

#19. An Unknown Sample Weighs 45.2 G And Takes 58.2 KJ To Vaporize. What Is its Heat Of Vaporization?

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Understanding the heat of vaporization is a fundamental concept in thermodynamics and physical chemistry. When we encounter an unknown sample with specific properties—such as its mass and the energy required to vaporize it—determining its heat of vaporization becomes an intriguing puzzle. This article explores how to calculate the heat of vaporization from given data, explains the significance of this property, and discusses related concepts to deepen your understanding of phase changes and thermodynamic calculations.

What Is the Heat of Vaporization?

The heat of vaporization, often denoted as ΔH_{vap} , is the amount of energy required to convert one mole of a substance from its liquid phase into vapor without changing its temperature. It is a crucial parameter in understanding a substance's phase transition behavior, energy requirements for boiling, and evaporation processes.

Key Points:

- Definition: The energy needed to turn a liquid into vapor at constant temperature and pressure.
- Units: Typically expressed in joules per mole (J/mol) or kilojoules per mole (kJ/mol).
- Significance: Indicates how much energy must be supplied to overcome intermolecular forces during vaporization.

Why Is Heat of Vaporization Important?

- It influences boiling points and evaporation rates.
- It is vital in designing distillation and evaporation processes.
- It helps in understanding energy balances in thermodynamic systems.
- It contributes to calculating vapor pressures and phase diagrams.

Given Data and Objective

In our scenario, an unknown sample has:

- Mass (m): 45.2 grams
- Energy required to vaporize (Q): 58.2 kilojoules (kJ)

The goal is to determine the heat of vaporization (ΔH_{vap}) for this substance.

Step-by-Step Calculation of Heat of Vaporization

To find ΔH_{vap} , we need to relate the total energy supplied to the amount of substance vaporized, expressed per mole. The general formula is:

$$\boxed{\Delta H_{\text{vap}} = \frac{\text{Total Energy Required (Q)}}{\text{Number of Moles (n)}}}$$

Step 1: Convert the Mass to Moles

To find the number of moles (n), we require the molar mass (M) of the unknown substance. However, since the molar mass is not directly provided, we can express the answer in terms of molar mass if needed or determine ΔH_{vap} per gram.

But, typically, the heat of vaporization is expressed per mole. If the molar mass is known, the calculation becomes straightforward:

$$n = \frac{m}{M}$$

Step 2: Calculate Moles (if Molar Mass Is Known)

Suppose the molar mass (M) is known or can be estimated; then:

$$n = \frac{45.2 \text{ g}}{M \text{ g/mol}}$$

Step 3: Calculate ΔH_{vap}

$$\Delta H_{\text{vap}} = \frac{Q}{n} = \frac{58.2 \text{ kJ}}{\frac{45.2}{M}} = \frac{58.2 \times M}{45.2} \text{ kJ/mol}$$

Thus,

$$\boxed{\Delta H_{\text{vap}} = \left(\frac{58.2 \times M}{45.2} \right) \text{ kJ/mol}}$$

Note: Without the molar mass, we can only express the heat of vaporization per gram:

$$\text{Heat of vaporization per gram} = \frac{58.2 \text{ kJ}}{45.2 \text{ g}} \approx 1.287 \text{ kJ/g}$$

If the molar mass is known, multiply this value by the molar mass to get ΔH_{vap} per mole.

Determining Molar Mass for Precise Calculation

Suppose you know or estimate the molar mass of the unknown sample; then you can proceed to find the exact heat of vaporization per mole.

Example:

- If the molar mass (M) is 100 g/mol,

$$n = \frac{45.2}{100} = 0.452 \text{ mol}$$

$$\Delta H_{\text{vap}} = \frac{58.2 \text{ kJ}}{0.452} \approx 128.8 \text{ kJ/mol}$$

This value indicates that approximately 128.8 kJ of energy is needed to vaporize one mole of this substance.

Understanding the Significance of the Calculated Heat of Vaporization

Once ΔH_{vap} is determined, it provides valuable insights into the physical properties of the substance:

- Intermolecular Forces: A higher ΔH_{vap} suggests stronger intermolecular attractions, such as hydrogen bonds.
- Vapor Pressure: Substances with high heats of vaporization tend to have lower vapor pressures at a given temperature.
- Boiling Point: Generally, a higher ΔH_{vap} correlates with higher boiling points.

Additional Factors to Consider

While the calculation above assumes ideal behavior and constant pressure conditions, real-world scenarios may involve:

- Pressure Variations: Vaporization energy can depend on pressure; calculations at different pressures require adjustment.
- Impurities: The presence of impurities can affect the energy needed to vaporize.
- Temperature Effects: Vaporization is typically measured at the boiling point; if the temperature differs, additional thermodynamic considerations may be necessary.

