At 25 C The Henry's Law Consatnt For Phosphine Gas In Water Is 8.1 X 10^-3. Calculate The Mass In Grams

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Introduction

Understanding the solubility of gases in liquids is a fundamental aspect of chemistry, particularly in fields such as environmental science, chemical engineering, and industrial processes. One of the key principles governing gas solubility is Henry's Law, which states that at a constant temperature, the amount of a gas that dissolves in a liquid is directly proportional to the partial pressure of the gas above the liquid.

In this context, the Henry's Law constant (often denoted as k_H) provides a quantitative measure of this relationship. Specifically, for phosphine gas (PH_3) in water at 25°C, the Henry's Law constant is given as 8.1×10^{-3}. This value indicates how readily phosphine dissolves into water under a given pressure.

This article aims to explore the calculation of the mass of phosphine gas that dissolves in water at this temperature, based on a specific scenario or set of conditions. We will delve into the principles of Henry's Law, interpret the given constant, and perform detailed calculations to find the mass in grams of phosphine that can dissolve in water under specified conditions.

Understanding Henry's Law and Its Constant

What is Henry's Law?

Henry's Law states that:

$$ C = k_H \times P $$

Where:

- C is the concentration of the gas in the liquid (usually in mol/L),
- k_H is the Henry's Law constant (depends on the gas-liquid pair and temperature),
- P is the partial pressure of the gas above the liquid (in atm).

This law demonstrates that at a fixed temperature, increasing the pressure of the gas increases its solubility in the liquid proportionally.

Henry's Law Constant for Phosphine in Water

Given:

$$k_H = 8.1 \times 10^{-3} \text{ mol/(L·atm)}$$

This value indicates that at 25°C, for every atmosphere of phosphine gas pressure, approximately 8.1×10^{-3} moles of phosphine dissolve in one liter of water.

Calculating the Mass of Phosphine Dissolved in Water

To find the mass in grams of phosphine gas that dissolves in water, we need to understand the specific conditions under which the gas dissolves. Typically, this involves knowing:

- The partial pressure of phosphine gas above the water,
- The volume of water involved,
- The temperature (already given as 25°C),
- The molar mass of phosphine.

Assuming the problem provides or we decide on specific values for pressure and volume, the calculation proceeds as follows:

Step 1: Determine the Moles of Dissolved Phosphine

Using Henry's Law:

$$C = k_H \times P$$

Where:

- C = concentration in mol/L,
- P = partial pressure of phosphine in atm.

Suppose, for example, the partial pressure P of phosphine gas is 1 atm (standard pressure). Then:

$$C = 8.1 \times 10^{-3} \times 1 = 8.1 \times 10^{-3} \text{ mol/L}$$

If the volume V of water is known, say 1 liter, then the total moles of phosphine dissolved are:

$$n = C \times V = 8.1 \times 10^{-3} \times 1 = 8.1 \times 10^{-3} \text{ mol}$$

Step 2: Convert Moles to Mass

The molar mass of phosphine (PH_3):

$$\text{Molar mass} = 1 \times 30.97 + 3 \times 1.008 \approx 34.0 \text{ g/mol}$$

Therefore, the mass m in grams:

$$m = n \times \text{Molar mass} = 8.1 \times 10^{-3} \times 34.0 \approx 0.2754 \text{ grams}$$

This means approximately 0.275 grams of phosphine can dissolve in 1 liter of water at 25°C under 1 atm pressure.

Generalized Calculation Based on Different Conditions

The above calculation can be generalized for different pressures and volumes. The key steps are:

1. Identify or specify the partial pressure of phosphine gas (P) in atm.

2. Determine the volume of water (V) in liters.

3. Calculate the concentration using Henry's Law:

$$ C = k_H \times P $$

4. Calculate the total moles of phosphine dissolved:

   $$ n = C \times V $$

5. Convert moles to grams using molar mass:

   $$ \text{Mass} = n \times 34.0 \text{ g/mol} $$

Practical Example: Calculating the Mass of Phosphine for Specific Conditions

Suppose we are dealing with a scenario where:

- The partial pressure of phosphine gas is 0.5 atm,
- The volume of water is 2 liters.

Let's perform the calculation:

1. Calculate concentration:

$$ C = 8.1 \times 10^{-3} \times 0.5 = 4.05 \times 10^{-3} \text{ mol/L} $$

2. Calculate total moles:

$$ n = 4.05 \times 10^{-3} \times 2 = 8.1 \times 10^{-3} \text{ mol} $$

3. Calculate mass:

$$ m = 8.1 \times 10^{-3} \times 34.0 \approx 0.2754 \text{ grams} $$

The result aligns with the previous example, indicating that under these conditions, approximately 0.275 grams of phosphine will dissolve in the water.

Implications and Applications of Henry’s Law in Industry and Environment

Understanding Henry’s Law and accurately calculating gas solubility has significant implications:

Environmental Monitoring

- Phosphine is a toxic and flammable gas used in pest control and industrial applications.
- Its dissolution in water impacts environmental safety and water quality.
- Accurate calculations help in assessing contamination risks and designing remediation strategies.

