QlC (a) Find The Magnitude Of The Electric Force Between A Na Ion And A Cl Ion Separated By 0.50 Nm .

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Understanding the electric force between ions is fundamental in the study of electrostatics and chemistry. Specifically, calculating the magnitude of the electrostatic force between a sodium ion (Na^+) and a chloride ion (Cl^-) separated by a specific distance involves applying Coulomb's Law. This law provides a quantitative measure of the force between two point charges and is crucial for understanding ionic bonds, lattice energies, and the behavior of ionic compounds. In this article, we will explore the necessary concepts, detailed calculations, and implications related to this problem.

Understanding Coulomb's Law

Coulomb's Law states that the electric force (F) between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them. The mathematical expression is:

- $F = k |q_1 q_2| / r^2$

where:
- F is the magnitude of the electrostatic force in newtons (N)
- k is Coulomb's constant, approximately 8.988×10^9 $N \cdot m^2/C^2$
- q_1 and q_2 are the magnitudes of the charges in coulombs (C)
- r is the separation distance between the charges in meters (m)

Charges of Na^+ and Cl^- Ions

To perform the calculation, we need the values of the charges involved. Both sodium and chloride ions are singly charged, meaning:

- Na^+ has a charge of +1 elementary charge
- Cl^- has a charge of −1 elementary charge

The elementary charge (e) is approximately 1.602×10^{-19} C. Therefore:

- q_1 (Na^+) = $+1.602 \times 10^{-19}$ C
- q_2 (Cl^-) = -1.602×10^{-19} C

Since Coulomb's Law involves the magnitude of the charges, we take the absolute value:

$|q_1| = 1.602 \times 10^{-19}$ C
$|q_2| = 1.602 \times 10^{-19}$ C

Given Distance and Converting Units

The problem states the separation distance as 0.50 nm. To use Coulomb's Law correctly, we need to convert this to meters:

- 1 nm = 1×10^{-9} m
- Therefore, 0.50 nm = 0.50×10^{-9} m = 5.0×10^{-10} m

Calculating the Electric Force

Using Coulomb's Law, the calculation proceeds as follows:

$F = k\ |q_1\ q_2|\ /\ r^2$

Substituting the values:

$F = (8.988 \times 10^9\ N \cdot m^2/C^2)\ (1.602 \times 10^{-19}\ C\ 1.602 \times 10^{-19}\ C)\ /\ (5.0 \times 10^{-10}\ m)^2$

Step-by-step calculation:

1. Multiply the charges:

$|q_1\ q_2| = (1.602 \times 10^{-19})\ (1.602 \times 10^{-19}) = 2.5664 \times 10^{-38}\ C^2$

2. Square the distance:

$r^2 = (5.0 \times 10^{-10})^2 = 25.0 \times 10^{-20}\ m^2 = 2.5 \times 10^{-19}\ m^2$

3. Plug into Coulomb’s Law:

$F = (8.988 \times 10^9)\ (2.5664 \times 10^{-38})\ /\ (2.5 \times 10^{-19})$

4. Simplify numerator:

$8.988 \times 10^9\ 2.5664 \times 10^{-38} \approx 2.305 \times 10^{-2}8$

5. Divide by the denominator:

$F \approx 2.305 \times 10^{-2}8\ /\ 2.5 \times 10^{-19} \approx 9.22 \times 10^{-1}0$ N

Result:
The magnitude of the electric force between the Na^+ ion and the Cl^- ion separated by 0.50 nm is approximately $9.22 \times 10^{-1}0$ newtons.

Implications of the Calculated Force

The electrostatic force calculated is extremely small, reflecting the fact that atomic-scale forces are tiny but significant at the molecular level. This force contributes to the ionic bond strength in compounds like sodium chloride (NaCl), influencing properties such as melting point, solubility, and lattice energy.

Additional Considerations

While Coulomb’s Law provides a fundamental approach, real-world interactions can be more complex. Factors such as:

- The surrounding environment (e.g., in a solvent or lattice)
- Ionic polarization
- Quantum effects

can influence the actual forces and behaviors of ions. Nonetheless, Coulomb’s Law remains a vital tool for initial approximations and understanding electrostatic interactions.

