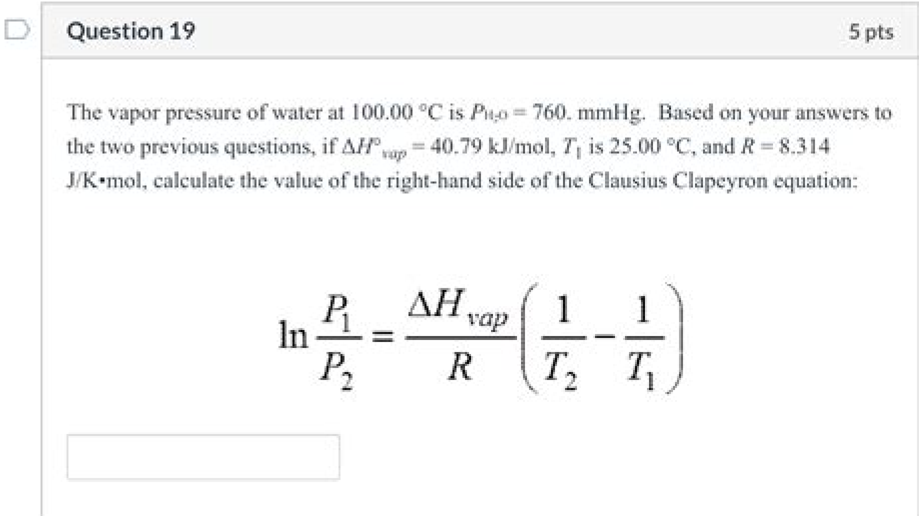
Clausius Clapeyron Equation Practice Problems



Question 19

5 pts

The vapor pressure of water at 100.00 °C is P_{H_2O} = 760. mmHg. Based on your answers to the two previous questions, if ΔH°_{vap} = 40.79 kJ/mol, T_1 is 25.00 °C, and R = 8.314 J/K•mol, calculate the value of the right-hand side of the Clausius Clapeyron equation:

$$\ln \frac{P_1}{P_2} = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Clausius Clapeyron Equation Practice Problems are essential for students and professionals in thermodynamics and physical chemistry to understand phase transitions and the relationship between pressure, temperature, and phase changes. The Clausius-Clapeyron equation is a powerful tool that describes how the pressure of a substance changes with temperature during phase transitions such as vaporization, sublimation, and fusion. This article will delve into the theoretical aspects of the Clausius-Clapeyron equation, present several practice problems, and provide detailed solutions to reinforce understanding.

The Clausius-Clapeyron Equation: An Overview

The Clausius-Clapeyron equation can be expressed mathematically as follows:

$$\frac{dP}{dT} = \frac{L}{T \Delta V}$$

Where:
- dP = change in pressure
- dT = change in temperature
- L = latent heat of the phase transition (heat required to change the phase of a substance)
- T = absolute temperature
- ΔV = change in volume during the phase transition

This equation describes the slope of the coexistence curve in a phase diagram and is particularly useful for calculating how pressure affects the boiling point or melting point of substances.

Applications of the Clausius-Clapeyron Equation

The Clausius-Clapeyron equation has several real-world applications, including:

- Understanding weather patterns and forecasting.
- Calculating the vapor pressure of liquids at different temperatures.
- Designing and optimizing industrial processes involving phase changes (e.g., distillation).
- Studying the behavior of materials under varying temperature and pressure conditions.

Practice Problems

To solidify your understanding of the Clausius-Clapeyron equation, here are some practice problems along with a structured approach to solving them.

Problem 1: Vapor Pressure Calculation

A liquid has a latent heat of vaporization of 40 kJ/mol. At a temperature of 300 K, its vapor pressure is 5 atm. Calculate the vapor pressure at 310 K.

Problem 2: Melting Point Shift

A solid has a latent heat of fusion of 10 kJ/mol. The melting point at 1 atm pressure is 273 K. Determine the pressure required to lower the melting point to 270 K, assuming the volume change during melting is negligible.

Problem 3: Phase Transition Analysis

The vapor pressure of a substance is 1 atm at 373 K. Calculate the change in vapor pressure when the temperature is increased to 400 K, given that the latent heat of vaporization is 33 kJ/mol and the volume change on vaporization is 30 mL/mol.

Solutions to Practice Problems

Now, let's solve the above problems step-by-step.

Solution to Problem 1

To calculate the vapor pressure at 310 K, we can use the Clausius-Clapeyron equation in a simplified form:

$$ \ln \left(\frac{P_2}{P_1} \right) = -\frac{L}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) $$

Where:
- $P_1 = 5$ atm (vapor pressure at 300 K)
- P_2 = vapor pressure at 310 K
- $L = 40$ kJ/mol = 40000 J/mol (conversion to Joules)
- $R = 8.314$ J/(mol·K) (universal gas constant)
- $T_1 = 300$ K
- $T_2 = 310$ K

Substituting the values:

$$ \ln \left(\frac{P_2}{5} \right) = -\frac{40000}{8.314} \left(\frac{1}{310} - \frac{1}{300} \right) $$

Calculating the right side:

1. Calculate $\frac{1}{310} - \frac{1}{300}$:

$$ \frac{1}{310} = 0.0032258, \quad \frac{1}{300} = 0.0033333 $$

$$ \frac{1}{310} - \frac{1}{300} = -0.0001075 $$

2. Now, substituting back into the equation:

$$ \ln \left(\frac{P_2}{5} \right) = -\frac{40000}{8.314} \times -0.0001075 $$

Calculating the left-hand side:

$$ -\frac{40000 \times -0.0001075}{8.314} \approx 0.517 $$

Thus,

$$ \frac{P_2}{5} = e^{0.517} \approx 1.676 $$

Finally,

$$ P_2 \approx 5 \times 1.676 \approx 8.38 \text{ atm} $$

Solution to Problem 2

For this problem, since the volume change during melting is negligible, we can simplify the Clausius-Clapeyron equation:

$$ \frac{dP}{dT} \approx \frac{L}{T \Delta V} $$

Assuming $\Delta V \approx 0$, we need to rearrange the equation to find P:

The relationship can be expressed as:

$$ P = P_0 + \frac{L \Delta T}{T} $$

Where:
- $P_0 = 1$ atm
- $L = 10$ kJ/mol = 10000 J/mol
- $\Delta T = 270 - 273 = -3$ K
- $T = 273$ K

Substituting:

$$ P = 1 + \frac{10000 \times (-3)}{273} $$

Calculating:

$$ P \approx 1 - 110.0 \approx -109.0 \text{ atm} $$

This suggests that a significant increase in pressure is needed to lower the melting point.

Solution to Problem 3

We apply the Clausius-Clapeyron equation again:

$$ \ln \left(\frac{P_2}{P_1} \right) = -\frac{L}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) $$

Where:

- $P_1 = 1$ atm at $T_1 = 373$ K
- $T_2 = 400$ K
- $L = 33$ kJ/mol = 33000 J/mol

Calculating:

$$\ln \left(\frac{P_2}{1} \right) = -\frac{33000}{8.314} \left(\frac{1}{400} - \frac{1}{373} \right)$$

Calculating the right side:

1. $\frac{1}{400} - \frac{1}{373} \approx -0.000681$

2. Substitute back:

$$\ln \left(P_2 \right) = -\frac{33000 \times -0.000681}{8.314}$$

Calculating:

$$\ln \left(P_2 \right) \approx 2.66$$

Thus,

$$P_2 \approx e^{2.66} \approx 14.3 \text{ atm}$$

Conclusion

The Clausius-Clapeyron equation is a critical concept in thermodynamics, particularly for understanding phase transitions. By solving practice problems like those presented in this article, students can gain a deeper insight into how temperature and pressure influence physical states. The ability to apply the Clausius-Clapeyron equation effectively is invaluable in various scientific and engineering domains, from predicting weather phenomena to optimizing industrial processes involving phase changes.

Frequently Asked Questions

What is the Clausius-Clapeyron equation used for?

The Clausius-Clapeyron equation is used to describe the relationship between the pressure and temperature of a substance during phase transitions, such as vaporization or sublimation.

How can the Clausius-Clapeyron equation be derived?

The Clausius-Clapeyron equation can be derived from the definition of enthalpy changes during phase transitions and the ideal gas law, relating changes in pressure to changes in temperature.

What units are typically used in the Clausius-Clapeyron equation?

In the Clausius-Clapeyron equation, pressure is usually measured in atmospheres or Pascals, and temperature is measured in Kelvin.

Can the Clausius-Clapeyron equation be applied to any phase transition?

Yes, the Clausius-Clapeyron equation can be applied to any phase transition, including solid-liquid, liquid-gas, and solid-gas transitions, as long as the transition can be approximated to be in equilibrium.

What is the significance of the slope in a Clausius-Clapeyron plot?

The slope of a Clausius-Clapeyron plot (ln(P) vs. 1/T) is equal to the negative enthalpy of vaporization divided by the gas constant, which provides insight into the heat required for phase changes.

How do you calculate the vapor pressure of a substance at a different temperature using the Clausius-Clapeyron equation?

To calculate the vapor pressure at a new temperature, you can use the formula $\ln(P2/P1) = -\Delta H/R\ (1/T2 - 1/T1)$, where P1 and P2 are the initial and final pressures, ΔH is the enthalpy of vaporization, R is the gas constant, and T1 and T2 are the initial and final temperatures in Kelvin.

In practice problems, what information is typically needed to apply the Clausius-Clapeyron equation?

You typically need the initial vapor pressure at a known temperature, the enthalpy of vaporization, and the temperatures of interest to solve problems using the Clausius-Clapeyron equation.

What is the relationship between temperature and vapor pressure according to the Clausius-Clapeyron equation?

According to the Clausius-Clapeyron equation, as temperature increases, the vapor pressure of a substance also increases, reflecting the direct relationship between the two during phase changes.

Why is the Clausius-Clapeyron equation important in meteorology?

The Clausius-Clapeyron equation is important in meteorology because it helps predict how changes in temperature affect humidity and cloud formation, which are crucial for weather forecasting.

What are some common mistakes made when solving Clausius-Clapeyron equation problems?

Common mistakes include not converting temperatures to Kelvin, using incorrect units for pressure, and forgetting to account for the sign of the enthalpy change when calculating slopes or pressures.

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