

Heat changes, energy cycles and bond enthalpies

Chemistry grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Each answer shows the formula, the substitution and the result with its unit and sign. Compare your cycles and bond counts line by line, because most lost marks come from signs and from forgetting how many moles take part.

Level: Chemistry grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB R1.1-R1.2

Problem 1 Name the enthalpy change

1. $2\text{C}(\text{graphite}) + 3\text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{C}_2\text{H}_5\text{OH}(\text{l})$.
2. $\text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$.
3. 100 kPa and 298 K (25 °C).

Problem 2 Exothermic or endothermic?

1. X is **exothermic** (products lower); Y is **endothermic**.
2. X: $120 - 200 = -80 \text{ kJ/mol}$. Y: $170 - 100 = +70 \text{ kJ/mol}$.
3. Forward E_a of X = $260 - 200 = 60 \text{ kJ/mol}$. Reverse $E_a = 260 - 120 = 140 \text{ kJ/mol}$.

Problem 3 Heat in a water bath

1. $\Delta T = 27.5 - 18.0 = 9.5 \text{ K}$.
2. $q = 150 \times 4.18 \times 9.5 = 5956.5 \text{ J} = 5.96 \text{ kJ}$.
3. $\Delta T = 5956.5 / (300 \times 4.18) = 4.75 \text{ K}$.

Problem 4 Dissolving sodium hydroxide

1. $n = 2.00 / 40.0 = 0.0500 \text{ mol}$.
2. $q = 100 \times 4.18 \times 5.3 = 2215 \text{ J}$.
3. $\Delta H = -2215 / 0.0500 = -44\,308 \text{ J/mol} = -44.3 \text{ kJ/mol}$.

Problem 5 Neutralisation

1. $q = 50.0 \times 4.18 \times 6.8 = 1421 \text{ J}$.
2. $n = 0.0250 \times 1.00 = 0.0250 \text{ mol}$.
3. $\Delta H = -1421 / 0.0250 = -56\,848 \text{ J/mol} = -56.8 \text{ kJ/mol}$.

Problem 6 Energy per gram and in kilocalories

1. $2803 / 180.0 = \mathbf{15.57 \text{ kJ/g}}$.
2. $25.0 \times 15.57 = \mathbf{389 \text{ kJ}}$ (389.3 kJ).
3. $389.3 / 4.184 = \mathbf{93.0 \text{ kcal}}$.

Problem 7 Carbon, carbon monoxide and Hess

1. The total enthalpy change is the same by any route between the same reactants and products.
2. $-393.5 = \Delta H_1 + (-283.0)$, so $\Delta H_1 = -393.5 + 283.0 = \mathbf{-110.5 \text{ kJ/mol}}$.
3. $\text{CO(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$: the enthalpy of combustion of carbon monoxide.

Problem 8 Combining equations

1. $\mathbf{N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)}$.
2. $180.5 + (-114.1) = \mathbf{+66.4 \text{ kJ}}$.
3. $66.4 / 2 = \mathbf{+33.2 \text{ kJ/mol}}$.

Problem 9 Formation of butane

1. $\mathbf{4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g)}$.
2. $\sum \Delta H_c(\text{reactants}) - \sum \Delta H_c(\text{products}) = 4(-393.5) + 5(-285.8) - (-2877) = -1574.0 - 1429.0 + 2877 = \mathbf{-126 \text{ kJ/mol}}$.

Problem 10 Reducing iron ore

1. $2(0) + 3(-393.5) = \mathbf{-1180.5 \text{ kJ}}$.
2. $-824.2 + 3(-110.5) = \mathbf{-1155.7 \text{ kJ}}$.
3. $\Delta H = -1180.5 - (-1155.7) = \mathbf{-24.8 \text{ kJ}}$.

Problem 11 Hydrogen chloride

1. $436 + 243 = \mathbf{679 \text{ kJ}}$.
2. $2 \times 432 = \mathbf{864 \text{ kJ}}$.
3. $\Delta H = 679 - 864 = \mathbf{-185 \text{ kJ}}$; per mole of HCl: -92.5 kJ/mol .

Problem 12 Hydrogenation of ethene

1. Broken: 1 C=C, 1 H-H. Formed: 1 C-C and 2 C-H.
2. Broken = $612 + 436 = 1048$. Formed = $347 + 2(413) = 1173$. $\Delta H = 1048 - 1173 = \mathbf{-125 \text{ kJ/mol}}$.
3. Yes, ΔH is negative.

