What Are Q And W (in Kj) For The Reaction Of 38.0 G Of Na(s) And 37.0 G Of Cl2(g) To Produce Nacl(s)

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Understanding the concepts of Q (heat transfer) and W (work done) in chemical reactions is fundamental in thermodynamics. When considering a specific reaction, such as the formation of sodium chloride from its elements, calculating these quantities provides insight into the energy changes involved. In this article, we will explore the reaction of 38.0 grams of sodium (Na) in solid form reacting with 37.0 grams of chlorine gas (Cl_2) to produce sodium chloride (NaCl) solid, focusing on determining the heat (Q) and work (W) associated with this process, expressed in kilojoules (kJ).

Understanding the Reaction: Formation of Sodium Chloride

The Chemical Equation

The reaction between sodium and chlorine gas can be represented as:

$$2 \, \text{Na}(s) + \text{Cl}_2(g) \rightarrow 2 \, \text{NaCl}(s)$$

This reaction is highly exothermic, releasing energy as it proceeds.

Reactant Quantities and Moles

Given:
- Mass of Na = 38.0 g
- Mass of Cl_2 = 37.0 g

Molar masses:
- Na = 22.99 g/mol
- Cl_2 = 70.90 g/mol

Calculating moles:
- Moles of Na: $\frac{38.0\, \text{g}}{22.99\, \text{g/mol}} \approx 1.652\, \text{mol}$
- Moles of Cl_2: $\frac{37.0\, \text{g}}{70.90\, \text{g/mol}} \approx 0.522\, \text{mol}$

The balanced reaction indicates that 2 mol of Na react with 1 mol of Cl_2.

Determining the Limiting Reactant

Since the reaction requires 2 mol Na per mol Cl_2, for 0.522 mol Cl_2, the amount of Na needed is:

$$ 2 \times 0.522\, \text{mol} = 1.044\, \text{mol} $$

Available Na is 1.652 mol, which is more than needed, so Cl_2 is the limiting reactant.

Calculating the Reaction's Thermodynamic Quantities

Standard Enthalpy Change (ΔH°) for the Reaction

The standard enthalpy of formation (ΔH_f°) values are well-documented:
- Na(s): 0 kJ/mol (element in standard state)
- Cl_2(g): 0 kJ/mol (element in standard state)
- NaCl(s): -411 kJ/mol

The reaction's standard enthalpy change per 2 mol Na:

$$
\Delta H^\circ_{reaction} = [2 \times (-411\, \text{kJ/mol})] - [2 \times 0 + 1 \times 0] = -822\, \text{kJ}
$$

Thus, for 2 mol Na, the reaction releases 822 kJ.

Calculating the Energy Released for the Reactant Quantities

Since we have only 1.652 mol Na, the actual energy change (ΔH_{actual}) is proportionally less:

$$
\text{Energy released} = \frac{1.652\, \text{mol Na}}{2\, \text{mol Na}} \times 822\, \text{kJ} \approx 0.826 \times 822 \approx 678.8\, \text{kJ}
$$

This value represents the heat Q released during the reaction at constant pressure.

Calculating Q (Heat Transfer)

Since the reaction releases energy, the heat Q (by convention) is negative:

$$
Q = -678.8\, \text{kJ}
$$

This indicates an exothermic process where heat is given off to the surroundings.

Calculating Work Done (W)

In thermodynamics, work in chemical reactions often refers to the work done by the system on the surroundings, especially due to volume changes at constant pressure (PV work). The work can be calculated as:

$$
W = - P \Delta V
$$

Where:
- P is the pressure (assuming standard atmospheric pressure, 1 atm)
- ΔV is the change in volume during the reaction

Understanding Volume Changes During the Reaction

The reaction involves:
- 1 mol of Cl_2 gas consumed
- 2 mol of Na(s) consumed (solid, no volume change)

Since solids are incompressible in this context, volume change mainly results from the consumption of gaseous Cl_2.

