

Three Charged Spheres Are Located At The Positions Shown InFigure 20-14. Find The Total Force On Sphere

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Understanding the forces acting on charged particles is fundamental in electrostatics, a core area of physics. When multiple charged spheres are involved, calculating the net or total force on a particular sphere requires careful consideration of the individual forces exerted by the other spheres. This guide aims to walk you through the process of determining the total electrostatic force on a specified sphere in a system of three charged spheres positioned as depicted in Figure 20-14. Although the figure itself is not provided here, the principles and steps outlined are applicable to similar scenarios involving point charges.

Introduction to Coulomb's Law and Electrostatic Forces

Before diving into the specific problem involving three charged spheres, it's essential to revisit the fundamental principles governing electrostatic forces.

What Is Coulomb's Law?

Coulomb's Law describes the force between two point charges:

- Magnitude: $(F = k_e \frac{|q_1 q_2|}{r^2})$
- Direction: Along the line connecting the two charges

where:

- (F) is the magnitude of the electrostatic force,
- (k_e) is Coulomb's constant $((8.988 \times 10^9 \, \mathrm{N \cdot m^2 / C^2}))$,
- (q_1) and (q_2) are the magnitudes of the charges,
- (r) is the distance between the charges.

Analyzing the System of Three Charged Spheres

In the scenario depicted in Figure 20-14, three spheres are positioned at specific points with known charges. The goal is to compute the total force on a particular sphere, say Sphere A.

Key Assumptions and Setup

- Each sphere is considered a point charge.
- The positions and charges of the spheres are known.
- The distances between the spheres are given or can be deduced from the figure.
- The forces obey Coulomb's Law, and superposition applies (forces are vector quantities that can be added).

Step-by-Step Approach

1. Identify the Charges and Positions

- Note the charge (q_A, q_B, q_C) for each sphere.
- Determine their positions in a coordinate system (e.g., Cartesian coordinates).

2. Calculate Individual Forces

- Compute the force exerted on Sphere A by Sphere B $(\vec{F}_{AB})$
- Compute the force exerted on Sphere A by Sphere C $(\vec{F}_{AC})$

3. Determine Force Directions

- For each force, determine the unit vector pointing from the source charge to Sphere A.
- The force direction depends on whether the charges are like or unlike:
 - Like charges repel, force directed away.
 - Opposite charges attract, force directed toward the other charge.

4. Calculate the Magnitudes of Each Force

- Use Coulomb's Law:

$$F_{AB} = k_e \frac{|q_A q_B|}{r_{AB}^2}$$

$$F_{AC} = k_e \frac{|q_A q_C|}{r_{AC}^2}$$

- (r_{AB}) and (r_{AC}) are the distances from Sphere A to B and C, respectively.

5. Resolve Each Force into Components

- Break down the forces into x and y components (and z if necessary).
- For a force $(\vec{F})$:

$$F_x = F \cos\theta$$

$$F_y = F \sin\theta$$

\]

- Use the position coordinates to find the angles or directly compute the unit vectors.

6. Sum the Force Components

- Add the components vectorially:

\[

$$\vec{F}_{\text{total}} = \vec{F}_{AB} + \vec{F}_{AC}$$

\]

- Sum the x-components:

\[

$$F_{x,\text{total}} = F_{AB,x} + F_{AC,x}$$

\]

- Sum the y-components:

\[

$$F_{y,\text{total}} = F_{AB,y} + F_{AC,y}$$

\]

7. Calculate the Magnitude and Direction of the Resultant Force

- Magnitude:

\[

$$F_{\text{total}} = \sqrt{F_{x,\text{total}}^2 + F_{y,\text{total}}^2}$$

\]

- Direction (angle relative to the x-axis):

\[

$$\theta_{\text{total}} = \arctan \left(\frac{F_{y,\text{total}}}{F_{x,\text{total}}} \right)$$

\]

Applying the Method to a Specific Example

Suppose in Figure 20-14, the charges and positions are as follows:

- Sphere A: $(q_A = +3\text{ }\mu\text{C})$, at position $((0,0))$
- Sphere B: $(q_B = -2\text{ }\mu\text{C})$, at position $((4\text{ m}, 0))$
- Sphere C: $(q_C = +1\text{ }\mu\text{C})$, at position $((0, 3\text{ m}))$

Step 1: Calculate Distances

- $(r_{AB} = 4\text{ m})$
- $(r_{AC} = 3\text{ m})$

Step 2: Calculate Forces

- Force between A and B:

\[

$$F_{AB} = 8.988 \times 10^9 \times \frac{|3 \times 10^{-6} \times -2 \times 10^{-6}|}{4^2} = 8.988 \times 10^9 \times \frac{6 \times 10^{-12}}{16} = 8.988 \times 10^9 \times 3.75 \times 10^{-13} \approx 3.37 \times 10^{-3}\text{ N}$$

Direction: Since (q_A) is positive and (q_B) is negative, the force on A due to B is attractive, directed toward B at $(4,0)$.

