

Rank The Compounds NH₃, CH₄ And PH₃ In Order Of Increasing Boiling Point.a) NH₃ < PH₃ < CH₄b) CH₄

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Understanding the boiling points of chemical compounds is essential in fields ranging from chemistry and chemical engineering to environmental science. When comparing molecules such as ammonia (NH₃), phosphine (PH₃), and methane (CH₄), their boiling points reveal a lot about their intermolecular forces, molecular structures, and physical properties. In this comprehensive article, we will explore how to rank these compounds based on their boiling points, analyze the reasons behind these rankings, and discuss the factors that influence boiling points in general.

Introduction to Boiling Points and Molecular Properties

The boiling point of a substance is the temperature at which its vapor pressure equals the external atmospheric pressure, causing the liquid to transition into a gas. Several factors influence boiling points:

- Intermolecular Forces: Stronger intermolecular forces require higher temperatures to break, resulting in higher boiling points.
- Molecular Mass: Heavier molecules tend to have higher boiling points due to increased Van der Waals forces.
- Molar Structure and Polarity: Polar molecules engage in dipole-dipole interactions, often elevating boiling points relative to non-polar molecules of similar mass.
- Hydrogen Bonding: Molecules capable of hydrogen bonding exhibit significantly higher boiling points.

By analyzing these factors, we can understand the different behaviors of NH₃, PH₃, and CH₄.

Overview of the Compounds

Let's briefly review the molecular structures and properties of each compound:

Ammonia (NH₃)

- Molecular Formula: NH₃
- Molecular Geometry: Trigonal pyramidal

- Molecular Mass: Approximately 17 g/mol
- Polarity: Polar molecule
- Intermolecular Forces: Hydrogen bonding, dipole-dipole interactions, London dispersion forces

Phosphine (PH₃)

- Molecular Formula: PH₃
- Molecular Geometry: Trigonal pyramidal
- Molecular Mass: Approximately 34 g/mol
- Polarity: Slightly polar
- Intermolecular Forces: Van der Waals forces, weak dipole-dipole interactions

Methane (CH₄)

- Molecular Formula: CH₄
- Molecular Geometry: Tetrahedral
- Molecular Mass: About 16 g/mol
- Polarity: Non-polar
- Intermolecular Forces: London dispersion forces

Analysis of Intermolecular Forces and Their Impact on Boiling Points

The key to understanding the boiling point ranking is to analyze the dominant intermolecular forces present in each compound.

Hydrogen Bonding in NH₃

Ammonia is well-known for its ability to form hydrogen bonds due to the presence of a highly electronegative nitrogen atom bonded to hydrogen. This results in:

- Strong hydrogen bonds that significantly increase the energy needed to vaporize NH₃.
- Elevated boiling point relative to molecules lacking hydrogen bonding.

Dipole-Dipole Interactions in PH₃

Phosphine exhibits some polarity because phosphorus is less electronegative than nitrogen, but:

- Its dipole-dipole interactions are weaker compared to the hydrogen bonding in NH₃.
- Overall, the intermolecular forces are primarily Van der Waals (London dispersion) and weak dipole interactions.

London Dispersion Forces in CH₄

Methane is a non-polar molecule:

- Intermolecular interactions are solely due to London dispersion forces.
- These are the weakest type of van der Waals forces, resulting in a lower boiling point.

Ranking of Compounds Based on Boiling Points

Considering the above, the ranking of their boiling points can be summarized as follows:

1. NH₃ (Ammonia): Highest boiling point due to hydrogen bonding.
2. PH₃ (Phosphine): Moderate boiling point, weaker dipole interactions.
3. CH₄ (Methane): Lowest boiling point, only London dispersion forces.

This corresponds to the order: NH₃ > PH₃ > CH₄

Empirical Data Supporting the Ranking

Let's examine the approximate boiling points:

- NH₃: -33.3°C
- PH₃: -87.7°C
- CH₄: -161.5°C

The actual data confirms our theoretical analysis:

- Ammonia's boiling point is significantly higher because of hydrogen bonding.
- Phosphine's boiling point is lower, reflecting weaker dipole interactions.
- Methane's boiling point is the lowest owing to its non-polar nature and minimal intermolecular forces.

