Dry Ice Is Solid Carbon Dioxide. A 0.05 G Sample Of Dry Ice Is Placed In An Evacuated 4.6L Vessel At

Dry Ice Is Solid Carbon Dioxide. A 0.05 G Sample Of Dry Ice Is Placed In An Evacuated 4.6L Vessel At a controlled temperature and pressure environment, providing a fascinating glimpse into the properties of this unique substance. Understanding dry ice's behavior, applications, and the science behind its phase changes is essential for industries ranging from food preservation to entertainment. This article explores the scientific principles governing dry ice, the significance of placing a small sample in a large evacuated vessel, and the broader implications of its use.

What Is Dry Ice? An Overview of Solid Carbon Dioxide

Definition and Composition

Dry ice is the solid form of carbon dioxide (CO_2). Unlike typical ice, which is frozen water, dry ice sublimates directly from a solid to a gas at atmospheric pressure, bypassing the liquid phase. This unique transition makes it valuable in various applications.

- Chemical Composition: Pure carbon dioxide, a colorless, odorless gas.
- Physical State: Solid at temperatures below -78.5°C (-109.3°F).
- Appearance: White, opaque blocks or pellets.

Properties of Dry Ice

Dry ice exhibits several distinctive properties:

- **High sublimation rate:** It sublimates rapidly at room temperature.
- **Temperature:** Maintains extremely low temperatures, ideal for cooling and freezing.
- **Density:** Approximately 1.56 g/cm³, denser than water ice.
- **Non-flammability:** It does not support combustion but can cause burns upon contact due to extreme cold.

Scientific Principles Behind Dry Ice Behavior in a

Sealed Vessel

Understanding Phase Changes: Sublimation and Deposition

The most notable characteristic of dry ice is its sublimation process:

- Sublimation: Transition from solid directly to gas.
- Deposition: Gas returning to solid form under certain conditions.

This phase change is governed by temperature and pressure, described in phase diagrams of CO_2.

Impact of Placing Dry Ice in an Evacuated 4.6L Vessel

When a small sample of dry ice (0.05 grams) is placed inside a large evacuated vessel, several phenomena occur:

- Sublimation in a vacuum: The absence of air (or other gases) allows dry ice to sublimate more rapidly.
- Pressure buildup: The sublimated CO_2 gas increases the pressure inside the vessel.
- Temperature changes: The sublimation absorbs heat (endothermic process), leading to cooling of the remaining dry ice.

Calculating the Behavior of Dry Ice in the Vessel

Estimating the Amount of Gas Produced

Given 0.05 grams of dry ice:

- Molar mass of CO_2: approximately 44 g/mol.
- Moles of CO_2 sublimated:

$$
\text{moles} = \frac{0.05\, \text{g}}{44\, \text{g/mol}} \approx 0.00114\, \text{mol}
$$

Using the ideal gas law to estimate pressure:

$$
PV = nRT
$$

Where:

- P = pressure,
- V = 4.6 L,
- n = 0.00114 mol,
- R = 0.08206 L·atm/(mol·K),
- T = temperature in Kelvin (assuming room temperature, ~298 K).

Calculating:

$$
P = \frac{nRT}{V} = \frac{0.00114 \times 0.08206 \times 298}{4.6} \approx 0.0061\, \text{atm}
$$

This suggests that at room temperature, the pressure generated by 0.05 g of dry ice in a 4.6 L vessel is very low. However, if the vessel is evacuated (initially no gases), the sublimation of dry ice will rapidly increase the pressure until equilibrium is reached or the dry ice is fully sublimated.

Effects of Vacuum on Sublimation Rate

In a vacuum:

- The sublimation rate increases because the external pressure is much lower than atmospheric pressure.
- The dry ice may sublimate almost instantaneously, leading to rapid gas expansion.
- The temperature of the remaining dry ice drops due to the endothermic nature of sublimation.