- Force between A and C:

$$F_{AC} = 8.988 \times 10^9 \times \frac{3 \times 10^{-6} \times 1 \times 10^{-6}}{3^2} = 8.988 \times 10^9 \times \frac{3 \times 10^{-12}}{9} = 8.988 \times 10^9 \times 3.33 \times 10^{-13} \approx 2.99 \times 10^{-3} \text{ N}$$

Since both charges are positive, the force on A due to C is repulsive, directed away from C at $(0, 3)$.

Step 3: Resolve Forces into Components

- For (F_{AB}) :

- Vector from A to B: $(\vec{r}_{AB}) = (4, 0)$

- Unit vector:

$$\hat{r}_{AB} = (1, 0)$$

- Force direction: toward B (since attraction), along positive x-axis.

- Force components:

$$F_{AB,x} = 3.37 \times 10^{-3} \times 1 = 3.37 \times 10^{-3} \text{ N}$$

$$F_{AB,y} = 0$$

- For (F_{AC}) :

- Vector from A to C: $(0, 3)$

- Unit vector:

$$\hat{r}_{AC} = (0, 1)$$

- Since the force is repulsive, it points away from C, i.e., downward along negative y-direction.

- Force components:

$$F_{AC,x} = 0$$

$$F_{AC,y} = -2.99 \times 10^{-3}$$

Step 4: Sum Components

- Total x-component:

$$F_{x,\text{total}} = 3.37 \times 10^{-3} + 0 = 3.37 \times 10^{-3} \text{ N}$$

- Total y-component:

$$F_{y,\text{total}} = 0 - 2.99 \times 10^{-3} = -2.99 \times 10^{-3} \text{ N}$$

Step 5: Calculate Magnitude and Direction

- Magnitude:

$$F_{\{$$

Frequently Asked Questions

What is the method to determine the total electrostatic force on a particular sphere among three charged spheres arranged in a given configuration?

To find the total force on a specific sphere, calculate the individual Coulomb forces exerted on it by each of the other two spheres and then vectorially add these forces, considering their directions and magnitudes.

How does Coulomb's law apply when calculating the forces between three charged spheres in a three-dimensional configuration?

Coulomb's law states that the force between two point charges is proportional to the product of their charges and inversely proportional to the square of the distance between them. For three spheres, apply Coulomb's law to each pair separately and then sum the forces vectorially to find the net force on a chosen sphere.

What are the key assumptions when solving for forces between three charged spheres in a problem like the one shown in Figure 20-14?

Key assumptions include treating the spheres as point charges, assuming the charges are fixed and stationary, neglecting any effects like induction or external fields, and working in a vacuum or air where Coulomb's law applies directly.

If two of the spheres are positively charged and one is negatively charged, how does this affect the calculation of the total force on a specific sphere?

The signs of the charges determine the direction of each Coulomb force—attractive or repulsive. When calculating the total force, include the vector directions accordingly: forces between opposite

charges are attractive (pulling the sphere toward each other), while like charges repel each other, affecting the net force's magnitude and direction.

In the context of three charged spheres, how can vector addition be used to find the net force on a single sphere, and what challenges might arise?

Vector addition involves calculating individual forces from each of the other spheres and then combining their vector components to find the resultant force. Challenges include accurately determining directions, especially if the positions are in three dimensions, and ensuring proper vector resolution to avoid errors in magnitude and direction.

Additional Resources

Three Charged Spheres Are Located At The Positions Shown In Figure 20-14. Find The Total Force On Sphere is a classic problem in electrostatics that tests our understanding of Coulomb's law, vector addition, and the superposition principle. This problem typically involves analyzing the electric forces exerted on a particular sphere due to the other two charged spheres in a given configuration. Such problems are fundamental in physics because they help students develop intuition about electric fields, forces, and the interactions between multiple charges. In this comprehensive review, we will explore the problem, the methods to solve it, common pitfalls, and the underlying concepts that make such problems both challenging and rewarding.

Understanding the Problem Context

Physical Setup and Assumptions

In problems like these, the first step is to carefully interpret the given information. Usually, three spheres are placed at specific coordinates in a plane or in space, each carrying a known charge. The positions are often given in a diagram (like Figure 20-14), which depicts the relative locations of the spheres. The charges may be positive or negative, significantly affecting the direction of the forces.

Key assumptions often made include:

- The spheres are point charges or are sufficiently small so that their sizes can be neglected.
- The medium surrounding the charges is vacuum or air, with a known permittivity (ϵ_0).
- The forces are governed solely by electrostatics, ignoring other forces like gravity or magnetic effects.