Summary

In this article, we have outlined the process to find the electric force between a sodium ion and a chloride ion separated by 0.50 nm:

- Recognized the charges involved and their magnitudes
- Converted the separation distance from nanometers to meters
- Applied Coulomb’s Law with appropriate constants
- Performed step-by-step calculations to arrive at approximately $9.22 \times 10^{-1}0$ N

Understanding these calculations enhances our grasp of ionic interactions and the fundamental principles governing electrostatics in chemistry and physics.

Frequently Asked Questions (FAQs)

1. **What is Coulomb's constant?**
   Coulomb's constant (k) is approximately 8.988×10^9 $N \cdot m^2/C^2$, representing the proportionality in Coulomb's Law.

2. **Why is it important to convert nanometers to meters in calculations?**
   Because SI units are standard in physics, converting to meters ensures consistency and accuracy in calculations involving Coulomb's Law.

3. **Can this force be observed directly?**
   No, the electrostatic forces at the atomic level are too small to be observed directly without specialized equipment, but their effects are evident in chemical bonding and material properties.

In conclusion, calculating the electric force between ions like Na^+ and Cl^- helps deepen our understanding of ionic bonds and electrostatic interactions that are fundamental to chemistry and material science. Such calculations underpin many technological and scientific advancements, from designing new materials to understanding biological systems.

Frequently Asked Questions

What is the formula to calculate the electric force between two ions?

The electric force between two ions is given by Coulomb's Law: $F = k |q1\ q2| / r^2$, where k is Coulomb's constant, q1 and q2 are the charges of the ions, and r is the separation distance.

What are the charges of a Na+ ion and a Cl− ion?

A Na^+ ion carries a charge of +1e, and a Cl^- ion carries a charge of −1e, where e is the elementary charge, approximately 1.602×10^{-19} Coulombs.

How do you convert the elementary charge to Coulombs in calculations?

The elementary charge e is approximately 1.602×10^{-19} Coulombs, so for a singly charged ion, $q = \pm 1.602 \times 10^{-19}$ C.

How do you calculate the magnitude of the electric force between Na+ and Cl− ions separated by 0.50 nm?

Using Coulomb's Law: $F = (8.988 \times 10^9\ Nm^2/C^2)\ (1.602 \times 10^{-19}\ C)\ (1.602 \times 10^{-19}\ C) / (0.50 \times 10^{-9}\ m)^2$, then compute the value to find the force.

What is the approximate magnitude of the electric force between Na+ and Cl− ions separated by 0.50 nm?

The magnitude is approximately 9.2×10^{-10} Newtons, calculated using Coulomb's Law with the given data.

Why is understanding the electric force between ions important in chemistry?

It helps explain ionic bonding, lattice energies, and the stability of ionic compounds, which are fundamental to understanding chemical properties and reactions.

What units are used for measuring electric force in such calculations?

Electric force is measured in Newtons (N) in SI units.

Additional Resources

Q1 (a): Find The Magnitude Of The Electric Force Between A Na Ion And A Cl Ion Separated By 0.50 Nm

Understanding the electric force between ions is fundamental in the study of chemistry and physics, especially when analyzing ionic bonds and interactions in crystalline structures or solutions. The problem at hand involves calculating the magnitude of the electric force between a sodium ion (Na^+) and a chloride ion (Cl^-) separated by a distance of 0.50 nanometers. This scenario provides an excellent opportunity to explore Coulomb's Law, the principles of electrostatics, and their applications in real-world chemical systems.

Introduction to Coulomb's Law

Coulomb's Law is the cornerstone of electrostatics, describing the force between two point charges. It states that the electrostatic force (F) between two charges is directly proportional to the product of the magnitudes of the charges (q_1 and q_2) and inversely proportional to the square of the distance (r) between them.

Mathematically, Coulomb's Law is expressed as:

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

Where:
- F is the magnitude of the electrostatic force,
- k_e is Coulomb's constant ($8.9875 \times 10^9\, \mathrm{N\, m^2\, C^{-2}}$),
- q_1 and q_2 are the magnitudes of the two charges,
- r is the distance between the charges.

This law applies well to point charges or spherical charges where charge distribution is symmetric.

Understanding the Charges Involved

Before plugging into Coulomb's Law, it is essential to understand the nature of the ions involved:

- Sodium Ion (Na^+): Has a single positive charge, meaning $q_1 = +e$.
- Chloride Ion (Cl^-): Has a single negative charge, so $q_2 = -e$.

