

Heat, enthalpy and Hess's law

AP Chemistry · Worksheet answers

Each answer shows the formula, the substitution and the result in bold. Pay attention to the sign of ΔH and to the number of significant figures, which follows the data given. Some estimates, such as those from bond enthalpies, are expected to differ from tabulated values.

Level: AP Chemistry · **Curriculum:** AP Chem Unit 6

Problem 1 Exothermic or endothermic

1. **Exothermic** ($\Delta H < 0$).
2. **Endothermic** (absorbs heat from the surroundings).
3. **Endothermic** ($\Delta H > 0$).
4. **Exothermic** (heat released).

Problem 2 Heat absorbed by water

1. $q = 250 \times 4.18 \times 15.0 = \mathbf{1.57 \times 10^4 \text{ J}}$ (15 675 J).
2. **15.7 kJ**.

Problem 3 Specific heat of copper

1. $\Delta T = 45.0 - 20.0 = \mathbf{25.0 \text{ }^\circ\text{C}}$.
2. $c = q/(m\Delta T) = 962/(100.0 \times 25.0) = \mathbf{0.385 \text{ J/(g }^\circ\text{C)}}$.

Problem 4 Heat from burning methane

1. ΔH is **negative** (-890 kJ/mol).
2. $n = 4.00/16.04 = 0.249 \text{ mol}$; heat = $0.249 \times 890 = \mathbf{222 \text{ kJ released}}$.

Problem 5 Adding two steps

1. $A \rightarrow B$: **+40 kJ**; $B \rightarrow C$: **-95 kJ**.
2. $A \rightarrow C$: $40 + (-95) = \mathbf{-55 \text{ kJ}}$.
3. $C \rightarrow A$: **+55 kJ**.

Problem 6 Reversing and scaling

1. **-180 kJ**.
2. **+90 kJ** (halved).
3. **+540 kJ** (equation $\times 3$).

Problem 7 Writing formation equations

1. $\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$.
2. $2 \text{ C(s)} + 3 \text{ H}_2\text{(g)} + \frac{1}{2} \text{ O}_2\text{(g)} \rightarrow \text{C}_2\text{H}_5\text{OH(l)}$.
3. $\text{Cl}_2\text{(g)}$ is the element in its standard state, so no change is needed to form it.

Problem 8 Neutralisation in a cup

1. $q = 100.0 \times 4.18 \times 6.5 = 2.72 \times 10^3 \text{ J}$.
2. $n = 0.0500 \text{ L} \times 1.00 = 0.0500 \text{ mol}$.
3. $\Delta H = -2.72 \text{ kJ}/0.0500 \text{ mol} = -54 \text{ kJ/mol}$.

Problem 9 A cold dissolving

1. $q = 108.0 \times 4.18 \times (-5.6) = -2528 \text{ J} = -2.53 \text{ kJ}$ for the solution.
2. $n = 8.00/80.04 = 0.09995 \text{ mol}$; $\Delta H = +2.53/0.09995 = +25 \text{ kJ/mol}$ (endothermic).
3. The dissolving needs energy to separate the ions, which it takes from the water, so the solution cools.

Problem 10 Hess's law with combustion data

1. $\text{C}_2\text{H}_4\text{(g)} + \text{H}_2\text{(g)} \rightarrow \text{C}_2\text{H}_6\text{(g)}$.
2. $\Delta H = \Delta H_c(\text{C}_2\text{H}_4) + \Delta H_c(\text{H}_2) - \Delta H_c(\text{C}_2\text{H}_6) = -1411 - 286 + 1560 = -137 \text{ kJ}$.

Problem 11 Formation enthalpies

1. **0** (element in standard state).
2. $\Delta H^\circ = 3(-393.5) - [-824.2 + 3(-110.5)] = -1180.5 + 1155.7 = -24.8 \text{ kJ}$.
3. Yes, **exothermic**.

Problem 12 Bond enthalpies for HCl

1. $436 + 243 = 679 \text{ kJ}$.
2. $2 \times 432 = 864 \text{ kJ}$.
3. $\Delta H = 679 - 864 = -185 \text{ kJ}$.