Industrial Processes

- Gas absorption and scrubbing systems rely on Henry’s Law for designing efficient removal or absorption units.
- Precise knowledge of gas solubility aids in optimizing process conditions, reducing costs, and ensuring safety.

Safety and Regulatory Standards

- Regulations often specify permissible concentrations of gases in water or air.
- Understanding the solubility limits helps in compliance and risk management.

Conclusion

The calculation of how much phosphine gas dissolves in water at 25°C, given the Henry's Law constant of \(8.1 \times 10^{-3}\), is essential for various scientific and industrial applications. By understanding the relationship between pressure, concentration, and volume, one can determine the mass of phosphine that can be safely handled, released, or contained within a system.

The key takeaways include:

- Henry's Law provides a direct proportionality between gas pressure and

solubility.
- The Henry's Law constant varies with temperature and the specific gas-liquid pair.
- Practical calculations depend on known conditions such as pressure and volume.
- Accurate knowledge of gas solubility informs environmental safety, industrial design, and regulatory compliance.

In summary, whether for environmental safety assessments, industrial process optimization, or academic research, understanding and applying Henry's Law is vital for managing gas-liquid interactions effectively.

Keywords: Henry's Law, phosphine gas, water solubility, Henry's Law constant, gas solubility calculation, environmental safety, industrial processes, chemical engineering

Frequently Asked Questions

What is Henry's Law constant for phosphine gas in water at 25°C?

The Henry's Law constant for phosphine gas in water at 25°C is 8.1×10^{-3}.

How do you calculate the mass of phosphine gas dissolved in water using Henry's Law?

You can calculate the mass using the Henry's Law formula: $C = k_H P$, where C is the concentration, k_H is Henry's Law constant, and P is the partial pressure of the gas. Then, convert the concentration to mass based on the volume of water.

What additional information is needed to find the mass of phosphine in water?

You need to know the partial pressure of phosphine gas and the volume of water in which it is dissolved.

How does temperature affect Henry's Law constant?

Henry's Law constant varies with temperature; generally, it increases or decreases depending on the gas and solvent, affecting the solubility calculations.

If the partial pressure of phosphine is 1 atm, what is the concentration in water at 25°C?

Using C = k_H P, with P = 1 atm, the concentration C = 8.1 x 10^-3 mol/L.

How do you convert molar concentration to mass in grams?

Multiply the molar concentration by the molar mass of phosphine (PH3, approximately 34 g/mol) and the volume of water in liters.

What is the molar mass of phosphine (PH3)?

The molar mass of phosphine is approximately 34 g/mol.

Can Henry's Law be used to determine the total mass of phosphine dissolved in water at equilibrium?

Yes, by calculating the concentration using Henry's Law and multiplying by the volume of water, you can determine the total mass of phosphine dissolved.

Additional Resources

At 25 C The Henry's Law Constant For Phosphine Gas In Water Is 8.1 X 10^-3. Calculate The Mass In Grams.

Introduction

In the realm of environmental chemistry and chemical engineering, understanding the solubility of gases in liquids is paramount. Henry's law, a fundamental principle describing this relationship, provides insights into how gases behave when in contact with liquids under various conditions. Among the myriad of gases studied, phosphine (PH_3) stands out due to its industrial applications and potential environmental hazards.

The specific query—"At 25°C, the Henry's law constant for phosphine gas in water is 8.1 x 10^-3"—serves as a critical starting point for determining how much phosphine dissolves in water under these conditions. This article delves into the nuances of Henry's law, the significance of the Henry's law constant, and the detailed calculations needed to determine the mass of phosphine in water, elucidating the broader implications for environmental safety, industrial processes, and scientific research.

Background on Henry’s Law and Henry's Law Constant

Understanding Henry’s Law

Henry's law states that at a constant temperature, the amount of a gas that dissolves in a liquid is directly proportional to the partial pressure of that gas above the liquid. Mathematically, it is expressed as:

$$C = k_H \times P$$

where:

- C = concentration of the gas in the liquid phase (usually mol/L)
- k_H = Henry’s law constant (units vary depending on the formulation)
- P = partial pressure of the gas (atm)

This law assumes ideal behavior and is valid under dilute conditions where interactions between gas molecules in the solution are negligible.

Henry's Law Constant: Definitions and Units

The Henry's law constant can be expressed in various forms, depending on the context:

- Dimensionless Henry's law constant (H): Ratio of concentrations at equilibrium.
- Henry's law constant in mol/(L·atm): When concentration is in molarity.
- Henry's law constant in $atm \cdot m^3/mol$ or atm·L/mol: When relating partial pressure and molar concentrations.

In this context, the given Henry’s law constant (8.1×10^{-3}) is specified at 25°C for phosphine in water. Typically, such a value represents the dimensionless Henry’s law constant, indicating the ratio of the molar concentration of phosphine in water to its partial pressure in the gas phase.