Practical Applications of Heat of Vaporization Data

Understanding and calculating the heat of vaporization has numerous practical applications:

1. Chemical Engineering:
 - Designing distillation columns.
 - Calculating energy requirements in separation processes.
2. Environmental Science:
 - Modeling evaporation rates of water and pollutants.
 - Assessing environmental impacts of volatile compounds.
3. Material Science:
 - Developing new materials with specific vaporization properties.
 - Understanding phase change behaviors in various substances.
4. Refrigeration and Heating:
 - Selecting appropriate refrigerants based on vaporization energies.

Conclusion

Determining the heat of vaporization from experimental data, such as the mass of a sample and the energy required for vaporization, is a fundamental skill in thermodynamics and physical chemistry. By understanding the relationship between energy, mass, molar mass, and phase change properties, scientists and engineers can predict a substance's behavior during vaporization, optimize processes, and develop new materials.

In the case of the unknown sample weighing 45.2 grams and requiring 58.2 kJ to vaporize, the key step is knowing or estimating its molar mass. Once that is established, calculating the heat of vaporization per mole becomes straightforward, enabling further analysis of its physical properties

and applications.

Remember: Always consider the context of your data, verify assumptions, and ensure unit consistency to obtain accurate results. Whether you're studying simple liquids or complex compounds, mastering these calculations enhances your understanding of thermodynamic processes and their practical implications.

Meta Description: Discover how to calculate the heat of vaporization for an unknown sample based on its mass and vaporization energy, and understand its significance in thermodynamics and physical chemistry.

Frequently Asked Questions

How do you calculate the heat of vaporization for an unknown sample given its mass and energy input?

The heat of vaporization ($\Delta H_{\text{vaporization}}$) is calculated by dividing the total energy required to vaporize the sample by its moles. First, convert the sample's mass to moles using its molar mass, then divide the energy (in joules) by the number of moles: $\Delta H_{\text{vaporization}} = \text{energy (J)} / \text{moles}$.

What is the significance of the heat of vaporization in thermodynamics?

The heat of vaporization represents the amount of energy needed to convert one mole of a substance from liquid to vapor at its boiling point without changing temperature. It reflects the strength of intermolecular forces within the substance.

Given the sample weighs 45.2 g and requires 58.2 kJ to vaporize, how can I find the heat of vaporization per mole?

First, determine the molar mass of the sample. Then, convert grams to moles by dividing 45.2 g by the molar mass. Next, convert 58.2 kJ to joules (58,200 J). Finally, divide the total energy by the number of moles to find the heat of vaporization per mole.

If the molar mass of the sample is unknown, can we still determine its heat of vaporization?

Without the molar mass, you can only find the energy per gram (specific latent heat), but to get the molar heat of vaporization, the molar mass must be known. Therefore, identifying or estimating the molar mass is essential for that calculation.

Why is it important to know the heat of vaporization of a substance?

Knowing the heat of vaporization helps in understanding the energy requirements for phase changes, designing industrial processes like distillation, and predicting how substances respond to temperature changes in various applications.

What steps should I follow to compute the heat of vaporization for this unknown sample?

First, find the molar mass of the sample. Second, convert the sample's mass to moles. Third, convert the energy required from kilojoules to joules. Fourth, divide the total energy by the number of moles to obtain the heat of vaporization in joules per mole.

Additional Resources

Heat of Vaporization: Unlocking the Secrets of Phase Change Energy

Understanding the heat of vaporization is fundamental in thermodynamics, material science, and various industrial processes. In this detailed review, we will explore what the heat of vaporization entails, how it can be calculated, and its significance in practical applications. We will analyze the problem: An unknown sample weighs 45.2 grams and requires 58.2 kilojoules (kJ) of energy to vaporize—a question that offers a gateway into understanding the heat of vaporization in real-world scenarios.

What Is the Heat of Vaporization?

Definition

The heat of vaporization, often denoted as (ΔH_{vap}) , is the amount of energy required to convert a unit mass or mole of a substance from its liquid phase into vapor (gas) at constant temperature and pressure. It reflects the strength of intermolecular forces holding the molecules together in the liquid state.

Key Points

- **Energy Requirement:** It quantifies the energy needed to overcome intermolecular attractions.
- **Units:** Typically expressed in joules per gram (J/g), kilojoules per mole (kJ/mol), or other energy per mass/mole units.
- **Temperature Dependence:** The value varies with temperature, generally decreasing as temperature approaches the critical point, but in many calculations, it is considered at the boiling point under constant pressure.

Importance in Science and Industry

- Design of Heating Systems: Knowledge of ΔH_{vap} guides the design of distillation, evaporation, and refrigeration systems.
- Material Characterization: It helps in understanding the molecular interactions within substances.
- Climate and Environmental Science: Vaporization processes influence weather patterns, evaporation rates, and climate modeling.

Calculating the Heat of Vaporization

The problem provides:

- Mass of the sample, m : 45.2 g
- Energy used to vaporize, Q : 58.2 kJ

Objective: Find the heat of vaporization per unit mass, i.e., ΔH_{vap} in kJ/g, or if needed, per mole.