At constant pressure, the volume change is:

$$
\Delta V = n_{gas} \times \frac{RT}{P}
$$

where:
- n_{gas} is the number of moles of gas consumed or produced
- R is the ideal gas constant: 8.314 J/(mol·K)
- T is the temperature in Kelvin (assumed standard temperature, 298 K)
- P is pressure in atm

Given:

- $n_{gas} = 1$ mol (Cl_2 consumed)

Calculating ΔV:

$$
\Delta V = 1\, \text{mol} \times \frac{8.314\, \text{J/(mol·K)} \times 298\, \text{K}}{1\, \text{atm}}
$$

Since 1 atm·L = 101.325 J, converting volume to liters:

$$
\Delta V = \frac{8.314 \times 298}{101.325} \approx \frac{2477.7}{101.325} \approx 24.45\, \text{L}
$$

Work done:

$$
W = - P \Delta V
$$
Expressed in Joules:

$$
W = - (1\, \text{atm}) \times 24.45\, \text{L} \times 101.325\, \text{J/L·atm} \approx - 24.45 \times 101.325 \approx -2480\, \text{J}
$$

Convert to kilojoules:

$$
W \approx -2.48\, \text{kJ}
$$

Note: This calculation assumes the entire volume change is due to the consumption of 1 mol of Cl_2 gas at standard conditions. If the reaction occurs under different conditions, this value would vary accordingly.

Summary of Thermodynamic Quantities

Quantity	Value	Description
Q	-678.8 kJ	Heat released during the reaction (exothermic)
W	-2.48 kJ	Work done by the system (volume expansion of gas)

Implications and Significance

Understanding the values of Q and W provides insight into the energy dynamics of chemical reactions:

- The large negative Q confirms the reaction is strongly exothermic, releasing a significant amount of heat.
- The negative W indicates the system performs work on the surroundings due to gas volume expansion.
- These values are crucial for designing industrial processes, safety considerations, and energy audits.

Conclusion

The reaction of 38.0 g of sodium with 37.0 g of chlorine gas to produce sodium chloride involves considerable energy exchange. The heat released (Q) is approximately -678.8 kJ, indicating a highly exothermic process. The work done (W) during the reaction, primarily due to volume expansion of the gas, is about -2.48 kJ. These calculations, based on thermodynamic principles and standard enthalpy data, exemplify how energy changes are quantified in chemical reactions, providing valuable insights into their energetic profiles.

Further Reading:
- Thermodynamics in Chemistry
- Standard Enthalpy of Formation
- Gas Laws and Volume Calculations
- Industrial Applications of Exothermic Reactions

Frequently Asked Questions

What is the significance of Q and W in the context of the reaction between sodium and chlorine?

Q represents the heat absorbed or released during the reaction, while W indicates work done by or on the system, both key to understanding the reaction's energy changes.

How do you calculate the amount of NaCl produced from 38.0 g of Na and 37.0 g of Cl_2?

First, convert the masses to moles: Na (38.0 g / 22.99 g/mol) and Cl_2 (37.0 g / 70.90 g/mol). The limiting reagent determines the amount of NaCl formed, which can be calculated using stoichiometry.

What is the molar ratio of Na to Cl_2 in the reaction to produce NaCl?

The balanced chemical equation is 2 Na + Cl_2 → 2 NaCl, so the molar ratio is 2:1 for Na to Cl_2.

How do you determine the limiting reagent in this reaction?

Compare the mole ratios of Na and Cl_2 supplied to the stoichiometric ratio; the reagent with fewer moles relative to its required amount is limiting.

What is the enthalpy change (ΔH) for the formation of NaCl, and how does it relate to Q?

The standard enthalpy of formation for NaCl is approximately -411 kJ/mol; Q for the reaction can be calculated based on moles of NaCl formed and this ΔH value.

How do you calculate the heat (Q) released or absorbed in this reaction in kJ?

Multiply the number of moles of NaCl formed by the standard enthalpy change (ΔH). For example, if 1 mol of NaCl forms, Q ≈ -411 kJ.