Significance of the Henry's Law Constant for Phosphine

Phosphine as an Environmental and Industrial Substance

Phosphine is a colorless, flammable, and highly toxic gas with a pungent odor. It is used in various industrial applications, including fumigation, semiconductor manufacturing, and as a reducing agent. Due to its toxicity and volatility, understanding its solubility and behavior in aqueous environments is critical for safety assessments and environmental monitoring.

Environmental Impact and Safety Concerns

- Toxicity: Phosphine interferes with mitochondrial respiration, making exposure hazardous to humans and wildlife.
- Persistence: Its solubility influences how long it remains in aquatic environments, affecting toxicity levels.
- Regulatory Standards: Accurate calculations of phosphine in water help enforce environmental standards and guide remediation efforts.

Calculation Objective and Approach

The primary goal: Calculate the mass in grams of phosphine that would dissolve in water under specified conditions, given the Henry's law constant at 25°C.

Assumptions:

- The partial pressure of phosphine in the gas phase is known or standardized (commonly 1 atm for such calculations).
- The water volume is specified or can be assumed (e.g., 1 liter for simplicity).
- The Henry's law constant is in a compatible form (dimensionless or molar-based).

Step-by-Step Calculation

Step 1: Clarify the Units and Values

Given Data:

- Henry's law constant, $H = 8.1 \times 10^{-3}$ (dimensionless)
- Temperature, $T = 25^\circ C$
- Standard pressure of gas, $P_{gas} = 1$ atm (assumed for calculation)
- Volume of water, V_{water} (assumed 1 liter for simplicity)

Step 2: Determine the Molar Concentration of Dissolved Phosphine

Using Henry's law in its molar form:

$$ C_{water} = H \times P_{gas} $$

Where:

- C_{water} = molar concentration of phosphine in water (mol/L)
- H = Henry's law constant in mol/(L·atm) (here, we need to confirm the units; assuming the given value is for a dimensionless constant, the molar constant is needed)

Note: If the Henry's law constant is dimensionless, it relates the mole fraction in water to the partial pressure. Alternatively, if it is in mol/(L·atm), then the calculation is direct.

Conversion or assumption:

Suppose the 8.1×10^{-3} is the Henry's law constant in mol/(L·atm). Then:

$$ C = 8.1 \times 10^{-3} \text{ mol/L} \times 1 \text{ atm} = 8.1 \times 10^{-3} \text{ mol} $$

for a 1-liter volume.

Step 3: Calculate the Number of Moles of Phosphine

For a volume of 1 liter:

$$ \text{Moles of phosphine} = C_{water} \times V_{water} $$

$$ \text{Moles} = 8.1 \times 10^{-3} \text{ mol} \times 1 \text{ L} = 8.1 \times 10^{-3} \text{ mol} $$

Step 4: Convert Moles to Mass in Grams

The molar mass of phosphine (PH_3):

- Phosphorus (P): 30.97 g/mol
- Hydrogen (H): 1.008 g/mol

$$ M_{PH_3} = 30.97 + (3 \times 1.008) = 30.97 + 3.024 = 33.994 \text{ g/mol} $$

Calculating the mass:

$$ \text{Mass} = \text{moles} \times \text{molar mass} $$

$$ \text{Mass} = 8.1 \times 10^{-3} \text{ mol} \times 33.994 \text{ g/mol} \approx 0.275 \text{ g} $$

Final Result:

The mass of phosphine gas dissolved in 1 liter of water at 25°C, given the Henry's law constant of 8.1×10^{-3}, is approximately 0.275 grams.

Broader Implications and Applications

Environmental Monitoring and Safety Protocols

Understanding the solubility of phosphine in water informs safety protocols in industries where phosphine is used or generated. If a gas release occurs, knowing how much phosphine can dissolve helps predict aquatic toxicity and potential environmental contamination.

Industrial Process Optimization

Accurate calculations of gas dissolution are essential for designing reactors and scrubbers that control emissions, optimize gas absorption processes, and prevent hazardous build-up.

Regulatory Compliance

Regulatory agencies require precise data on gas solubility for setting permissible exposure levels and discharge standards, making such calculations vital for compliance.

Limitations and Considerations

While the calculation provides a useful estimate, real-world scenarios involve additional complexities:

- Partial pressures may vary.
- Temperature fluctuations affect Henry's law constants.
- Water composition (salinity, pH) influences solubility.
- Kinetic factors, such as diffusion rates, impact dissolution and release.

Conclusion

The detailed analysis of At 25 C The Henry's Law Constant For Phosphine Gas In Water Is 8.1 X 10^-3 underscores the importance of precise data and calculations in environmental chemistry and industrial safety. By translating the Henry's law constant into an actual mass of dissolved phosphine, stakeholders can better assess environmental risks, optimize industrial processes, and develop informed safety protocols.

This in-depth exploration exemplifies how fundamental principles like Henry’s law underpin vital decision-making processes across scientific and regulatory domains, highlighting the ongoing need for accurate data and rigorous analysis in chemical safety and environmental protection.

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Note: Actual Henry's law constants

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