

Bond Enthalpies

Answer key with worked solutions

A. Ideas

1. Bond enthalpy.

The energy needed to **break one mole** of a bond in gaseous molecules to form gaseous atoms. Breaking a bond needs energy to overcome the attraction between the nuclei and the shared electrons (**endothermic**); forming a bond releases the same amount of energy (**exothermic**).

2. Bond order.

Length, shortest first: $\text{C}\equiv\text{C}$, $\text{C}=\text{C}$, $\text{C}-\text{C}$. Strength, weakest first: $\text{C}-\text{C}$, $\text{C}=\text{C}$, $\text{C}\equiv\text{C}$. The second bond in $\text{C}=\text{C}$ is a **π bond**, formed by side-on overlap, which is weaker than the σ bond, so $\text{C}=\text{C}$ (614 kJ/mol) is less than $2 \times 348 = 696$ kJ/mol.

B. Estimating ΔH

3. $\text{H}_2 + \text{F}_2$.

Broken: $436 \text{ kJ/mol} + 155 \text{ kJ/mol} = 591 \text{ kJ/mol}$. Formed: $2 \times 567 \text{ kJ/mol} = 1134 \text{ kJ/mol}$.
 $\Delta H \approx 591 \text{ kJ/mol} - 1134 \text{ kJ/mol} = -543 \text{ kJ/mol}$

4. Chlorination of methane.

Broken: $\text{C}-\text{H} + \text{Cl}-\text{Cl} = 413 \text{ kJ/mol} + 242 \text{ kJ/mol} = 655 \text{ kJ/mol}$. Formed: $\text{C}-\text{Cl} + \text{H}-\text{Cl} = 328 \text{ kJ/mol} + 431 \text{ kJ/mol} = 759 \text{ kJ/mol}$.
 $\Delta H \approx 655 \text{ kJ/mol} - 759 \text{ kJ/mol} = -104 \text{ kJ/mol}$

5. Hydrogenation of ethyne.

The two $\text{C}-\text{H}$ bonds of ethyne are unchanged, so count only the bonds that change.
Broken: $\text{C}\equiv\text{C} + 2 \text{ H}-\text{H} = 839 \text{ kJ/mol} + 2 \times 436 \text{ kJ/mol} = 1711 \text{ kJ/mol}$
Formed: $\text{C}-\text{C} + 4 \text{ new C}-\text{H} = 348 \text{ kJ/mol} + 4 \times 413 \text{ kJ/mol} = 2000 \text{ kJ/mol}$
 $\Delta H \approx 1711 \text{ kJ/mol} - 2000 \text{ kJ/mol} = -289 \text{ kJ/mol}$

6. Combustion of ethane.

Broken: 2 C₂H₆ contain 2 C-C and 12 C-H; plus 7 O=O:

$$\begin{aligned}(2 \times 348 + 12 \times 413 + 7 \times 498) \text{ kJ} \\ = (696 + 4956 + 3486) \text{ kJ} \\ = 9138 \text{ kJ}\end{aligned}$$

Formed: 4 CO₂ contain 8 C=O; 6 H₂O contain 12 O-H:

$$\begin{aligned}(8 \times 799 + 12 \times 463) \text{ kJ} \\ = (6392 + 5556) \text{ kJ} \\ = 11\,948 \text{ kJ}\end{aligned}$$

$\Delta H \approx 9138 \text{ kJ} - 11\,948 \text{ kJ} = -2810 \text{ kJ}$ for the equation as written, which is **-1405 kJ per mole of ethane.**

C. Working backwards

7. H-I.

$$\begin{aligned}-9 \text{ kJ/mol} &= (436 + 151) \text{ kJ/mol} - 2x \\ 2x &= 587 \text{ kJ/mol} + 9 \text{ kJ/mol} = 596 \text{ kJ/mol} \\ x &= \mathbf{298 \text{ kJ/mol}}\end{aligned}$$

D. Challenge

8. Why the difference.

(1) The measured value forms **liquid** water: condensing water vapour releases extra energy, which the gas-phase bond enthalpies leave out. (2) The bond enthalpies are **averages** over many compounds, not the exact values for the bonds in methane, carbon dioxide and water.