Applications and Significance of Dry Ice

Industrial and Commercial Uses

Dry ice has a wide array of applications:

- **Food preservation:** Used in shipping perishable goods, ice cream production, and cleaning of food processing equipment.
- **Medical field:** For cryogenic preservation and sterilization processes.
- **Entertainment:** Produces fog effects in theaters, concerts, and haunted houses.
- **Cleaning:** Dry ice blasting removes contaminants without damaging surfaces.

Advantages of Using Dry Ice

- No residual liquid waste.
- Extremely cold temperature for rapid cooling.
- Environmentally friendly, as CO_2 is a natural byproduct and sublimates into the atmosphere.

Safety Considerations When Handling Dry Ice

Risks and Precautions

Handling dry ice requires careful attention due to its extreme cold and sublimation properties:

- Burns and frostbite: Direct contact can cause cold burns.
- Asphyxiation risk: Sublimated CO_2 can displace oxygen in enclosed spaces.
- Proper ventilation: Always use dry ice in well-ventilated areas.
- Protective gear: Use gloves and eye protection when handling.

Storage Recommendations

- Store in insulated, well-ventilated containers.
- Avoid airtight containers to prevent pressure buildup.
- Keep away from children and pets.

Scientific Experiments and Educational Demonstrations

Learning from the Dry Ice in a Vacuum

Placing a small dry ice sample in a sealed, evacuated vessel is a common educational experiment to demonstrate:

- Sublimation and phase transitions.
- Gas laws and pressure-volume relationships.
- The endothermic nature of sublimation.
- The properties of gases and their behavior under different conditions.

Experimental Procedure Outline

- Weigh a known amount of dry ice.
- Place it inside a sealed vessel connected to a vacuum pump.
- Evacuate the vessel to a specified pressure.
- Observe the rate of sublimation and pressure changes.
- Record temperature and pressure over time to analyze the behavior.

Environmental Impact and Sustainability

CO_2 Recycling and Carbon Footprint

While dry ice is useful in many applications, its environmental impact must be considered:

- CO_2 used for dry ice is often a byproduct of industrial processes, which can help reduce waste.
- Sublimation releases CO_2 into the atmosphere, contributing to greenhouse gases.
- Efforts are ongoing to develop sustainable and recycled sources of CO_2 for dry ice production.

Future Developments

Research continues into:

- Improving the energy efficiency of dry ice production.
- Developing biodegradable alternatives.
- Enhancing safety protocols for handling and storage.

Conclusion

Dry ice, as solid carbon dioxide, offers a remarkable combination of physical and chemical properties that make it invaluable across various fields. The experiment involving a small sample in an evacuated vessel provides insights into sublimation, gas laws, and phase transitions. Understanding these principles not only deepens scientific knowledge but also informs safer and more effective application of dry ice technology. As industries evolve and environmental considerations grow, the future of dry ice will likely involve more sustainable practices, innovative uses, and continued exploration of its fascinating properties.

Frequently Asked Questions

What happens when dry ice is placed in an evacuated vessel?

When dry ice (solid carbon dioxide) is placed in an evacuated vessel, it sublimates directly from a solid to a gas, creating a dense CO_2 vapor inside the container.

How much CO_2 gas is produced from a 0.05 g sample of dry ice?

Using molar mass of CO_2 (44.01 g/mol), 0.05 g of dry ice produces approximately 0.00114 mol of CO_2 gas, which occupies a volume of about 5.2 liters at standard temperature and pressure.

What is the significance of the vessel being evacuated in this experiment?

An evacuated vessel ensures no external air or gases interfere, allowing accurate measurement of the CO_2 produced from the dry ice sublimation and preventing pressure buildup.

How does the temperature affect the sublimation of dry ice in

this scenario?

Higher temperatures increase the sublimation rate of dry ice, leading to faster production of CO_2 gas, while lower temperatures slow down sublimation but do not prevent it entirely.

What is the expected pressure inside the vessel after the dry ice sublimates?

Assuming ideal gas behavior, the pressure can be calculated using the ideal gas law (PV=nRT). For 0.00114 mol of CO_2 in 4.6 L at room temperature, the pressure is approximately 0.78 atm.

Why is dry ice used in various scientific and industrial applications?