Factors Affecting Boiling Point Beyond Intermolecular Forces

While intermolecular forces are primary, other factors can influence boiling points:

- Molecular Mass: Larger molecules tend to have higher boiling points.
- Molecular Shape: More compact molecules may have lower boiling points than elongated molecules.
- External Pressure: Changes in atmospheric pressure alter boiling points, but standard conditions are typically assumed.

In our case, the molecular masses are:

- NH_3 : 17 g/mol
- PH_3 : 34 g/mol
- CH_4 : 16 g/mol

Despite PH_3 being heavier than NH_3 , its weaker intermolecular forces cause its boiling point to be lower than NH_3 's.

Implications and Applications of Boiling Point Rankings

Understanding boiling points helps in various practical applications:

- Industrial Separation: Techniques like distillation rely on differences in boiling points.
- Chemical Storage: Proper temperature controls depend on boiling point data.
- Environmental Impact: The volatility of compounds influences their environmental behavior.

For instance, ammonia's high boiling point relative to methane makes it easier to liquefy and store, which is crucial in refrigeration and fertilizer industries.

Conclusion: Final Ranking and Summary

In conclusion, the ranking of NH_3 , PH_3 , and CH_4 by increasing boiling point is:

- CH_4 (Methane): -161.5°C
- PH_3 (Phosphine): -87.7°C
- NH_3 (Ammonia): -33.3°C

This order aligns with the strength of their intermolecular forces:

- Hydrogen bonding in NH_3 significantly raises its boiling point.
- Weak dipole interactions in PH_3 result in a moderate boiling point.
- Solely London dispersion forces in CH_4 lead to the lowest boiling point.

Understanding these differences is crucial for scientists and engineers working with gases, designing separation processes, and developing applications based on their physical properties.

Keywords for SEO Optimization:

- Boiling points of NH_3 , CH_4 , PH_3
- Intermolecular forces and boiling point
- Ammonia vs phosphine vs methane
- Molecular structure and boiling point
- Hydrogen bonding in gases
- Gas properties and boiling temperature
- Chemical compound boiling point ranking

- Physical properties of ammonia, methane, phosphine

By grasping the factors influencing boiling points and evaluating the molecular characteristics of these compounds, you can better predict and utilize their physical properties in various scientific and industrial contexts.

Frequently Asked Questions

What is the correct order of boiling points for NH₃, CH₄, and PH₃?

The correct order is $\text{NH}_3 < \text{PH}_3 < \text{CH}_4$.

Why does ammonia (NH₃) have a higher boiling point than methane (CH₄)?

NH₃ has hydrogen bonding due to its N-H bonds, which increases its boiling point compared to CH₄, which only exhibits London dispersion forces.

How does the molecular structure influence the boiling points of NH₃, PH₃, and CH₄?

Molecular structure affects intermolecular forces; molecules capable of hydrogen bonding (like NH₃) have higher boiling points than those that only experience dispersion forces (like CH₄). PH₃ has weaker dipole interactions than NH₃, resulting in a boiling point between NH₃ and CH₄.

Why is PH₃'s boiling point higher than CH₄ but lower than NH₃?

PH₃ has some dipole-dipole interactions but lacks hydrogen bonding, resulting in a higher boiling point than CH₄ (which only has dispersion forces) but lower than NH₃, which can form hydrogen bonds.

Does hydrogen bonding significantly affect the boiling point of NH₃ compared to PH₃ and CH₄?

Yes, hydrogen bonding in NH₃ significantly raises its boiling point compared to PH₃ and CH₄, which do not form hydrogen bonds.

Which intermolecular forces are primarily responsible for the boiling points of these compounds?

Hydrogen bonding in NH₃, dipole-dipole interactions in PH₃, and London dispersion forces in CH₄ are the primary intermolecular forces affecting their boiling points.

