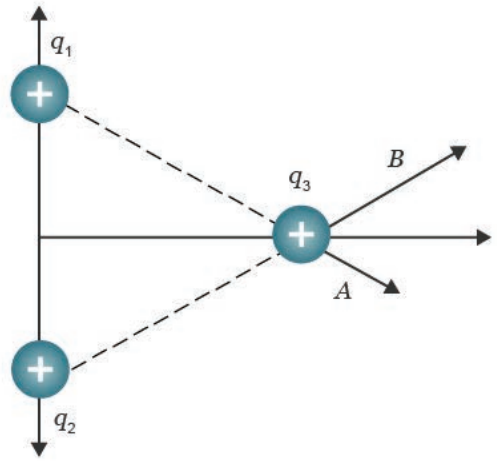
$$F_{12} = \left(\frac{-0.315\ \mathrm{N}}{0.64}\right)$$

$$= \boxed{-0.49\ \mathrm{N}}$$

Slide 7

Superposition Principle

- The **superposition principle** states that the net [electrical] force on a specific charge is equal to the sum of the [vector] components of the charges applying forces on it.



Instruction | Coulomb's Law

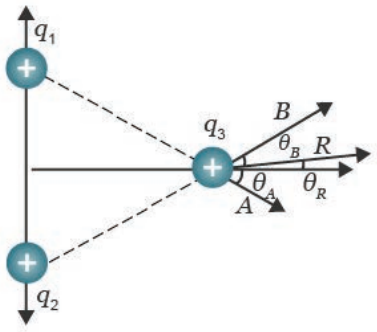
Slide 7

Steps of the Superposition Principle, Part 1

STRATEGY

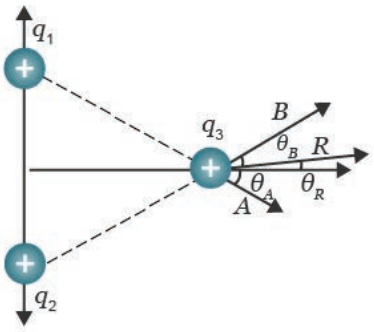
- Suppose that q_3 is placed in a field containing q_1 and q_2. As a result, q_1 and q_2 repel q_3. Find the magnitude and direction of the resulting vector R.

1. Define vectors A and B.
2. Calculate the magnitudes for vectors A and B.
3. Calculate the x and y components, including the angles, of each vector.



Steps of the Superposition Principle, Part 2

4. Sum the vector components of A and B to find the vector components of R.
5. Calculate the magnitude of vector R.
6. Calculate the direction of θ_R.



Instruction | Coulomb's Law

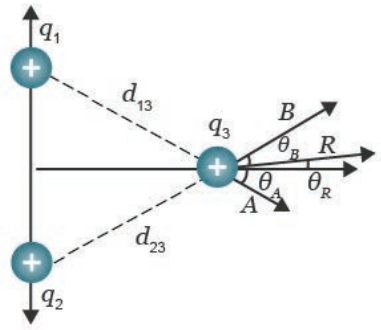
Slide 9

Solve a Two-Dimensional Problem, Part 1

EXAMPLE

A 3 μC charge q_1 and a 6 μC charge q_2 are 0.05 m from the *x*-axis. A 6 μC charge q_3 is 0.12 m from the *y*-axis. The distances d_{13} and d_{23} are 0.13 m. Find the magnitude and direction of the resulting vector *R*. Step 1, identify vectors *A* and *B*, is done in the diagram.

