Notes for Exam Preparation: Enthalpy Changes

Enthalpy Changes

What are Enthalpy Changes?

Enthalpy change (Δ H) refers to the heat energy absorbed or released during a chemical reaction at constant pressure. It is a key concept in thermodynamics, representing the difference between the enthalpy of the products and the reactants.

- Exothermic Reactions: Release heat to the surroundings. The enthalpy change is negative (ΔH < 0).
- Endothermic Reactions: Absorb heat from the surroundings. The enthalpy change is positive (ΔH > 0).

Enthalpy Profile Diagrams

Enthalpy profile diagrams, or reaction coordinate diagrams, illustrate the energy changes during a chemical reaction. They show the relative energies of reactants, products, and the transition state.

- Exothermic Reaction Diagram: Reactants are higher in energy than products.
- Endothermic Reaction Diagram: Reactants are lower in energy than products.

Standard Enthalpy Changes

 Standard Enthalpy Change of Neutralisation (ΔH_neut): The enthalpy change when one mole of water is formed from the reaction of an acid and a base under standard conditions.

HCl (aq) + NaOH (aq) \rightarrow NaCl (aq) + H₂O (I)

- 2. **Standard Enthalpy Change of Solution (ΔH_sol)**: The enthalpy change when one mole of solute dissolves in a solvent to form an infinitely dilute solution.
- 3. NaCl (s) \rightarrow Na⁺ (aq) + Cl⁻ (aq)
- 4. **Standard Enthalpy Change of Atomisation (ΔH_atm)**: The enthalpy change when one mole of gaseous atoms is formed from the element in its standard state.

 $CI_{2}\left(g
ight)
ightarrow 2CI$

 Standard Enthalpy Change of Hydration (ΔH_hyd): The enthalpy change when one mole of gaseous ions is dissolved in water to form an infinitely dilute solution. Na⁺ (g) → Na⁺ (aq)

Measuring Enthalpy Changes

Calorimetry

Calorimetry is the measurement of heat changes in physical and chemical processes. A calorimeter is used to measure the temperature change of the system, which can be used to calculate the enthalpy change.

• Calorimeter Equation: q=mc∆T

where q is the heat absorbed or released, mmm is the mass of the substance, c is the specific heat capacity, and ΔT is the temperature change.

Enthalpy Change of Neutralisation by Experiment

1. **Procedure**: Mix a known volume and concentration of acid with a base in a polystyrene cup.

2. Example Calculation:

- 25 cm³ of 1 M HCl is mixed with 25 cm³ of 1 M NaOH.
- Temperature change observed: 6.5°C.
- Using the equation $q=mc\Delta T$
- m (mass of solution) = 50 g (assuming density of solution is 1 g/cm³)
 - c (specific heat capacity of water) = 4.18 J/g°C
 - ΔT = 6.5°C
 - q=50×4.18×6.5=1358.5
- Moles of water formed = 0.025 mol
- Enthalpy change of neutralisation Δ Hneut=1358.50.025=-54.34kJ/mol

Enthalpy Change of Solution by Experiment

- 1. **Procedure**: Dissolve a known mass of solute in water in a polystyrene cup and measure the temperature change.
- 2. Example Calculation:
 - 5 g of KCI is dissolved in 50 cm³ of water.
 - Temperature change observed: -1.2°C.
 - Using the equation $q=mc\Delta T$
 - m (mass of solution) = 50 g
 - c (specific heat capacity of water) = 4.18 J/g°C
 - ΔT = -1.2°C
 - q=50×4.18×-1.2=-251J
 - Moles of KCl = 0.067 mol
 - Enthalpy change of solution Δ Hsol=-2510.067=-3.75 kJ/mol

Finding the Enthalpy Change of Combustion

Experiment: The enthalpy change of combustion of propan-1-ol

- 1. Procedure:
 - Burn a known mass of propan-1-ol in a spirit burner.
 - Heat a known volume of water with the flame.
 - Measure the temperature change of the water.

2. Calculation:

- Mass of propan-1-ol burned: 0.95 g.
- Volume of water heated: 100 cm³.
- Temperature change of water: 24.5°C.
- Using the equation $q=mc\Delta T$
 - m (mass of water) = 100 g
 - c (specific heat capacity of water) = 4.18 J/g°C
 - ΔT = 24.5°C
 - q=100×4.18×24.5=10241J
- Moles of propan-1-ol burned = 0.95 / 60.1 = 0.0158 mol
- Enthalpy change of combustion ΔHcomb=-102410.0158=-648.1kJ/mol

Summary

- Enthalpy Change: Heat energy changes at constant pressure.
- Exothermic Reactions: Release heat (ΔH < 0).
- Endothermic Reactions: Absorb heat (ΔH > 0).
- Calorimetry: Technique to measure heat changes.
- **Standard Enthalpy Changes**: Defined for neutralisation, solution, atomisation, and hydration.
- **Experimentation**: Calorimetry is used to find the enthalpy changes in neutralisation, solution, and combustion reactions.

Hess's Law

Introduction Hess's Law states that the total enthalpy change for a reaction is the same, regardless of the route by which the chemical change occurs. This is a direct consequence of the conservation of energy.