Dry ice is used for cooling, creating fog effects, and transporting perishable goods because it sublimates directly to gas without leaving liquid residue, and its cold temperature helps preserve items.

Additional Resources

Dry Ice Is Solid Carbon Dioxide: An In-Depth Analysis of Its Behavior in a Sealed Environment

Dry ice, the solid form of carbon dioxide (CO_2), has long been valued across industries for its unique properties—chiefly its ability to sublime directly from solid to gas without passing through a liquid phase under typical conditions. This characteristic makes it an ideal cooling agent, a cleaning medium, and a medium for creating fog effects. In this comprehensive review, we examine a specific scenario: a 0.05 g sample of dry ice placed in a sealed 4.6 L evacuated vessel. Through this, we aim to explore the physical principles governing dry ice's behavior in confined environments, analyze the thermodynamic processes involved, and discuss practical implications and safety considerations.

Understanding Dry Ice: Composition and Properties

Dry ice is the solid form of carbon dioxide, which sublimates at -78.5°C (-109.3°F) under atmospheric pressure. Unlike water ice, which melts into liquid water, dry ice transitions directly into gaseous CO_2—a process known as sublimation. This property makes it particularly useful in scenarios where water or other liquids are undesired.

Key features of dry ice include:

- High sublimation energy: It absorbs substantial heat during sublimation.
- Temperature stability: Sublimates at a consistent temperature under standard pressure.
- Density: Approximately 1.6 g/cm^3, denser than water ice.
- Safety considerations: As a gas, it can displace oxygen, posing asphyxiation risks in enclosed spaces.

Thermodynamics of Dry Ice in a Sealed Vessel

When a small amount of dry ice is placed into a sealed, evacuated vessel, the subsequent behavior is dictated by thermodynamic principles, including vapor pressure, temperature, and the ideal gas law.

Initial Conditions and Assumptions

- Sample mass: 0.05 g of dry ice.
- Vessel volume: 4.6 L (or 0.0046 m^3).
- Initial environment: Evacuated vessel, implying negligible initial pressure inside.
- External temperature: Assumed to be at room temperature (~25°C or 298 K) unless otherwise specified.

Given the initial vacuum, the dry ice will begin sublimating immediately, releasing CO_2 gas. As it sublimates, the gas pressure inside the vessel builds until equilibrium is established at a temperature corresponding to the vapor pressure of CO_2 at that temperature.

Vapor Pressure of CO_2

The vapor pressure of dry ice at various temperatures is well-documented. At -78.5°C, the vapor pressure is approximately 5.2 atm; at higher temperatures, this pressure increases. Since the environment is initially at room temperature, the pressure will rise rapidly as sublimation occurs.

Implication: The gas will exert pressure on the vessel walls, and the system will reach equilibrium when the partial pressure of CO_2 equals its vapor pressure at the vessel's temperature.

Calculating the Equilibrium Pressure and Gas Volume

To understand the behavior quantitatively, we can use the ideal gas law:

$$ PV = nRT $$

Where:

- P = pressure of CO_2 gas at equilibrium
- V = volume of the vessel (4.6 L)
- n = number of moles of CO_2 produced
- R = ideal gas constant (8.314 J/(mol·K))
- T = temperature in Kelvin

Step 1: Determine moles of dry ice

Given that dry ice is solid carbon dioxide:

$$
\text{Molecular weight of CO}_2 = 44.01\, \text{g/mol}
$$

$$
n = \frac{0.05\, \text{g}}{44.01\, \text{g/mol}} \approx 0.001136\, \text{mol}
$$

Step 2: Estimate the temperature

Assuming the dry ice sublimates at room temperature (~298 K), the vapor pressure of CO_2 at this temperature is approximately 64 atm, based on standard vapor pressure tables.