- Step 2: Calculate the magnitudes of vectors *A* and *B*.
  - $A = k\dfrac{(3\times10^{-6}\,\text{C})(6\times10^{-6}\,\text{C})}{(0.13\,\text{m})^2} =$ 9.6 N
  - $B = k\dfrac{(6\times10^{-6}\,\text{C})(6\times10^{-6}\,\text{C})}{(0.13\,\text{m})^2} =$ 19.2 N



Instruction | Coulomb's Law

Slide 9

Solve a Two-Dimensional Problem, Part 2

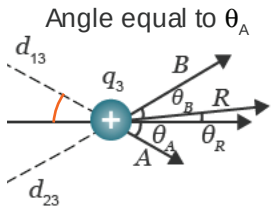
A 3 μC charge q_1 and a 6 μC charge q_2 are 0.05 m from the *x*-axis. A 6 μC charge q_3 is 0.12 m from the *y*-axis. The distances d_{13} and d_{23} are 0.13 m. Find the magnitude and direction of the resulting vector *R*. Step 1, identify vectors *A* and *B*, is done in the diagram.

- Step 3: Calculate the *x*, *y* components of vector *A*.
  - $F_{Ax} = A\cos\theta = (9.6\text{ N})(\cos(23°)) =$ **8.8 N**
  - $F_{Ay} = -A\sin\theta = (-9.6\text{ N})(\sin(23°)) =$ **−3.8 N**

$$\text{Sin}\,\theta = \frac{\text{opp}}{\text{hyp}}$$

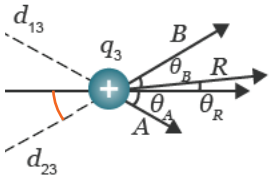
$$= \frac{0.05\text{ m}}{0.13\text{ m}}$$

$$\sin^{-1}\left(\frac{0.05\text{ m}}{0.13\text{ m}}\right) = \theta = \textbf{23°}$$



Solve a Two-Dimensional Problem, Part 3

A 3 μC charge q_1 and a 6 μC charge q_2 are 0.05 m from the *x*-axis. A 6 μC charge q_3 is 0.12 m from the *y*-axis. The distances d_{13} and d_{23} are 0.13 m. Find the magnitude and direction of the resulting vector *R*. Step 1, identify vectors *A* and *B*, is done in the diagram.



Angle equal to θ_B

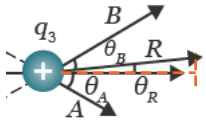
- Step 3 continued: Calculate the *x*, *y* components of vector *B*.
  - $F_{Bx} = B\cos\theta = (19.2\text{ N})(\cos(23°)) =$ **17.7 N**
  - $F_{By} = B\sin\theta = (19.2\text{ N})(\sin(23°)) =$ **7.5 N**

Solve a Two-Dimensional Problem, Part 4

EXAMPLE

A 3 μC charge q_1 and a 6 μC charge q_2 are 0.05 m from the *x*-axis. A 6 μC charge q_3 is 0.12 m from the *y*-axis. The distances d_{13} and d_{23} are 0.13 m. Find the magnitude and direction of the resulting vector *R*. Step 1, identify vectors *A* and *B*, is done in the diagram.

- Step 4: Sum the *x*, *y* components of vectors *A* and *B* to get the *x*, *y* components of vector *R*.
  - $R_x = F_{Ax} + F_{By} =$ 8.8 N + 17.7 N $= 26.5\,\text{N}$
  - $R_y = F_{Ay} + F_{By} = -3.8\,\text{N} + 7.5\,\text{N} =$ 3.7 N

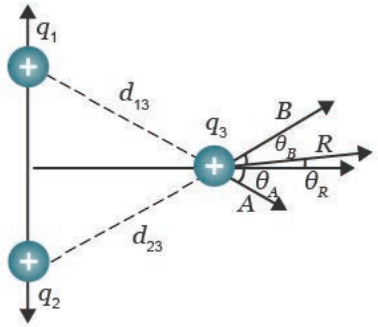


Solve a Two-Dimensional Problem, Part 5

A 3 μC charge q_1 and a 6 μC charge q_2 are 0.05 m from the *x*-axis. A 6 μC charge q_3 is 0.12 m from the *y*-axis. The distances d_{13} and d_{23} are 0.13 m. Find the magnitude and direction of the resulting vector *R*. Step 1, identify vectors *A* and *B*, is done in the diagram.