Step 1: Understand the Given Data

- The energy input Q is used solely for vaporization, assuming negligible heat loss.
- The sample's mass is known, but the molar mass is not provided, so the calculation will initially focus on energy per gram.

Step 2: Calculate the Heat of Vaporization in kJ/g

$$\boxed{\Delta H_{\text{vap}} = \frac{Q}{m}}$$

Plugging in the known values:

$$\Delta H_{\text{vap}} = \frac{58.2 \text{ kJ}}{45.2 \text{ g}} \approx 1.287 \text{ kJ/g}$$

Result: The heat of vaporization for the unknown sample is approximately 1.287 kJ per gram.

Step 3: Convert to Molar Basis (Optional)

To express the heat of vaporization in kJ/mol, the molar mass (M) of the unknown sample is needed. Without this, we cannot compute an exact molar value. However, if an approximate molar mass was known, the conversion would be:

$$\Delta H_{\text{vap}} \text{ (kJ/mol)} = \left(\Delta H_{\text{vap}} \text{ (kJ/g)} \right) \times M \text{ (g/mol)}$$

Understanding the Significance of the Calculated Value

Interpreting the Result

- A value of approximately 1.287 kJ/g indicates the energy needed to vaporize each gram of the substance.
- For comparison, water's heat of vaporization is about 2.26 kJ/g at 100°C, which suggests the unknown might have weaker intermolecular forces or a different molecular structure.

Implications

- The magnitude of ΔH_{vap} provides insights into the nature of the substance.
- Lower values often indicate substances with weaker intermolecular forces (e.g., volatile organic compounds).
- Higher values suggest strong molecular attractions, such as in water or alcohols.

Factors Influencing Heat of Vaporization

Temperature Dependence

- As temperature approaches the critical point, ΔH_{vap} tends to decrease.
- The value is usually specified at the boiling point under standard pressure.

Intermolecular Forces

- Strong hydrogen bonding increases ΔH_{vap} .
- Van der Waals forces and dipole-dipole interactions also affect the energy required.

Molecular Structure and Size

- Larger molecules or those with complex structures generally have higher heats of vaporization.

Experimental Determination of Heat of Vaporization

Methods

- Calorimetry: Direct measurement using a calorimeter designed for phase change studies.
- Clausius-Clapeyron Equation: Indirect calculation based on vapor pressure data at different temperatures.

Clausius-Clapeyron Equation

$$\ln P = -\frac{\Delta H_{\text{vap}}}{RT} + C$$

where:

- P = vapor pressure at temperature T ,
- R = universal gas constant,
- C = constant.

Plotting $\ln P$ vs. $1/T$ yields a straight line, from which ΔH_{vap} can be derived.

Applications and Practical Relevance

Industrial Processes

- Distillation: Accurate knowledge of ΔH_{vap} allows for energy-efficient separation of mixtures.
- Cryogenics and Refrigeration: Understanding vaporization energy is crucial in designing cooling systems.
- Pharmaceuticals and Food Processing: Controlled vaporization influences product stability and extraction processes.

Environmental and Climate Science

- Volatile compounds influence atmospheric chemistry and climate modeling.
- Evaporation rates are directly related to vaporization energy, affecting water cycle dynamics.

Material Development

- Designing new materials, such as refrigerants or solvents, requires knowledge of vaporization properties.

Limitations and Considerations in the Calculation

- Assumption of Complete Vaporization: The calculation assumes all energy goes into vaporization, neglecting heat losses.
- Pure Substance Assumption: The sample is assumed pure; mixture effects can alter (ΔH_{vap}) .
- Temperature Specificity: The value is valid at the temperature of vaporization; differing conditions affect the result.
- Molecular Data Needed for Molar Values: Without molar mass, only per-gram values are accessible.

Conclusion and Summary

The problem of determining the heat of vaporization from the provided data is straightforward once the core concept is understood. By dividing the energy input by the mass of the sample, we find that:

$$\boxed{\text{Heat of Vaporization} \approx 1.287, \text{ kJ/g}}$$

This value provides a quantitative measure of the energy required to vaporize one gram of the unknown substance, reflecting the strength of the intermolecular forces at play. Such calculations are fundamental across numerous scientific disciplines and industrial applications, enabling engineers and scientists to optimize processes, understand material properties, and predict behavior under various thermal conditions.

The broader understanding of the heat of vaporization not only helps interpret specific problems but also enhances comprehension of phase transitions, thermodynamics, and molecular interactions. Whether designing energy-efficient distillation units, developing new materials, or modeling climate systems, the concept remains central to the science of heat and matter.

In essence, the heat of vaporization is a vital parameter that bridges molecular interactions and macroscopic energy transfer, and this problem illustrates how simple division of energy by mass can unlock profound insights into the nature of substances.

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