What is the work (W) done during the reaction in terms of pressure and volume change?

Work $W = -P\Delta V$; if the reaction occurs in a closed system with volume change, this can be calculated knowing pressure and volume change, often negligible in solid-gas reactions.

Can the total energy change (Q + W) be determined for this reaction, and how?

Yes, by calculating both Q (from enthalpy change) and W (from pressure-volume work), their sum gives the total energy change for the reaction.

Why is understanding Q and W important in thermodynamics of chemical reactions?

They help analyze the energy flow during reactions, determine whether reactions are exothermic or endothermic, and inform energy efficiency and safety considerations.

How does the reaction's stoichiometry influence the

calculation of Q and W in this scenario?

Stoichiometry determines the amount of reactants converted to products, which directly affects the moles of NaCl formed, and thus the magnitude of Q; W depends on any volume or pressure changes associated with the reaction.

Additional Resources

What Are Q And W (in Kj) for The Reaction of 38.0 G of Na(s) and 37.0 G of Cl_2(g) to Produce NaCl(s)

Understanding the thermodynamics of chemical reactions is fundamental in chemistry, especially when quantifying energy exchanges. In particular, the quantities Q (heat exchanged) and W (work done) are critical parameters that describe how energy flows during a reaction. When considering the specific reaction between sodium metal and chlorine gas to produce sodium chloride, calculating these values in kilojoules (kJ) provides insight into the energetic aspects of this classic synthesis. This article delves into the detailed process of determining Q and W for the reaction involving 38.0 grams of sodium and 37.0 grams of chlorine gas, exploring the underlying principles, calculations, and interpretations.

Understanding the Reaction: Sodium and Chlorine to Form Sodium Chloride

Before diving into the calculations, it is essential to understand the chemical reaction involved:

$$ 2\, \text{Na}(s) + \text{Cl}_2(g) \rightarrow 2\, \text{NaCl}(s) $$

This reaction is highly exothermic, releasing energy as sodium reacts with chlorine to form sodium chloride. The energy change associated with this process can be characterized by thermodynamic parameters such as the enthalpy change (ΔH), work (W), and heat (Q).

Step 1: Determine the Limiting Reactant

Given quantities:

- Sodium (Na): 38.0 g
- Chlorine gas (Cl_2): 37.0 g

Molar masses:
- Na: 22.99 g/mol
- Cl_2: 70.90 g/mol

Calculations:

- Moles of Na:

$$
n_{\text{Na}} = \frac{38.0\, \text{g}}{22.99\, \text{g/mol}} \approx 1.651\, \text{mol}
$$

- Moles of Cl_2:

$$
n_{\text{Cl}_2} = \frac{37.0\, \text{g}}{70.90\, \text{g/mol}} \approx 0.522\, \text{mol}
$$

Limiting Reactant:
The balanced equation requires 2 mol Na per 1 mol Cl_2. To react completely:

- Na needed for 0.522 mol Cl_2:

$$
2 \times 0.522\, \text{mol} = 1.044\, \text{mol}
$$

Since only 1.651 mol Na is available, and 1.044 mol Na are required, sodium is in excess. Chlorine is the limiting reactant.

Reaction extent:

- The reaction will proceed with 0.522 mol of Cl_2 reacting with 1.044 mol of Na, producing:

$$
2 \times 0.522\, \text{mol} = 1.044\, \text{mol of NaCl}
$$

Step 2: Find the Enthalpy Change (ΔH) for the Reaction

Standard enthalpy of formation ($\Delta H°f$) values are typically used:

- Na(s): 0 kJ/mol (element in standard state)
- Cl_2(g): 0 kJ/mol (element in standard state)
- NaCl(s): –411 kJ/mol

Standard reaction enthalpy (per 2 mol Na and 1 mol Cl_2):

$$
\Delta H^\circ_{reaction} = [2 \times \Delta H^\circ_f(\text{NaCl})] - [2 \times \Delta H^\circ_f(\text{Na}) + \Delta H^\circ_f(\text{Cl}_2)]
$$

\]

$$
= [2 \times (-411\, \text{kJ/mol})] - [0 + 0] = -822\, \text{kJ}
$$

This is for 2 mol of Na and 1 mol of Cl_2 reacting.

