Energy cycles in reactions

Reactivity 1.2 · SL and AHL

Where does a flame's energy come from?

> The bonds in the products are stronger than the bonds in the reactants.

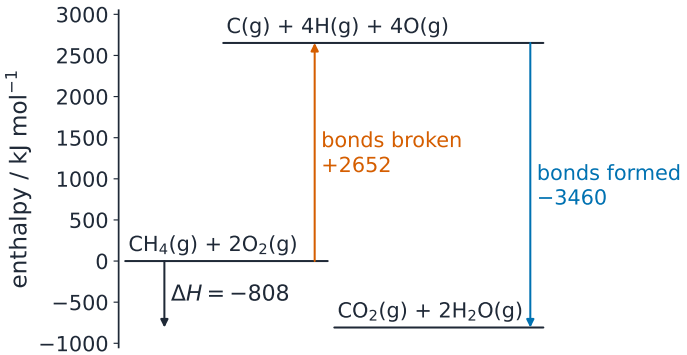
- Burning one mole of methane releases about 800 kJ.
- No atoms are made or destroyed, so the energy comes from bonds.
- This unit: bond enthalpies $\rightarrow$ **Hess's law** $\rightarrow$ formation and Born–Haber cycles.

Breaking needs energy, making releases it

- Bond breaking is endothermic; bond making is exothermic.
- Data booklet values are averages over many compounds.

Bond enthalpy the energy needed to break one mole of a covalent bond, with all substances gaseous

Bonds broken minus bonds formed



CH$_4$ + 2O$_2$: $\Delta H = 2652 - 3460 = -808$ kJ mol^{-1}

Check: hydrogen and chlorine

Your turn

What is ΔH for $H_2 + Cl_2 \rightarrow 2HCl$?

A. $+247$ kJ mol^{-1}

B. -184 kJ mol^{-1}

C. -431 kJ mol^{-1}

D. $+184$ kJ mol^{-1}

Why bond enthalpy answers are approximate

Averages

Values are means over many compounds.

Not the exact bonds in these molecules.

Gases only

Bond enthalpies apply to the gas state.

Changes of state are left out.

Hess's law

- Enthalpy is a state function, like height on a mountain.
- Build a cycle with the target reaction on one route.

> **Hess's law** the enthalpy change of a reaction is independent of the route, if the initial and final conditions are the same

Combining equations

1. **Keep.** $C + O_2 \rightarrow CO_2$, -394
2. **Reverse.** $CO_2 \rightarrow CO + \frac{1}{2}O_2$, $+283$
3. **Add.** CO_2 cancels, $\frac{1}{2}O_2$ is left on the left.

Decision

$C + \frac{1}{2}O_2 \rightarrow CO$, $\Delta H = -111$ kJ mol^{-1}

Worked example: ethyne

1. **Double (1).** $2\mathrm{C} + 2\mathrm{O_2} \rightarrow 2\mathrm{CO_2}$, $2(-394)$
2. **Keep (2).** $\mathrm{H_2} + \frac{1}{2}\mathrm{O_2} \rightarrow \mathrm{H_2O}$, -286
3. **Reverse (3).** $2\mathrm{CO_2} + \mathrm{H_2O} \rightarrow \mathrm{C_2H_2} + \frac{5}{2}\mathrm{O_2}$, $+1301$

Decision

$\Delta H = -788 - 286 + 1301 = +227$ kJ mol^{-1}

AHL: Formation and combustion data

Formation data

Products minus reactants.

Ethanol:
$[2(-394) + 3(-286)] - (-278) = -1368$

Combustion data

Reactants minus products.

Methane:
$[-394 + 2(-286)] - (-890) = -76$

AHL: The Born–Haber cycle

Step for NaCl	**ΔH / kJ mol^{-1}**
atomization of Na, Na(s) $\rightarrow$ Na(g)	$+107$
atomization of Cl, $\frac{1}{2}$Cl$_2$(g) $\rightarrow$ Cl(g)	$+121$
first ionization energy of Na	$+496$
first electron affinity of Cl	-349
formation, Na(s) + $\frac{1}{2}$Cl$_2$(g) $\rightarrow$ NaCl(s)	-411

AHL: Calculating the lattice enthalpy

- Atomization of Cl is half the Cl–Cl bond enthalpy.
- MgO needs two ionization energies and two electron affinities.

$$\Delta H_{\text{latt}} = 411 + 107 + 121 + 496 - 349 = +786 \text{ kJ mol}^{-1}$$

The second electron affinity of oxygen is positive.

Exam tips

> When you reverse an equation, change the sign of ΔH.

- Write "broken minus formed" before substituting.
- Bond enthalpies are for gases.
- AHL. Formation: products minus reactants. Combustion: reactants minus products.
- AHL. IB lattice enthalpy is positive.

Check yourself

Try these

Use bond enthalpies to find ΔH for $C_2H_4 + H_2 \rightarrow C_2H_6$.

Find ΔH for $S + \frac{3}{2}O_2 \rightarrow SO_3$ from the two given equations.

Give two reasons why bond enthalpy answers are approximate.

AHL. Calculate the lattice enthalpy of KCl from its cycle.