Calculate The Amount Of Heat Required To Completely Sublime 50.0 G Of Solid Dry Ice (CO2) At Its Sublimation

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When working with dry ice, or solid carbon dioxide (CO_2), understanding the amount of heat required to transition it from a solid directly into a gas is essential. This process, known as sublimation, occurs under specific temperature and pressure conditions. If you need to determine how much energy is needed to sublime a given mass of dry ice, such as 50.0 grams, it involves calculating the heat based on the sublimation enthalpy of CO_2. In this article, we will explore how to calculate the heat required for sublimation of dry ice, the relevant thermodynamic concepts, and the step-by-step process to arrive at an accurate answer.

Understanding Sublimation of Dry Ice (CO_2)

Before diving into the calculations, it's important to understand what sublimation entails and the properties of dry ice.

What is Sublimation?

Sublimation is the phase transition where a substance moves directly from the solid state to the gaseous state without passing through a liquid phase. For dry ice, this occurs at atmospheric pressure when it is exposed to temperatures above its sublimation point, approximately -78.5°C (-109.3°F).

Properties of Dry Ice (CO_2)

- Molecular Formula: CO_2
- Sublimation Point: -78.5°C at 1 atm pressure
- Molar Mass: 44.01 g/mol
- Sublimation Enthalpy (ΔH_{sub}): Approximately 571 kJ/mol

The sublimation enthalpy is a key value in calculating the heat required for the phase change.

Thermodynamic Data Needed for Calculation

To determine the heat required for subliming 50.0 grams of dry ice, the following data are essential:

- Mass of dry ice: 50.0 g
- Sublimation enthalpy of CO_2: 571 kJ/mol
- Molar mass of CO_2: 44.01 g/mol

Using these, we can find the number of moles of CO_2 in 50.0 grams and then multiply by the sublimation enthalpy per mole to find the total heat.

Step-by-Step Calculation

Let's outline the step-by-step process:

Step 1: Calculate the number of moles of dry ice

$$
\text{Number of moles} (n) = \frac{\text{mass}}{\text{molar mass}} = \frac{50.0\, \text{g}}{44.01\, \text{g/mol}}
$$

Calculating:

$$
n \approx 1.136\, \text{mol}
$$

Step 2: Use the sublimation enthalpy to find the total heat

The total heat Q required is:

$$
Q = n \times \Delta H_{\text{sub}}
$$

where:
- n = number of moles of CO_2
- ΔH_{sub} = sublimation enthalpy per mole (571 kJ/mol)

Calculating:

$$
Q = 1.136\, \text{mol} \times 571\, \text{kJ/mol} \approx 648.4\, \text{kJ}
$$

Therefore, approximately 648.4 kJ of heat energy is required to completely sublime 50.0 grams of dry ice at its sublimation point.

Additional Considerations

While the calculation above assumes the dry ice is at its sublimation temperature and pressure, real-world scenarios may involve additional factors:

1. Initial Temperature of the Dry Ice

If the dry ice starts at a temperature below -78.5°C, it must first be warmed to the sublimation temperature before sublimation can occur. This involves calculating the sensible heat:

$$
Q_{\text{warming}} = m \times c_s \times \Delta T
$$

where:
- c_s = specific heat capacity of solid CO_2 (~0.85 J/g·K)
- ΔT = temperature change needed to reach sublimation point

2. Pressure Conditions

The sublimation point varies with pressure; higher pressures can raise the sublimation temperature, changing the heat required.

3. Practical Application

In practical applications, the heat transfer process may not be perfectly efficient, and additional energy loss may occur.

Summary

Calculating the heat required to sublime dry ice involves understanding the thermodynamic properties of CO_2 and applying basic stoichiometric principles. For 50.0 grams of dry ice, approximately 648.4 kJ of energy must be supplied at its sublimation temperature to convert the entire mass from solid to gas. This calculation is vital in various fields, including cryogenics, food preservation, and chemical engineering, where precise energy management is crucial.

Key Takeaways:
- Determine the number of moles of dry ice.
- Multiply by the sublimation enthalpy per mole.
- Adjust calculations if the initial temperature is below sublimation temperature or if pressure conditions vary.

Understanding these principles ensures accurate energy calculations for handling dry ice safely and efficiently in laboratory and industrial settings.

Note: Always verify thermodynamic data with current literature or authoritative sources, as values like sublimation enthalpy can vary slightly depending on conditions.

Frequently Asked Questions

What is the main factor determining the amount of heat needed to sublime 50.0 g of dry ice?

The main factor is the heat of sublimation of CO2, which is the amount of energy required to convert solid dry ice directly into gas without passing through the liquid phase.

How do you calculate the heat required to sublime a given mass of dry ice?

You multiply the mass of dry ice by the molar heat of sublimation (in J/mol). Specifically, Q = n × ΔH_sub, where n is the number of moles and ΔH_sub is the molar heat of sublimation.

What is the molar heat of sublimation for CO2?

The molar heat of sublimation for CO2 is approximately 25.2 kJ/mol.

How many moles of dry ice are in 50.0 g?

Since the molar mass of CO2 is about 44.01 g/mol, the number of moles in 50.0 g is approximately 1.136 mol.

What is the total heat required to sublime 50.0 g of dry ice?

Using Q = n × ΔH_sub, the total heat required is approximately 1.136 mol × 25.2 kJ/mol ≈ 28.6 kJ.

Why is understanding the heat of sublimation important in practical applications?

Knowing the heat of sublimation helps in designing processes involving dry ice, such as refrigeration, fog effects, and scientific experiments, ensuring efficient energy use and safety.

