Enthalpy, calorimetry and Hess’s law

OCR A H032 and H432 · AS and A level

Show your working where needed. Check the worked answers when you finish.

Name _____ Date _____

1. Formation of nitrogen dioxide

Write the equation for the standard enthalpy of formation of gaseous NO_2. Include state symbols and explain your choice of coefficients.

2. Energy received by a solution

A solution of mass 88.0 g warms by 12.3 K. Its specific heat capacity is 4.18 J g^{-1} K^{-1}. Calculate the energy gained by the solution in kJ.

3. Mixing acid and alkali

30.0 cm^3 of 1.20 mol dm^{-3} HCl is mixed with 40.0 cm^3 of 0.700 mol dm^{-3} NaOH in an insulated cup. Both solutions start at the same temperature. The temperature rises by 5.35 K.

Assume density 1.00 g cm^{-3} and specific heat capacity 4.18 J g^{-1} K^{-1}. Calculate the enthalpy change per mole of water formed.

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4. Combustion in a simple calorimeter

Burning 0.680 g of propan-1-ol warms 150.0 g of water by 19.4 K. Use M = 60.0 g mol^{-1} and c = 4.18 J g^{-1} K^{-1}. Calculate the measured molar enthalpy of combustion. Explain how heat loss affects this value.

5. Hydrogenation of ethene

$C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$

Standard enthalpies of formation for $C_2H_4(g)$ and $C_2H_6(g)$ are +52.3 and −84.7 kJ mol^{-1} respectively. Calculate the standard enthalpy change for the reaction.

6. Hydrogenation of cyclohexene

Standard combustion enthalpies are −3753 kJ mol^{-1} for cyclohexene, −286 kJ mol^{-1} for hydrogen and −3920 kJ mol^{-1} for cyclohexane. Calculate ΔH for cyclohexene(l) + $H_2(g)$ → cyclohexane(l).

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7. Hydrogenation of propene

$CH_3CH{=}CH_2(g) + H_2(g) \rightarrow CH_3CH_2CH_3(g)$

Mean bond enthalpies in kJ mol^{-1} are C=C 612, H-H 436, C-C 347 and C-H 413. Estimate ΔH and explain why the value is approximate.

8. Temperature readings after mixing

The initial temperature is 21.4 °C. Reactants are mixed at 120 s. At 180, 240 and 300 s, the mixture is cooling and its temperatures are 32.6, 32.1 and 31.6 °C.

Use the cooling readings to estimate the corrected temperature rise. Use 58.0 g of solution, c = 4.18 J g^{-1} K^{-1} and 0.0500 mol of product formed to estimate ΔH per mole of product.

9. Extra challenge · A route to an oxide

0.0200 mol each of Mg and MgO are reacted separately with excess hydrochloric acid. The corrected rises are 21.8 K and 7.30 K respectively. In each test the solution has mass 100.0 g and c = 4.18 J g^{-1} K^{-1}.

The enthalpy of combustion of H_2 is −286 kJ mol^{-1}. Use these data to obtain ΔH for $Mg(s) + ½O_2(g) \rightarrow MgO(s)$. Show the steps in your route.

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Worked answers

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1. Formation of nitrogen dioxide

$\frac{1}{2}N_2(g) + O_2(g) \rightarrow NO_2(g)$. One mole of NO_2 forms from its elements in their standard states. It contains one mole of nitrogen atoms, supplied by half a mole of N_2.

2. Energy received by a solution

$q = mc\Delta T = 88.0 \times 4.18 \times 12.3 = 4524.432$ J, or 4.52 kJ. The temperature rise means the solution has gained energy.

3. Mixing acid and alkali

HCl provides 0.0360 mol and NaOH provides 0.0280 mol. NaOH limits the reaction and 0.0280 mol of water forms.

$q = 70.0 \times 4.18 \times 5.35 = 1565.41$ J. $\Delta H = -1.56541 \div 0.0280 = -55.9$ kJ mol^{-1}.

4. Combustion in a simple calorimeter

q(water) = 150.0 × 4.18 × 19.4 = 12163.8 J. The fuel amount is 0.680 ÷ 60.0 mol, giving $\Delta H = -1.07 \times 10^3$ kJ mol^{-1}.

Heat lost to the surroundings reduces the measured temperature rise, making the measured value less negative.

5. Hydrogenation of ethene

The standard formation enthalpy of $H_2(g)$ is zero because it is an element in its standard state.

Use products minus reactants. $\Delta H = -84.7 - (52.3 + 0) = -137.0$ kJ mol^{-1}.

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Worked answers

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6. Hydrogenation of cyclohexene

Combusting either side gives $6CO_2(g) + 6H_2O(l)$.

$\Delta H + (-3920) = -3753 - 286$. Solving gives $\Delta H = -119$ kJ mol^{-1}.

7. Hydrogenation of propene

The changed bonds are one C=C and one H-H broken, and one C-C and two C-H formed.

$\Delta H \approx (612 + 436) - (347 + 2 \times 413) = -125$ kJ mol^{-1}. Mean values average over different molecular environments.

8. Temperature readings after mixing

The cooling trend falls by 0.5 K every 60 s. Extrapolating it back to 120 s gives 33.1 °C and a corrected temperature rise of 11.7 K.

The solution gains $58.0 \times 4.18 \times 11.7$ J. The reaction releases this energy, so $\Delta H = -2.836548 \div 0.0500 = -56.7$ kJ mol^{-1}.

9. Extra challenge · A route to an oxide

$Mg + 2HCl \rightarrow MgCl_2 + H_2$ gives $\Delta H = -100.0 \times 4.18 \times 21.8 \div (1000 \times 0.0200) = -455.62$ kJ mol^{-1}. $MgO + 2HCl \rightarrow MgCl_2 + H_2O$ gives $\Delta H = -152.57$ kJ mol^{-1} by the same method.

Add the Mg reaction to $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ and the reverse of the MgO reaction. Acid, $MgCl_2$, H_2 and H_2O cancel. The total is $-455.62 - 286 + 152.57 = -589$ kJ mol^{-1}.

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