Problem 13 Spirit burner

1. $q = 200.0 \times 4.18 \times 25.0 = 20.9 \text{ kJ}$.
2. $n = 1.20/46.07 = 0.02605 \text{ mol}$; $\Delta H = -20.9/0.02605 = -802 \text{ kJ/mol}$.
3. $802/1367 = 59 \%$; the rest was lost to the air, the can and incomplete combustion.

Problem 14 Melting and warming ice

1. $10.0 \times 334 = 3340 \text{ J}$.

- $10.0 \times 4.18 \times 25.0 = \mathbf{1045 \text{ J}}$.
- Total = $\mathbf{4385 \text{ J} = 4.39 \text{ kJ}}$.

Problem 15 Hydrogenation by bond enthalpy

- Broken: $614 + 436 = 1050$. Formed: $347 + 2(413) = 1173$. $\Delta H = 1050 - 1173 = \mathbf{-123 \text{ kJ}}$.
- The Hess value is -137 kJ . Bond enthalpies are averages for many molecules, so the estimate is about **14 kJ different**.

Problem 16 Calorimeter with a heat capacity

- $\Delta T = 4.9 \text{ }^\circ\text{C}$. $q(\text{solution}) = 100.0 \times 4.18 \times 4.9 = \mathbf{2048 \text{ J}}$; $q(\text{calorimeter}) = 25.0 \times 4.9 = \mathbf{122.5 \text{ J}}$. Total 2171 J .
- $n(\text{Cu}^{2+}) = 0.1000 \times 0.100 = 0.0100 \text{ mol}$; $\Delta H = -2.171/0.0100 = \mathbf{-2.2 \times 10^2 \text{ kJ/mol}}$.
- Excess zinc makes sure all the Cu^{2+} reacts, so the moles of Cu^{2+} is the limiting amount.

Problem 17 Formation enthalpy from combustion

- $\mathbf{CH_3OH(l) + 3/2 O_2(g) \rightarrow CO_2(g) + 2 H_2O(l)}$.
- $-726 = [-393.5 + 2(-285.8)] - \Delta H^\circ_f$, so $\Delta H^\circ_f = -965.1 + 726 = \mathbf{-239.1 \text{ kJ/mol}}$.

Problem 18 Ethyne from its elements

- Target = $2 \times (2) + (3) - (1)$: $2 \text{ C} + 2 \text{ O}_2 \rightarrow 2 \text{ CO}_2$; $\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$; $2 \text{ CO}_2 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_2 + \frac{5}{2} \text{ O}_2$. Cancel to give $\mathbf{2 \text{ C(s)} + H_2(g) \rightarrow C_2H_2(g)}$.
- $\Delta H = 2(-393.5) + (-285.8) - (-1300) = -787.0 - 285.8 + 1300 = \mathbf{+227.2 \text{ kJ}}$.
- ΔH is positive, so ethyne is **less stable** (higher enthalpy) than carbon and hydrogen.

Problem 19 Ammonia synthesis

- Broken: $945 + 3(436) = 2253$. Formed: $6(391) = 2346$. $\Delta H = \mathbf{-93 \text{ kJ}}$ for 2 mol NH_3 .
- $1000 \text{ g}/17.03 = 58.7 \text{ mol}$; heat = $58.7 \times 46.5 = \mathbf{2.7 \times 10^3 \text{ kJ per kg}}$.
- The reaction is exothermic, and heat build-up would raise the temperature and shift the equilibrium back towards reactants, so heat must be removed.

Problem 20 Reading a temperature-time graph

- During mixing the cup loses heat to the surroundings. The cooling trend is extended back to the time of mixing to find the temperature the mixture would have reached without heat loss.
- Extrapolated maximum = $\mathbf{35.6 \text{ }^\circ\text{C}}$; $\Delta T = 35.6 - 22.0 = \mathbf{13.6 \text{ }^\circ\text{C}}$.
- $q = 100.0 \times 4.18 \times 13.6 = 5685 \text{ J}$; $n = 0.100 \text{ mol}$; $\Delta H = \mathbf{-57 \text{ kJ/mol} (-56.8)}$.
- With $35.4 \text{ }^\circ\text{C}$, $\Delta T = 13.4 \text{ }^\circ\text{C}$ and $\Delta H = -56 \text{ kJ/mol} (-56.0)$. The raw reading is lower because heat had already been lost, so the magnitude of ΔH is **underestimated**.