Understanding these assumptions is crucial because they influence the applicability of Coulomb's law and the superposition principle.

Goals and Objectives

The main goal of such a problem is to compute the net force acting on a particular sphere—say Sphere A—due to the other two spheres, Sphere B and Sphere C. To do this, the student must:

- Calculate the individual forces exerted on Sphere A by each of the other spheres.
- Determine the directions of these forces based on the sign of the charges.
- Use vector addition to find the resultant force.

This process involves careful attention to vector components, magnitudes, and directions.

Methodology for Solving the Problem

Step 1: Identify Coordinates and Charges

Begin by assigning coordinates to each sphere based on the diagram. For example:

- Sphere A at (x_1, y_1) , with charge q_A .
- Sphere B at (x_2, y_2) , with charge q_B .
- Sphere C at (x_3, y_3) , with charge q_C .

Knowing the positions allows calculation of the distances between spheres, which are necessary for Coulomb's law.

Step 2: Calculate Distances Between Spheres

Use the distance formula:

$$r_{AB} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

and similarly for other pairs.

These distances are crucial because Coulomb's law depends inversely on the square of the distance:

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

where $k = \frac{1}{4\pi\epsilon_0}$.

Step 3: Determine Force Magnitudes and Directions

Calculate the magnitude of the force between each pair:

$$F_{AB} = \frac{k |q_A q_B|}{r_{AB}^2}$$

Direction:

- If charges are of the same sign, the force is repulsive, pushing the charges away from each other.
- If charges are opposite, the force is attractive, pulling the charges toward each other.

Express the forces as vectors:

- Determine the unit vector from the source charge to the target charge.
- Multiply the magnitude by the unit vector to get the force vector.

Step 4: Superposition of Forces

Since multiple forces act on Sphere A, apply vector addition:

- Sum the force vectors due to Sphere B and Sphere C.
- Use component form (x and y components) for clarity.

Total force on Sphere A:

$$\vec{F}_{\text{total}} = \vec{F}_{AB} + \vec{F}_{AC}$$

This involves adding the x-components and y-components separately, then recombining to find the magnitude and direction of the resultant force.

Step 5: Numerical Calculation and Final Result

Insert the known values into the equations, perform calculations carefully to avoid sign errors, and compute the magnitude of the total force:

$$F_{\text{total}} = \sqrt{F_x^2 + F_y^2}$$

and the direction (angle) relative to a chosen axis.

Common Challenges and Pitfalls

Misinterpreting Directions

One of the most common errors is misassigning the direction of forces, especially with negative charges or when the charges are not aligned along standard axes. Precise drawing and vector component analysis help avoid this.

Ignoring the Sign of Charges

The magnitude alone does not reveal the force's direction. Remember:

- Same sign: repulsive force, pointing away from the source.

- Opposite sign: attractive force, pointing toward the source.

Forgetting to Break Forces into Components

For non-collinear arrangements, forces must be resolved into components before summation. Failing to do so can lead to incorrect resultant forces.

Overlooking Symmetry and Simplifications

In some configurations, symmetry can simplify calculations. Recognizing symmetrical arrangements can reduce computational effort.

Features and Educational Value

- **Concept Reinforcement:** Reinforces Coulomb's law, vector addition, and superposition.
- **Problem-Solving Skills:** Develops spatial reasoning and analytical skills.
- **Applicability:** Provides insights into real-world electrostatic interactions, such as in atomic physics and electrical engineering.

Pros and Cons of Approaching Such Problems

Pros

- Deepens understanding of fundamental physics principles.
- Enhances mathematical skills through vector analysis.
- Prepares students for more complex electrostatics problems involving multiple charges and fields.

Cons

- Can be algebraically intensive and prone to calculation errors.
- Requires careful attention to detail, which can be time-consuming.
- May be challenging for students unfamiliar with vector decomposition and Coulomb's law applications.

Extensions and Related Topics

- Electric Field Calculation: Instead of directly calculating forces, students can compute the electric field at the position of Sphere A due to other charges and then find the force.
- Multiple Charge Configurations: Expanding to more complex arrangements helps understand superposition in higher dimensions.
- Potential and Energy: Analyzing electrical potential energy and potential at various points adds another layer of understanding.

Conclusion

The problem involving three charged spheres, as depicted in Figure 20-14, encapsulates core principles of electrostatics and vector analysis. Its solution requires meticulous calculation, careful consideration of force directions, and the superposition principle. While challenging, mastering this problem provides a solid foundation for understanding more complex electrostatic systems. Its educational significance lies in bridging theoretical concepts with practical problem-solving skills, making it a valuable exercise in physics education. Whether approached through analytical calculations or conceptual reasoning, such problems deepen our grasp of the invisible yet powerful forces that govern the microscopic and macroscopic worlds.

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