Would you expect PH₃ to have a higher or lower boiling point than water (H₂O)?

PH₃ has a lower boiling point than water because it does not exhibit hydrogen bonding to the same extent as water.

How does atomic size influence the boiling points of NH₃, PH₃, and CH₄?

Larger atomic size (as in phosphorus vs. nitrogen) leads to increased London dispersion forces, which can raise boiling points; however, hydrogen bonding dominates in NH₃, making it have the highest boiling point among these molecules.

Additional Resources

Boiling Points of NH₃, CH₄, and PH₃: An In-Depth Comparative Analysis

Understanding the boiling points of chemical compounds is fundamental in chemistry, as it reveals crucial insights into the intermolecular forces, molecular structure, and physical properties of substances. When comparing compounds such as ammonia (NH₃), methane (CH₄), and phosphine (PH₃), their boiling points reflect the delicate balance between intermolecular attractions, molecular size, polarity, and hydrogen bonding capabilities. This article offers an extensive, analytical exploration of these three compounds, elucidating the factors that determine their boiling points and establishing a clear order based on detailed scientific reasoning.

Introduction to the Compounds: NH₃, CH₄, and PH₃

Before delving into the boiling point comparisons, it is essential to understand the fundamental properties and structures of the three compounds:

- Ammonia (NH₃): A colorless gas with a pungent odor, ammonia contains nitrogen bonded to three hydrogen atoms. It is known for its significant hydrogen bonding capability owing to the presence of a lone pair on nitrogen and N-H bonds.
- Methane (CH₄): The simplest alkane, methane is a colorless, odorless gas with a tetrahedral structure. Its molecules are nonpolar and primarily exhibit weak Van der Waals forces.
- Phosphine (PH₃): A colorless, flammable gas with a foul odor, phosphine features phosphorus bonded to three hydrogen atoms. Its molecular geometry is trigonal pyramidal, similar to ammonia, but it exhibits different intermolecular interactions.

Factors Influencing Boiling Points

The boiling point of a substance depends on the strength of the intermolecular forces that must be overcome during phase transition from liquid to vapor. Several factors influence these forces:

- **Molecular Mass:** Heavier molecules tend to have higher boiling points due to increased Van der Waals forces.
- **Polarity:** Polar molecules experience dipole-dipole interactions, which are stronger than dispersion forces in nonpolar molecules.
- **Hydrogen Bonding:** A special, strong form of dipole-dipole interaction, hydrogen bonding significantly elevates boiling points, especially when N-H, O-H, or F-H bonds are involved.
- **Molecular Geometry and Electron Lone Pairs:** The shape of the molecule and the presence of lone pairs influence polarity and intermolecular interactions.

Analyzing Each Compound's Intermolecular Forces and Molecular Characteristics

1. Ammonia (NH_3)

Structure and Bonding:

- NH_3 has a trigonal pyramidal shape with bond angles approximately 107° , owing to the lone pair on nitrogen.
- The nitrogen atom is more electronegative than hydrogen, resulting in a polar molecule.

Intermolecular Forces:

- **Hydrogen Bonding:** NH_3 exhibits strong hydrogen bonding due to N-H bonds and a lone pair on nitrogen. The lone pair acts as a hydrogen bond acceptor, and hydrogen attached to nitrogen acts as a donor.
- **Dipole-Dipole Interactions:** Present, owing to molecular polarity.
- **Dispersion Forces:** Present but comparatively weaker than hydrogen bonds.

Impact on Boiling Point:

- The presence of hydrogen bonds significantly raises NH_3 's boiling point relative to nonpolar molecules of similar molar mass.

2. Methane (CH_4)

Structure and Bonding:

- CH_4 has a tetrahedral geometry with bond angles of approximately 109.5° .
- The molecule is nonpolar due to the symmetrical distribution of electron

density.

Intermolecular Forces:

- Dispersion (London) Forces: The only significant intermolecular force.
- Dipole-Dipole & Hydrogen Bonding: Absent, as the molecule is nonpolar and lacks N-H, O-H, or F-H bonds.

