

A Charge 4.98 NC Is Placed At The Origin Of An Xy-coordinate System, And A Charge -2.04 NC Is Placed

A Charge 4.98 NC Is Placed At The Origin Of An Xy-coordinate System, And A Charge -2.04 NC Is Placed at the start of the opening paragraph. This scenario represents a foundational problem in electrostatics, involving point charges positioned within a coordinate system and their resulting electric fields and potentials. Understanding the behavior and interactions of these charges provides critical insights into Coulomb's law, electric field concepts, and potential energy calculations. This article explores the detailed analysis of this configuration, including the calculation of electric fields, forces, potential energies, and the influence of charge magnitudes and positions within the XY-plane.

Introduction to Point Charges in an XY-Coordinate System

In electrostatics, point charges are idealized particles with electric charge concentrated at a single point. When placed within a coordinate system, their interactions can be precisely calculated using Coulomb's law, which states:

- The electric force between two point charges is directly proportional to the product of their magnitudes.
- The force acts along the line connecting the charges.
- The force is attractive if the charges are opposite and repulsive if they are like charges.

The configuration described involves two charges:

- A positive charge of 4.98 nanocoulombs (NC) located at the origin (0,0).
- A negative charge of -2.04 nanocoulombs (NC) placed somewhere else in the XY-plane.

Understanding their relative positions and the resulting electric fields and forces requires a systematic approach.

Setting Up the Coordinate System and Charge Positions

Position of the Charges

- The positive charge, $(q_1 = +4.98 \text{ NC})$, is at the origin: $(0,0)$.
- The negative charge, $(q_2 = -2.04 \text{ NC})$, is placed at a specific point, say $((x_2, y_2))$.

For detailed analysis, the position of the second charge must be specified. For example, suppose:

- (q_2) is located at $((x_2, y_2) = (x, y))$.

The relative position vector between the charges:

$$\begin{aligned} \vec{r} &= (x, y) - (0, 0) = (x, y) \end{aligned}$$

The magnitude of this vector:

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

The direction from (q_1) to (q_2) :

$$\hat{r} = \frac{\vec{r}}{r} = \left(\frac{x}{r}, \frac{y}{r} \right)$$

Calculating the Electric Field

The electric field due to a point charge at a specific point in space is given by Coulomb's law:

$$\vec{E} = \frac{k |q|}{r^2} \hat{r}$$

where:

- (k) is Coulomb's constant, approximately $(8.988 \times 10^9 \text{ Nm}^2/\text{C}^2)$,
- (q) is the charge magnitude,
- (r) is the distance from the charge to the point of interest,
- $(\hat{r})$ is the unit vector pointing from the charge to the point.

Electric field at a point due to (q_1) :

Since (q_1) is at the origin, the electric field at a point $((x,y))$:

$$\vec{E}_1 = \frac{k \times 4.98 \times 10^{-9} \text{ C}}{r^2} \hat{r}$$

Electric field at a point due to (q_2) :

Similarly, for (q_2) at $((x_2, y_2))$:

$$\vec{E}_2 = \frac{k \times (-2.04 \times 10^{-9} \text{ C})}{r_2^2} \hat{r}_2$$

where:

- $(r_2 = \sqrt{(x - x_2)^2 + (y - y_2)^2})$,
- $(\hat{r}_2)$ is the unit vector from (q_2) to the point.

Force on Each Charge

Using Coulomb's law, the force exerted on one charge due to the other is:

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

Important points:

- The direction of the force depends on the signs of the charges.
- The magnitude of the force:

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

- The force on (q_1) due to (q_2) :

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

- The force on (q_2) due to (q_1) :

$\vec{F}_{21} =$

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

By Newton's third law, these forces are equal in magnitude and opposite in direction.

Potential Energy of the System

The electrostatic potential energy between two point charges is:

$$U = \frac{k q_1 q_2}{r}$$

where:

- r is the separation between the charges.

Given the charges:

$$U = \frac{8.988 \times 10^9 \times (4.98 \times 10^{-9})(-2.04 \times 10^{-9})}{r}$$

The negative sign indicates the potential energy is negative, consistent with an attractive interaction between unlike charges.

Influence of Charge Magnitudes and Positions

Understanding how the charges interact depends on their magnitudes and relative positions:

- **Magnitude of Charges:** Larger magnitudes produce stronger electric fields and forces.
- **Sign of Charges:** Opposite signs lead to attractive forces; like signs lead to repulsive forces.
- **Positioning:** The distance r influences the strength of interactions; closer charges have stronger forces and higher potential energy magnitude.

Example: Varying the Position of q_2

If q_2 is moved farther from q_1 , the interaction weakens:

- Electric field magnitude decreases as $\propto 1/r^2$.
- Force magnitude decreases as $\propto 1/r^2$.
- Potential energy becomes less negative, approaching zero as $r \rightarrow \infty$.

Applications and Practical Considerations

Understanding this charge configuration is essential in multiple physics and engineering contexts:

Electrostatic Force Calculations

- Designing electrostatic systems requires accurate force calculations to prevent unintended discharges.
- In microelectromechanical systems (MEMS), precise charge placement can manipulate components.