Problem 13 Spirit burner

- $q = 200 \times 4.18 \times 24.0 = \mathbf{20\,064\,J}$.
- $n = 0.80 / 60.0 = 0.0133\text{ mol}$; $\Delta H_c = -20\,064 / 0.013333 = -1.505 \times 10^6\text{ J/mol} = \mathbf{-1505\,kJ/mol}$.
- $(2021 - 1505) / 2021 \times 100 = \mathbf{25.5\, \%}$. Heat escapes to the air and the can, and combustion is incomplete.

Problem 14 Bond enthalpy versus data

- Broken: $3(413) + 358 + 464 + 1.5(498) = 2808\text{ kJ}$. Formed: $2(805) + 4(464) = 3466\text{ kJ}$. $\Delta H = \mathbf{-658\,kJ/mol}$.
- $\Delta H = (-393.5 + 2(-241.8)) - (-201.0) = -877.1 + 201.0 = \mathbf{-676.1\,kJ/mol}$.
- Difference = 18.1 kJ/mol (2.7 %). Mean bond enthalpies are averages, not values for these exact molecules.

Problem 15 Zinc and copper sulfate

- The cooling line is $T = 45.8 - 1.0(t - 4)$, so at 4 min $T = 45.8\text{ }^\circ\text{C}$. $\Delta T = 45.8 - 20.0 = \mathbf{25.8\,K}$.
- $q = 50.0 \times 4.18 \times 25.8 = \mathbf{5392\,J}$.
- $n = 0.0500 \times 0.500 = 0.0250\text{ mol}$; $\Delta H = -5392 / 0.0250 = \mathbf{-216\,kJ/mol}$.

Problem 16 Hydration of copper sulfate

- Route A: anhydrous solid + water $\rightarrow$ hydrate $\rightarrow$ solution (ΔH_{hyd} then $+11.7$). Route B: anhydrous solid $\rightarrow$ solution (-66.1).
- $\Delta H_{\text{hyd}} + 11.7 = -66.1$, so $\Delta H_{\text{hyd}} = \mathbf{-77.8\,kJ/mol}$.
- It is hard to add exactly five moles of water and stop at the hydrate without partial dissolving, so the enthalpy cannot be measured by simple calorimetry.

Problem 17 Formation of ethyne

- $\mathbf{2C(s) + H_2(g) \rightarrow C_2H_2(g)}$.
- $\Delta H_f = 2(-393.5) + (-285.8) - (-1300) = -1072.8 + 1300 = \mathbf{+227.2\,kJ/mol}$.
- Positive: ethyne is higher in enthalpy than its elements, so it is energy-rich and releases a lot of energy when it burns.

Problem 18 Mean C-H bond enthalpy

- Route: $\text{CH}_4 \rightarrow \text{C(s)} + 2\text{H}_2$ ($-\Delta H_f$), then $\text{C(s)} \rightarrow \text{C(g)}$, then $2\text{H}_2 \rightarrow 4\text{H(g)}$.
- $\Delta H = 74.8 + 716.7 + 4(218.0) = \mathbf{+1663.5\,kJ}$.
- $1663.5 / 4 = \mathbf{416\,kJ/mol}$ (415.9).

Problem 19 Hydration of ethene

1. Broken: $C=C + O-H = 612 + 464 = 1076$. Formed: $C-C + C-H + C-O = 347 + 413 + 358 = 1118$. $\Delta H = -42 \text{ kJ/mol}$.
2. $\Delta H = -235.3 - (52.3 - 241.8) = -235.3 + 189.5 = -45.8 \text{ kJ/mol}$.
3. $3.8 / 45.8 \times 100 = 8.3 \%$. Mean bond enthalpies are averages and ignore differences between particular molecules.

Problem 20 Spot the errors

1. The heated mass is the **solution (100 g)**, not the solid: $q = 100 \times 4.18 \times 5.3$.
2. A rise in temperature means heat was released, so ΔH is **negative: -44.3 kJ/mol** .
3. The answer is in J/mol; divide by 1000: **-44.3 kJ/mol** .
4. It must be **$\Sigma(\text{bonds broken}) - \Sigma(\text{bonds formed})$** .