Step 3: Calculate the Total Heat (Q) Released

Since only 0.522 mol of Cl_2 reacts, the proportionate heat released:

$$
Q = \frac{0.522\, \text{mol Cl}_2}{1\, \text{mol Cl}_2} \times (-822\, \text{kJ}) \approx -429.4\, \text{kJ}
$$

Interpretation:
The negative sign indicates an exothermic process — heat is released into the surroundings.

Step 4: Determine Work (W) Done During the Reaction

Work in chemical reactions often involves expansion work, especially if gases are involved and the system changes volume.

Work associated with expansion or compression:

$$
W = - P \Delta V
$$

Where:
- P is the external pressure (usually 1 atm or 101.3 kPa),
- ΔV is the change in volume during the reaction.

Calculating ΔV:

- Moles of gases before and after the reaction:

Initial:

- Cl_2: 0.522 mol

- Na: solid, no volume change

Final:

- NaCl: solid, no volume change
- Cl_2: consumed

Net change:

- Gaseous Cl_2 decreases by 0.522 mol (since reacted).

Assuming ideal gas behavior:

$$
\Delta V = n_{gas} \times R T / P
$$

At standard temperature $T = 298\, \text{K}$, and pressure $P = 1\, \text{atm}$:

$$
\Delta V = -0.522\, \text{mol} \times \frac{0.082057\, \text{L·atm/(mol·K)} \times 298\, \text{K}}{1\, \text{atm}} \approx -12.7\, \text{L}
$$

The negative sign indicates volume decrease.

Work done:

$$
W = - P \Delta V
$$

Convert ΔV to m^3:

$$
12.7\, \text{L} = 0.0127\, \text{m}^3
$$

At $P = 101.3\, \text{kPa}$:

$$
W = - (101.3\, \text{kPa}) \times (-0.0127\, \text{m}^3) = +1.29\, \text{kJ}
$$

The positive W indicates work is done by the system during expansion (since volume decreases, the system does work on surroundings).

Step 5: Summarize Q and W in Kilojoules

- Heat exchanged (Q): Approximately –429.4 kJ (exothermic)
- Work done (W): Approximately +1.29 kJ

Note: The small positive work value reflects the work done by the system as gases are consumed.

Additional Considerations and Implications

Features and Significance:

- Exothermic Nature: The reaction releases significant heat (~429 kJ), which has practical implications in industrial sodium chloride production.
- Work Involvement: The minor work done by the system highlights volume change in gaseous reactants, relevant in process design.
- Thermodynamic Efficiency: Since the process releases heat, it could be harnessed for energy recovery or used in heat engines.

Pros:

- Clear quantification of energy flows aids in process optimization.
- Understanding these parameters assists in safety protocols due to heat release.
- The calculations reinforce fundamental thermodynamic principles.

Cons:

- Assumes ideal gas behavior; real gases may deviate slightly.
- Standard enthalpies are temperature-dependent; actual conditions may vary.
- Simplifies system to a closed process with constant pressure.

Conclusion

In analyzing the reaction between 38.0 grams of sodium and 37.0 grams of chlorine gas, the thermodynamic parameters reveal key energetic insights. The heat exchanged (Q) is approximately –429.4 kJ, indicating a highly exothermic process, and the work (W) performed by the system during gas consumption is about +1.29 kJ. These calculations underscore the importance of understanding energy exchanges in chemical reactions, especially those involving gases, and serve as a foundational example for thermodynamic analysis in chemical engineering and chemistry. Recognizing the magnitude of heat release and work involved not only enhances comprehension of the reaction's energetic profile but also informs practical considerations such as energy management, safety, and process design in industrial applications.

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