Step 3: Calculate the pressure

Using the ideal gas law:

$$
P = \frac{nRT}{V}
$$

Convert volume to cubic meters:

$$
V = 4.6\, \text{L} = 0.0046\, \text{m}^3
$$

Calculate:

$$
P = \frac{(0.001136\, \text{mol}) \times 8.314\, \text{J/(mol·K)} \times 298\, \text{K}}{0.0046\, \text{m}^3}
$$

$$
P \approx \frac{(0.001136) \times (2477.572)}{0.0046} \approx \frac{2.817\, \text{J}}{0.0046\, \text{m}^3} \approx 612.6\, \text{kPa}
$$

Converting to atmospheres:

$$
\frac{612.6\, \text{kPa}}{101.3\, \text{kPa/atm}} \approx 6.05\, \text{atm}
$$

Interpretation:

The calculated pressure (~6 atm) is significantly lower than the vapor pressure of CO_2 at room temperature (~64 atm). This indicates that the dry ice will sublime until the internal pressure reaches the vapor pressure corresponding to the temperature—in this case, approximately 64 atm—assuming the vessel can withstand this pressure.

Behavior of Dry Ice in the Sealed Vessel

Given the above calculations, the following sequence of events is typical:

1. Immediate Sublimation: Upon placement, the dry ice begins sublimating rapidly because of the vacuum conditions, which cause a steep vapor pressure gradient.
2. Pressure Increase: As CO_2 gas accumulates, pressure inside the vessel increases, approaching the vapor pressure corresponding to the vessel's temperature.
3. Equilibrium Establishment: Sublimation slows down and eventually stops when the vapor pressure of CO_2 at the ambient temperature equals the internal pressure. The system reaches a dynamic equilibrium with ongoing sublimation and deposition rates balancing.
4. Temperature Stabilization: The temperature inside the vessel tends to remain near the sublimation temperature of dry ice (~-78.5°C) under ideal conditions, but in a sealed environment with no heat exchange, the temperature may shift depending on heat transfer processes.

Note: Because the initial conditions involve evacuation, the rapid sublimation can cause a significant pressure rise, potentially stressing the vessel if not designed to withstand high pressures.

Practical Implications and Safety Considerations

When working with dry ice in sealed environments, safety is paramount. The rapid sublimation and pressure buildup can pose risks of explosion or rupture if the vessel isn't rated for high pressures.

Features of sealed dry ice systems:

- Pros:
- Enables controlled experiments on sublimation and gas behavior.
- Useful for creating high-pressure environments for scientific studies.
- Eliminates moisture contamination, which is beneficial in specific industrial applications.

- Cons:
- Potential for dangerous pressure build-up.
- Risk of vessel rupture if pressure exceeds design limits.
- Difficult to control temperature and pressure precisely without external regulation.

Safety precautions include:

- Using pressure-rated vessels designed for high-pressure gases.
- Monitoring internal pressure and temperature during experiments.

- Ensuring proper venting or pressure relief systems.
- Conducting experiments in well-ventilated areas to prevent CO_2 accumulation.

Applications and Real-World Uses of Dry Ice in Sealed Environments

Understanding the behavior of dry ice in sealed containers informs various practical applications:

- Industrial Cleaning: High-pressure CO_2 vapor helps remove contaminants.
- Food Preservation: Sealed environments maintain low temperatures and prevent moisture ingress.
- Scientific Experiments: Studying sublimation dynamics, gas laws, and phase transitions.
- Engineering Tests: Assessing material strength and safety under high-pressure CO_2 conditions.

Conclusion: Key Takeaways

Placing a small amount of dry ice into a sealed, evacuated vessel leads to rapid sublimation and significant pressure buildup, driven by the thermodynamic properties of CO_2. The vapor pressure at the system's temperature dictates the equilibrium pressure, which can reach high levels if the vessel withstands the stress. This scenario vividly demonstrates fundamental principles of phase changes, ideal gas behavior, and pressure-temperature relationships.

In summary:

- Dry ice sublimates directly to CO_2 gas, especially in vacuum conditions.
- The internal pressure depends on the amount of dry ice, vessel volume, and temperature.
- Proper safety measures are essential to prevent accidents.
- Such studies deepen our understanding of phase transitions and gas laws, informing both industrial applications and safety protocols.

By analyzing the behavior of dry ice in a sealed environment, we gain insight into the fascinating interplay between thermodynamics and material science—knowledge that is crucial for safe handling and innovative application of this versatile substance.

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