Conserving Energy Energy cannot be created or destroyed; it can only be transferred or transformed from one form to another. Hess's Law allows us to calculate enthalpy changes for reactions where the direct route is challenging to measure.

Enthalpy Cycles Enthalpy cycles (or Hess cycles) are diagrams that represent the enthalpy changes during chemical reactions. They help visualize the indirect routes taken to convert reactants to products.

Enthalpy Change of Reaction from Enthalpy Changes of Formation

- Enthalpy Change of Formation (ΔHf°ΔH_f^\circΔHf°): The enthalpy change when one mole of a compound is formed from its elements in their standard states. ΔHreaction=ΣΔHf°(products)-ΣΔHf°(reactants)
- 2. Example Calculation:
 - Consider the formation of water: 2H2(g)+O2(g)→2H2O
 - Given Δ Hf•H2O(I) is -286 kJ/mol.
 - ΔHreaction=2(-286)-[2(0)+1(0)]=-572 kJ/mol.

Enthalpy Change of Formation from Enthalpy Changes of Combustion

- Enthalpy Change of Combustion (ΔHc ∘): The enthalpy change when one mole of a substance is completely burnt in oxygen. ΔHf∘=ΣΔHc∘(reactants)-ΣΔHc∘(products)
- 2. Example Calculation:
 - Consider the combustion of methane: $CH4(g)+2O2(g)\rightarrow CO2(g)+2H2O(I)$
 - Given ΔHc∘ for CH_4is -890 kJ/mol, for CO2 is -393 kJ/mol, and for H2OH_2OH2O is -286 kJ/mol.
 - ΔHf◦=-393-[(-890)+2(-286)]=-74 kJ/mol.

Calculating the Enthalpy Change of Hydration of an Anhydrous Salt

- Enthalpy Change of Hydration (ΔHhyd): The enthalpy change when one mole of an anhydrous salt dissolves in water to form a hydrated solution. ΔHhyd=ΔHsol+ΔHlatt
- 2. Example Calculation:
 - Given ΔHsoll (enthalpy change of solution) for NaCl is +3.9 kJ/mol and Δ H_latt (lattice enthalpy) is -787 kJ/mol.
 - ΔHhyd=3.9-787=-783.1

Bond Energies and Enthalpy Changes

Bond Energy: The energy required to break one mole of a particular bond in a gaseous molecule.

Average Bond Energy: The average energy needed to break a particular type of bond in a range of different compounds.

Calculating Enthalpy Changes Using Bond Energies

- 1. Bond Breaking and Bond Making:
 - Breaking bonds absorbs energy (endothermic, Δ H>0).
 - Making bonds releases energy (exothermic, ΔH <0).
 - Overall enthalpy change:
 - $\Delta H = \Sigma$ (Bond energies of bonds broken) Σ (Bond energies of bonds formed)

2. Example Calculation:

- Consider the reaction: $H2(g)+CI2(g)\rightarrow 2HCI(g)$
- Given bond energies: H-H = 436 kJ/mol, Cl-Cl = 243 kJ/mol, H-Cl = 431 kJ/mol.
- \circ Bonds broken: 1(H–H)+1(Cl–Cl)=436+243=679 kJ.
- Bonds formed: $2(H-CI)=2\times431=862$ kJ.
- ΔH=679−862=−183 kJ/mol.

Summary

• **Hess's Law**: Total enthalpy change for a reaction is the same, regardless of the route taken.

- **Conserving Energy**: Energy is neither created nor destroyed, only transferred or transformed.
- Enthalpy Cycles: Visual representations of enthalpy changes in reactions.
- **Standard Enthalpy Changes**: Defined for formation, combustion, and hydration.
- Bond Energies: Used to calculate enthalpy changes in reactions.
- **Bond Breaking and Making**: Breaking bonds is endothermic, making bonds is exothermic.

Practice Questions

Multiple Choice Questions (MCQs)

- 1. Which of the following statements about Hess's Law is correct?
 - A) It only applies to endothermic reactions.
 - B) It states that the total enthalpy change is dependent on the reaction pathway.
 - C) It is a consequence of the first law of thermodynamics.
 - D) It can only be used with standard enthalpy changes.
 - Answer: C
- 2. The standard enthalpy change of formation of $CO_2(g)$ is:
 - A) The enthalpy change when one mole of carbon is burned in oxygen to form CO₂.
 - B) The enthalpy change when one mole of CO_2 is formed from its elements in their standard states.
 - \circ C) The enthalpy change when one mole of CO₂ is dissolved in water.
 - \circ D) The enthalpy change when one mole of CO₂ is combusted.
 - Answer: B

Observations and Reasoning Questions

- 1. **Question**: Explain why the enthalpy change of formation for an element in its standard state is zero. **Answer**: The enthalpy change of formation for an element in its standard state is defined as zero because it serves as the reference point for enthalpy calculations. In its standard state, the element is in its most stable form, and no energy change is required to form it from itself.
- 2. **Question**: Describe how Hess's Law can be used to determine the enthalpy change of a reaction that cannot be measured directly. **Answer**: Hess's Law can be applied by constructing an enthalpy cycle that connects the reactants and products through a series of steps with known enthalpy changes. By summing these known enthalpy changes, the overall enthalpy change for the reaction can be determined indirectly.

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