Electric Field Visualization

- Electric field lines illustrate the direction and strength of the field.
- Positive charges are sources of field lines, negative charges are sinks.

Potential Mapping

- Equipotential surfaces help visualize regions of equal potential, critical in designing shielding and insulation.

Conclusion

The placement of charges within an XY-coordinate system profoundly impacts the electrostatic interactions that occur. A charge of 4.98 nC at the origin and a charge of -2.04 nC at a specified point exemplify fundamental principles of Coulomb's law, electric fields, forces, and potential energy. By methodically calculating distances, electric field vectors, forces, and potential energies, physicists and engineers can predict and manipulate electrostatic phenomena with high precision. These concepts form the backbone of electrostatics and have broad applications, from designing electronic components to understanding natural phenomena like lightning and static electricity.

References

- Coulomb's Law - Fundamental Principles of Electrostatics
- Electric Field and Potential - Physics Textbooks and Educational Resources
- Electrostatics Applications in Modern Technology

Frequently Asked Questions

What is the significance of placing a charge at the origin in an XY-coordinate system?

Placing a charge at the origin serves as a reference point for analyzing the electric field and potential at various positions in the system. It simplifies calculations and visualization of the electric interactions with other charges placed in the coordinate plane.

How does the electric force between the 4.98 NC and -2.04 NC charges vary with their positions?

The electric force depends on the distance between the charges and their magnitudes, following Coulomb's law. As the charges are positioned at specific points in the XY-plane, the magnitude and direction of the force can be calculated based on their relative coordinates.

What is the electric potential at a point due to these two charges?

The electric potential at a point is the algebraic sum of the potentials due to each charge individually. It can be calculated using the formula $V = k q / r$ for each charge, where r is the distance from the point to each charge.

How can we determine the electric field at a specific point caused by these charges?

The electric field at a point is the vector sum of the fields due to each charge. Each field is calculated as $E = k |q| / r^2$, with direction pointing away from positive charges and toward negative charges, then combined vectorially.

What are the potential applications of analyzing such charge

configurations?

Analyzing these configurations helps in understanding fundamental electrostatic principles, designing electronic components, studying interactions in molecular and atomic physics, and developing electric field mapping techniques.

How does Coulomb's law apply to the interaction between the charges in this setup?

Coulomb's law states that the magnitude of the electrostatic force between two point charges is proportional to the product of their magnitudes and inversely proportional to the square of the distance between them. It governs the force calculation in this configuration.

If the charges are moved closer together, how does that affect the electric forces and potentials?

Moving the charges closer increases the magnitude of the electric force between them, as force is inversely proportional to the square of the distance. Similarly, the electric potential at points near the charges increases in magnitude.

What precautions should be taken when working with these charge magnitudes in practical experiments?

Ensure proper insulation, avoid direct contact with high-voltage charges, use appropriate measuring instruments, and follow safety protocols to prevent electrical shocks and unintended discharges, especially when working with nano- or microcoulomb scales.

Additional Resources

A Charge 4.98 NC Is Placed At The Origin Of An Xy-coordinate System, And A Charge -2.04 NC Is Placed

In the realm of electrostatics, understanding how electric charges interact within a coordinate system provides foundational insights into the behavior of electric fields and potentials. Today, we explore a scenario involving two point charges strategically positioned within a two-dimensional X-Y coordinate system. One charge, a positive 4.98 nanocoulombs (NC), is located precisely at the origin, while a second charge, a negative 2.04 nanocoulombs (NC), is placed elsewhere in the plane. This setup serves as a fundamental example for grasping concepts such as Coulomb's law, electric field vectors, and potential energy. By dissecting the configuration, examining the forces involved, and analyzing the resulting electric field, we aim to shed light on the complex yet intriguing interactions that govern electrostatic phenomena.

Understanding the Setup: Coordinates and Charges

The Origin and Placement of the First Charge

In this scenario, the first charge, labeled as $(q_1 = +4.98 \text{ NC})$, is located at the origin point $((0, 0))$ of an X-Y plane. The choice of the origin as the placement for this charge is both convenient and common in physics problems, as it simplifies calculations by providing a fixed reference point. This charge is positive, implying that it will generate an electric field radiating outward in all directions.

The Positioning of the Second Charge

The second charge, $(q_2 = -2.04 \text{ NC})$, is placed at some coordinate $((x, y))$, which must be specified or assumed for detailed calculations. For illustrative purposes, let's suppose that (q_2) is located at $((x, y) = (d, 0))$, meaning it is placed along the positive x-axis at a distance (d) from the origin.

This placement is significant because it allows us to analyze the interactions between the two charges straightforwardly:

- The magnitude of the charges: $(|q_1| = 4.98 \text{ NC})$, $(|q_2| = 2.04 \text{ NC})$.
- The nature of the charges: (q_1) is positive, (q_2) is negative, leading to attractive interactions.
- The distance between the charges: $(r = d)$, the key parameter influencing the force magnitude.