Impact on Boiling Point:

- Weak dispersion forces result in a low boiling point, characteristic of small, nonpolar hydrocarbons.

3. Phosphine (PH_3)

Structure and Bonding:

- PH_3 has a trigonal pyramidal shape similar to NH_3 , with bond angles around 93.5° .
- Phosphorus is less electronegative than nitrogen, leading to a less polar molecule than NH_3 .

Intermolecular Forces:

- Dipole-Dipole Interactions: Present but weaker compared to NH_3 , due to lower polarity.
- Hydrogen Bonding: Possible in principle, but weak or negligible because phosphorus is less electronegative and less effective at forming strong hydrogen bonds compared to nitrogen.
- Dispersion Forces: Present and increase with molecular mass.

Impact on Boiling Point:

- Since PH_3 is heavier than NH_3 , but has weaker hydrogen bonding, its boiling point is higher than methane but lower than ammonia.

Comparative Analysis of Boiling Points

Having established the nature of intermolecular forces and molecular properties, we now analyze how these factors translate into boiling points.

1. Ammonia (NH_3)

The strong hydrogen bonding in ammonia significantly elevates its boiling point compared to molecules of similar molar mass. This intermolecular attraction requires considerable energy to break, resulting in boiling at approximately -33.3°C .

2. Phosphine (PH_3)

While PH_3 is heavier than NH_3 , its capacity for hydrogen bonding is considerably weaker or negligible. Its boiling point is around -87°C , which

is lower than NH_3 , but higher than methane. The increased molar mass enhances dispersion forces, contributing to a higher boiling point than methane.

3. Methane (CH_4)

Methane has the lowest boiling point among the three, approximately -161.5°C , owing to the absence of dipole moments and hydrogen bonding, with only weak London dispersion forces holding molecules together.

Order of Increasing Boiling Point

Based on the detailed analysis, the compounds can be ordered according to their boiling points as follows:

- Methane (CH_4): Lowest boiling point due to weak dispersion forces.
- Phosphine (PH_3): Higher than methane, owing to increased molecular mass and some dipole-dipole interactions, but limited hydrogen bonding.
- Ammonia (NH_3): Highest boiling point because of strong hydrogen bonding and polarity.

This order can be summarized as:

b) $\text{CH}_4 < \text{PH}_3 < \text{NH}_3$

which aligns with the second proposed order in the initial query.

Implications and Applications

The understanding of boiling point trends in these compounds has practical implications:

- Industrial Processes: Knowledge of boiling points informs distillation and separation techniques.
- Safety Considerations: Recognizing the volatility of these gases aids in handling and storage.
- Material Design: Insights into intermolecular forces guide the synthesis of compounds with desired physical properties.

Furthermore, the principles elucidated here extend to other molecular systems, emphasizing the importance of molecular structure, polarity, and hydrogen bonding in determining physical characteristics.

Conclusion

The comparative analysis of NH_3 , CH_4 , and PH_3 underscores the complex interplay of molecular mass, polarity, and hydrogen bonding in defining boiling points. The dominant factor—hydrogen bonding in ammonia—accounts for its significantly higher boiling point, despite having a lower molar mass than phosphine. Methane, lacking strong intermolecular forces, exhibits the lowest boiling point. The order of increasing boiling point— $\text{CH}_4 < \text{PH}_3 < \text{NH}_3$ —is thus well-supported by molecular physics and chemistry principles.

Understanding these differences not only enhances our grasp of fundamental chemistry but also informs practical applications, from industrial separation processes to safety protocols. As such, the study of boiling points remains a cornerstone of physical chemistry, illustrating how microscopic interactions manifest in macroscopic properties.

Rank The Compounds NH_3 CH_4 And PH_3 In Order Of Increasing Boiling Point A NH_3 Lt PH_3 Lt CH_4

Rank The Compounds NH_3 CH_4 And PH_3 In Order Of Increasing Boiling Point A NH_3 Lt PH_3 Lt CH_4

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