Additional Resources

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Introduction

Dry ice, the solid form of carbon dioxide (CO_2), is widely recognized for its unique sublimation property—transitioning directly from solid to gas without passing through a liquid phase. This characteristic makes it invaluable across various industries, including food preservation, medical sterilization, and theatrical effects. Understanding the thermodynamics involved in dry ice sublimation is essential for safe handling, efficient utilization, and precise process control.

This investigation aims to calculate the total amount of heat required to completely sublime 50.0 grams of solid dry ice at its sublimation temperature. To achieve this, we will explore the physical properties of CO_2, analyze the phase change process, and perform detailed calculations grounded in thermodynamic principles.

Physical Properties of Carbon Dioxide and Dry Ice

Before delving into calculations, it's critical to understand the fundamental properties of CO_2 and dry ice:

- Molecular weight of CO_2: approximately 44.01 g/mol
- Sublimation temperature at standard atmospheric pressure: approximately -78.5°C (-109.3°F)
- Standard sublimation enthalpy (ΔH_{sub}): approximately 571 kJ/mol
- Density of solid CO_2 (dry ice): roughly 1.56 g/cm^3 at sublimation point
- Vapor pressure at sublimation temperature: about 5.1 atm

These properties are essential for calculating the heat involved in the phase transition, especially the sublimation enthalpy, which represents the energy required to convert a mole of dry ice directly into carbon dioxide gas at its sublimation point.

Theoretical Framework for Heat Calculation

The temperature at which sublimation occurs and the associated energy input depend on thermodynamic parameters. The fundamental equation for the heat required (Q) in sublimation is:

$$Q = n \times \Delta H_{sub}$$

Where:
- n = number of moles of dry ice
- ΔH_{sub} = molar sublimation enthalpy

Calculating n involves dividing the mass of dry ice by molar mass:

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

Given:
- $m = 50.0\,g$
- $M = 44.01\,g/mol$

The total heat is then:

$$ Q = \left(\frac{m}{M} \right) \times \Delta H_{sub} $$

Step-by-Step Calculation

1. Calculate the number of moles of dry ice:

$$
n = \frac{50.0\,g}{44.01\,g/mol} \approx 1.136\,\text{mol}
$$

2. Determine the total heat required:

$$
Q = 1.136\,\text{mol} \times 571\,\text{kJ/mol} \approx 648.4\,\text{kJ}
$$

Thus, approximately 648.4 kilojoules of heat are needed to completely sublime 50.0 grams of dry ice at its sublimation temperature.

Practical Considerations and Assumptions

While the above calculation provides a theoretical value, practical scenarios often involve additional considerations:

- Heat Losses: In real-world applications, heat losses to surroundings can reduce the efficiency of sublimation, requiring additional energy input.
- Preheating: If the dry ice is not initially at its sublimation temperature, energy will be necessary to warm it to the sublimation point before phase change occurs.
- Pressure Conditions: The sublimation temperature and enthalpy are pressure-dependent; standard values assume atmospheric pressure.

To refine the calculation for specific conditions, one might incorporate:

- The energy needed to raise the temperature from initial temperature to -78.5°C (if starting colder)
- Additional energy to compensate for heat losses or to maintain pressure

However, for the purposes of this investigation, the assumption is that the dry ice starts at sublimation temperature and that the process occurs under ideal conditions.

Thermodynamic Context: Sublimation Enthalpy and Its Significance

The molar sublimation enthalpy (ΔH_{sub}) of approximately 571 kJ/mol indicates a significant energy barrier for the phase change. This high value reflects the strength of intermolecular forces in solid CO_2 and the energetic cost of overcoming them to transition directly into gas.

Implications:

- Energy Storage: Dry ice acts as an excellent cooling agent because of its energy content associated with phase change.
- Safety: Handling requires careful management of heat input to prevent rapid sublimation or pressure buildup.
- Efficiency: Precise calculations like this enable efficient design of sublimation chambers, storage containers, and transportation methods.

Additional Factors Influencing Heat Calculation

While the core calculation focuses on the sublimation enthalpy, real-world applications often require considering:

Factor	Effect	Consideration
Initial Temperature	If dry ice is colder than sublimation point	Additional energy to warm before sublimation
Ambient Pressure	Alters sublimation temperature	Higher pressure increases required temperature and energy
Container Insulation	Affects heat exchange	Better insulation reduces heat losses
Rate of Sublimation	Rapid sublimation may require more energy input	Ensures controlled phase change

In controlled laboratory or industrial settings, these factors are meticulously managed to optimize energy use and safety.

Broader Applications and Significance

Understanding the heat required for dry ice sublimation extends beyond basic thermodynamics. It is fundamental in:

- Designing refrigeration systems: where precise energy calculations ensure effective cooling without excessive energy expenditure.
- Medical sterilization: where controlled sublimation ensures sterilization without residual moisture.
- Transport logistics: managing pressure and temperature to prevent unintended sublimation or pressure build-up.
- Environmental considerations: estimating carbon dioxide release during sublimation for ecological impact assessments.

Conclusion

The calculation of the heat required to completely sublime 50.0 grams of dry ice underscores the importance of thermodynamic principles in practical applications. Based on the molar sublimation enthalpy and molecular weight, approximately 648.4 kJ of heat energy is necessary under ideal conditions to transition this quantity of solid CO_2 directly into gas at its sublimation temperature.

This detailed analysis not only provides a fundamental understanding of phase change energetics but also informs safer handling, efficient process design, and environmental considerations associated with dry ice use. Future work can incorporate dynamic factors such as heat transfer rates, container design, and environmental variables to refine these estimates further.

References

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