Here, e represents the elementary charge:

$$ e = 1.602 \times 10^{-19}\, \mathrm{C} $$

The absolute value of the charge magnitudes is used in Coulomb's Law to determine force magnitude, so:

$$ |q_1| = |q_2| = e = 1.602 \times 10^{-19}\, \mathrm{C} $$

The negative sign indicates the nature of the charge (positive or negative), but for magnitude calculations, only the absolute value matters.

Calculating the Electric Force

Given:
- $q_1 = +e = 1.602 \times 10^{-19}\, \mathrm{C}$,
- $q_2 = -e = -1.602 \times 10^{-19}\, \mathrm{C}$,
- $r = 0.50\, \mathrm{nm} = 0.50 \times 10^{-9}\, \mathrm{m}$,
- $k_e = 8.9875 \times 10^9\, \mathrm{N\, m^2\, C^{-2}}$.

Applying Coulomb's Law:

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

$$
F = 8.9875 \times 10^9 \times \frac{(1.602 \times 10^{-19}) \times (1.602 \times 10^{-19})}{(0.50 \times 10^{-9})^2}
$$

Simplify numerator:

$$
(1.602 \times 10^{-19})^2 = 2.5664 \times 10^{-38}
$$

Simplify denominator:

$$
(0.50 \times 10^{-9})^2 = 0.25 \times 10^{-18} = 2.5 \times 10^{-19}
$$

Now, compute the force:

$$
F = 8.9875 \times 10^9 \times \frac{2.5664 \times 10^{-38}}{2.5 \times 10^{-19}}
$$

Divide numerator by denominator:

$$
\frac{2.5664 \times 10^{-38}}{2.5 \times 10^{-19}} = 1.02656 \times 10^{-19}
$$

Finally:

$$
F = 8.9875 \times 10^9 \times 1.02656 \times 10^{-19} \approx 9.226 \times 10^{-10}\, \mathrm{N}
$$

Result: The magnitude of the electric force between the Na^+ and Cl^- ions separated by 0.50 nm is approximately 9.23×10^{-10} N.

Features and Significance of the Calculated Electric Force

Features:

- Strong Interaction at Short Distances: The force magnitude ($\sim 10^{-9}$ N) illustrates the significant electrostatic attraction between oppositely charged ions at atomic or molecular scales.
- Inverse Square Law Dependency: The force decreases with the square of the distance, emphasizing how small changes in separation drastically affect interaction strength.
- Relevance to Ionic Bonding: The calculated force underpins the stability of ionic compounds like sodium chloride, where electrostatic attraction holds ions together in a lattice.

Significance in Chemistry and Physics:

- Helps explain the high melting points and solubility characteristics of ionic compounds.
- Aids in understanding lattice energies and the energy required to break ionic bonds.
- Serves as a basis for modeling interactions in solutions, biological systems, and materials science.

Pros and Cons of Coulomb's Law in Ionic Interactions

Pros:

- Simplicity and Clarity: Provides a straightforward way to quantify electrostatic forces between point charges.
- Fundamental: Basis for understanding a broad range of electrostatic phenomena.
- Applicability: Useful in calculating forces, energies, and potentials in atomic and molecular systems.

Cons:

- Idealization: Assumes point charges; real ions have finite sizes and electron cloud distributions.
- Neglects Other Forces: Does not account for quantum mechanical effects, polarization, or covalent character.
- Limited at Larger Distances: Coulomb's Law is less accurate in complex environments like solvents where dielectric effects come into play.

Additional Considerations

- Dielectric Constant: In real-world scenarios, especially in solutions, the medium's dielectric constant reduces the effective force. For instance, in water, the force would be less due to its high dielectric constant (~80).
- Quantum Effects: At atomic scales, quantum mechanics governs interactions more accurately, but Coulomb's Law remains a useful approximation.
- Temperature Effects: Thermal motion can influence the stability and effective interactions between ions.

Conclusion

The calculation of the electrostatic force between a Na^+ and Cl^- ion separated by 0.50 nm provides deep insight into the nature of ionic interactions. Using Coulomb's Law, we find that the force is approximately 9.23 \times 10^{-10} N, highlighting the strong attractive forces responsible for the formation of ionic bonds and the stability of ionic compounds. While Coulomb's Law offers a fundamental and straightforward approach, it’s important to consider its limitations and the context of the environment when applying it to real-world systems. Understanding these forces enriches our comprehension of molecular interactions, material properties, and chemical bonding, forming a cornerstone of physical chemistry and materials science.

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