- Step 5: Calculate the magnitude of *R*.
  - $R = \sqrt{R_x^2 + R_y^2} = \sqrt{(26.5\,\text{N})^2 + (3.7\,\text{N})^2}$

    $=$ 26.8 N
- Step 6: Calculate the direction of *R* (ϑ_R).
  - $\theta_R = tan^{-1}\dfrac{R_y}{R_x} = tan^{-1}\dfrac{3.7\,\text{N}}{26.5\,\text{N}} = 7.9°$



Instruction | Coulomb's Law

Slide 11

Double Check the Answer

- Solution:
  - *R* has a magnitude of [26.9 N] and is 7.9° north of east.
- Quick check:
  - 7.9° north of east is located between vectors *A* and *B*, as expected.
  - Vector *R* is [longer] than either *A* or *B*.

Slide 14

Coulomb's Law and the Universal Law of Gravitation

- Both Coulomb's law and the universal law of gravitation have an infinite reach.
- Electrical force can be either attractive or repulsive.
- Gravitational force is only [attractive].

Force	Formula	Constant	Directly Proportional to	Inversely Proportional to
electrical	$F_e = \mathrm{k}\frac{q_1 q_2}{d^2}$	$8.99 \times 10^9 \,\mathrm{N} \cdot \frac{\mathrm{m}^2}{\mathrm{C}^2}$	charge	distance squared
gravitational	$F_g = \mathrm{G}\frac{m_1 m_2}{d^2}$	$6.67 \times 10^{-11} \,\mathrm{N} \cdot \frac{\mathrm{m}^2}{\mathrm{kg}^2}$	mass	distance squared

Slide 16

Gravitational Force on Hydrogen Atom

Compare the electrical and gravitational forces between the proton and electron in a hydrogen atom, assuming an average separation distance of $5.29 \times 10^{-11}\,\text{m}$ 5.29×10^{-11}.

- Mass of an electron: $9.11 \times 10^{-31}\ \text{kg}$
- Mass of a proton: $1.673 \times 10^{-27}\ \text{kg}$
- Charge of an electron: $1.61 \times 10^{-19}\ \text{C}$
- Charge of a proton: $1.61 \times 10^{-19}\ \text{C}$
- $F_g = \text{G}\frac{m_1 m_2}{d^2} =$ $3.63 \times 10^{-47}\,\text{N}$
- $F_e = \text{k}\frac{q_1 q_2}{d^2} =$ $8.83 \times 10^{-8}\,\text{N}$
- $\frac{F_e}{F_g} = \frac{8.83 \times 10^{-8}\,\text{N}}{3.63 \times 10^{-47}\,\text{N}} =$ 2.29×10^{39}
- The electrical force 2.29×10^{39} times stronger than gravity.

Summary | Coulomb's Law

Lesson Question

What is Coulomb's law?

Answer

(Sample answer) Coulomb's law states that the force of attraction between two charges is affected by the amount of charge and the square of the distance between the two charges. The force is proportional to $\frac{1}{r^2}$.

Slide 2

Review: Key concepts

- Coulomb's law states that the force of [attraction] or repulsion between two charges is affected by the amount of charge and the square of the [distance] between the two charges.
  - $F_e = k\frac{q_1 q_2}{d^2}$
- To solve problems involving multiple charges, follow these six steps.
  - Define vectors *A* and *B*.
  - Calculate the magnitudes for vectors *A* and *B*.
  - Calculate the *x* and *y* components, including the angles, of each vector.
  - Sum the vector components of *A* and *B* to find the vector components of *R*.
  - Calculate the magnitude of vector *R*.
  - Calculate the direction of θ_R.

Summary | Coulomb's Law

Use this space to write any questions or thoughts about this lesson.