The Importance of Coordinate Choice in Electrostatics

Choosing a coordinate system centered at the origin and aligning the second charge along an axis simplifies the analysis:

- It enables straightforward calculation of distances using the Pythagorean theorem.
- It facilitates the vector addition of electric fields.
- It helps visualize the field lines and potential distributions.

Understanding how the placement affects the electrostatic interactions forms the backbone of analyzing similar real-world systems, such as charged particles in traps or molecules in electrostatic assemblies.

Coulomb's Law: Quantifying the Electric Force

The Fundamental Equation

At the heart of electrostatics lies Coulomb's law, which quantifies the force between two point charges:

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

where:

- (F) is the magnitude of the electrostatic force,
- (k_e) is Coulomb's constant, approximately $(8.9875 \times 10^9 \text{ Nm}^2/\text{C}^2)$,

- (q_1) and (q_2) are the magnitudes of the charges,
- (r) is the distance between the charges.

Calculating the Force Magnitude

Suppose the second charge is placed at a distance $(d = 0.1, \text{m})$ from the origin. The force between the two charges then becomes:

$$F = (8.9875 \times 10^9) \times \frac{(4.98 \times 10^{-9})(2.04 \times 10^{-9})}{(0.1)^2}$$

Calculating numerator:

$$(8.9875 \times 10^9) \times (4.98 \times 10^{-9}) \times (2.04 \times 10^{-9}) \approx 8.9875 \times 10^9 \times 1.016 \times 10^{-17} \approx 9.13 \times 10^{-8}$$

Dividing by (0.01) (since $(0.1)^2 = 0.01$):

$$F \approx \frac{9.13 \times 10^{-8}}{0.01} = 9.13 \times 10^{-6} \text{ N}$$

This force is approximately $(9.13, \mu\text{N})$, a tiny but significant force at microscopic scales.

Direction of the Force

Since (q_1) is positive and (q_2) is negative, the force between them is attractive. The force on (q_1) points toward (q_2) , and reciprocally, the force on (q_2) points toward (q_1) . The vector nature of this force must be considered when analyzing the electric field and potential at various points.

Electric Field: Conceptual and Mathematical Perspectives

The Electric Field Concept

An electric field $(\vec{E})$ describes the force per unit charge at any point in space due to a source charge:

$$\vec{E} = \frac{\vec{F}}{q}$$

For a point charge, the electric field at a position $(\vec{r})$ (relative to the charge) is given by:

$$\vec{E} = k_e \frac{q}{r^2} \hat{r}$$

\]

where:

- $\hat{r}$ is the unit vector pointing from the source charge to the point in question,
- r is the distance from the source charge to that point.

Electric Field Due to the First Charge

Since q_1 is at the origin, the electric field it produces at any point (x, y) is:

$$\vec{E}_1 = k_e \frac{q_1}{r_1^2} \hat{r}_1$$

where:

- $r_1 = \sqrt{x^2 + y^2}$,
- $\hat{r}_1 = \frac{\vec{r}}{r_1} = \left(\frac{x}{r_1}, \frac{y}{r_1} \right)$.

Electric Field Due to the Second Charge

Similarly, the electric field due to q_2 at (x, y) is:

$$\vec{E}_2 = k_e \frac{q_2}{r_2^2} \hat{r}_2$$

where:

- $r_2 = \sqrt{(x - d)^2 + y^2}$,
- $\hat{r}_2 = \frac{\vec{r} - \vec{r}_{q_2}}{r_2} = \left(\frac{x - d}{r_2}, \frac{y}{r_2} \right)$,
- $\vec{r}_{q_2} = (d, 0)$.

Superposition of Electric Fields

The total electric field at any point in the plane is the vector sum:

$$\vec{E}_{\text{total}} = \vec{E}_1 + \vec{E}_2$$

This superposition principle is central to electrostatics, allowing the calculation of the net field by summing individual contributions.

Potential Energy and Electric Potential

Electric Potential Due to a Point Charge

The electric potential (V) at a point due to a point charge (q) is:

$$V = k_e \frac{q}{r}$$

where (r) is the distance from the charge to the point.

Total Potential at a Point

The superposition principle applies here as well, so the total potential at a point is:

$$V_{\text{total}} = V_1 + V_2 = k_e \left(\frac{q_1}{r_1} + \frac{q_2}{r_2} \right)$$

Calculating the potential helps in understanding the energy landscape in the charge configuration and is essential in analyses such as determining stable equilibrium points or potential barriers.

Practical Implications and Applications

Electrostatic Interactions in Microelectronics

Understanding the interactions between charges like those described is crucial in designing microelectronic components, where minute charges and fields influence device behavior. For instance, in capacitors, the distribution of charges and resulting fields determine the device's capacitance and performance.

Particle Traps and Coulomb Crystals

In physics laboratories, arrangements similar to this setup are used to trap ions in electromagnetic traps. The controlled placement of charges allows scientists to study quantum phenomena, perform precise measurements, and develop quantum computers.

Molecular and Atomic Physics

At the molecular level, electrostatic interactions between charged

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