# MSJChem

## Tutorials for IB Chemistry

# Reactivity 1.2

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# Calculating ΔH using average bond enthalpies

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# Average bond enthalpies

Average bond enthalpy is the energy required to break one mole of bonds in a gaseous molecule averaged over similar compounds.

Bond breaking is endothermic – energy is required to break a bond.

Bond formation is exothermic – energy is released when bonds are formed.

$$\Delta H = \sum(\text{bonds broken}) - \sum(\text{bonds formed})$$

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# Average bond enthalpies

## 11. Bond enthalpies and average bond enthalpies at 298 K

### Single bonds (kJ mol$^{-1}$)

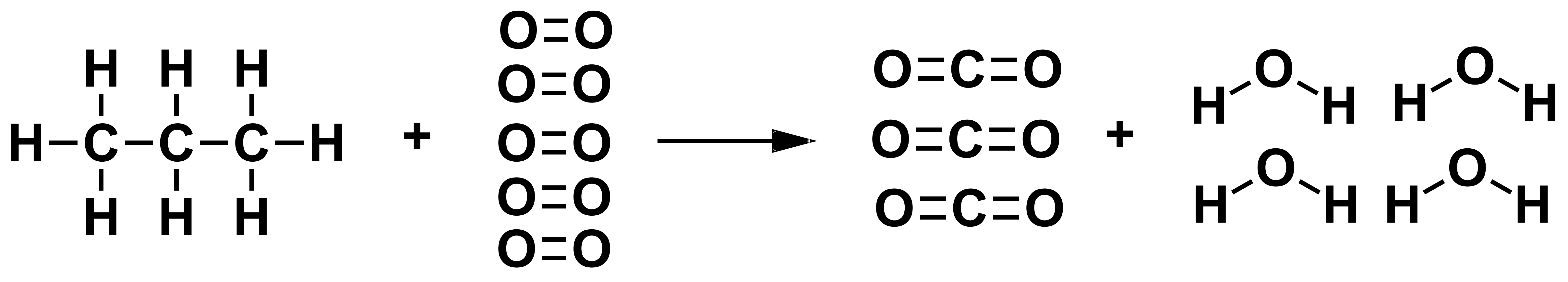
| | Br | C | Cl | F | H | I | N | O | P | S | Si |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Br** | 193 | 285 | 219 | 249 | 366 | 178 | | 201 | 264 | 218 | 330 |
| **C** | 285 | 346 | 324 | 492 | 414 | 228 | 286 | 358 | 264 | 289 | 307 |
| **Cl** | 219 | 324 | 242 | 255 | 431 | 211 | 192 | 206 | 322 | 271 | 400 |
| **F** | 249 | 492 | 255 | 159 | 567 | 280 | 278 | 191 | 490 | 327 | 597 |
| **H** | 366 | 414 | 431 | 567 | 436 | 298 | 391 | 463 | 322 | 364 | 323 |
| **I** | 178 | 228 | 211 | 280 | 298 | 151 | | 201 | 184 | | 234 |
| **N** | | 286 | 192 | 278 | 391 | | 158 | 214 | | | |
| **O** | 201 | 358 | 206 | 191 | 463 | 201 | 214 | 144 | 363 | | 466 |
| **P** | 264 | 264 | 322 | 490 | 322 | 184 | | 363 | 198 | | |
| **S** | 218 | 289 | 271 | 327 | 364 | | | | | 266 | 293 |
| **Si** | 330 | 307 | 400 | 597 | 323 | 234 | | 466 | | 293 | 226 |

### Multiple bonds (kJ mol$^{-1}$)

| | | |
|---|---|---|
| C=C 614 | C≡N 890 | N≡N 945 |
| C≡C 839 | C=O 804 | N=O 587 |
| C⩦C 507 (in benzene) | C=S 536 | O=O 498 |
| C=N 615 | N=N 470 | S=S 429 |

# Average bond enthalpies

$$C_3H_{8(g)} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(l)}$$



| | | | |
|---|---|---|---|
| 2 × 346 kJ | 5 × 498 kJ | 6 × 804 kJ | 8 × 463 kJ |
| 8 × 414 kJ | | | |
| 4004 kJ | 2490 kJ | 4824 kJ | 3704 kJ |

$$\Delta H = 6494 - 8528 = -2034 \text{ kJ mol}^{-1}$$

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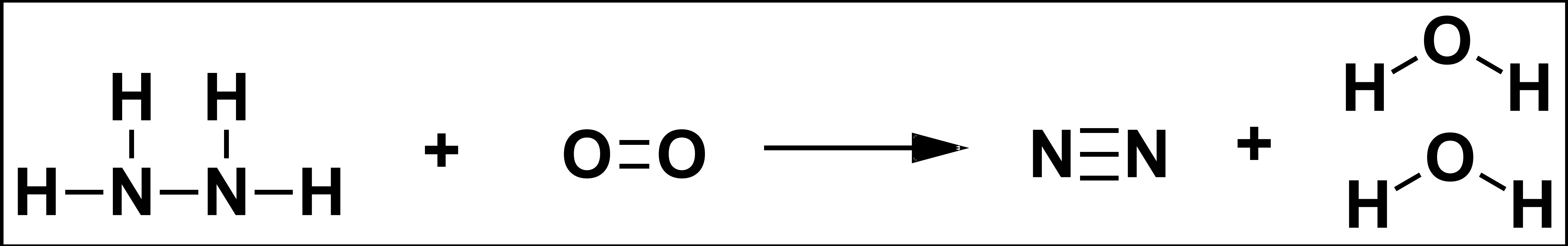
# Average bond enthalpies

$$N_2H_4 + O_2 \rightarrow N_2 + 2H_2O$$




| | | | |
|---|---|---|---|
| 1 × 158 kJ | 1 × 498 kJ | 1 × 945 kJ | 4 × 463 kJ |
| 4 × 391 kJ | | | |
| 1722 kJ | 498 kJ | 945 kJ | 1852 kJ |

$$\Delta H = 2220 - 2797 = -577 \text{ kJ mol}^{-1}$$

# Average bond enthalpies

Enthalpy changes calculated using average bond enthalpies are often different to the actual value.

| Substance | Formula | State | $\Delta H_c^{\ominus}$ (kJ mol$^{-1}$) |
|---|---|---|---|
| propane | $C_3H_8$ | g | −2219 |

Average bond enthalpies are calculated by calculating the energy required to break the same bond in similar compounds and then averaging the value – the actual bond enthalpy value may be different.

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# Calculating $\Delta H$ of a reaction that is the sum of multiple reactions with known $\Delta H$ values

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# Hess's law

The standard enthalpy changes of three combustion reactions are given below in kJ.

| | |
|---|---|
| $2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 4CO_{2(g)} + 6H_2O_{(l)}$ | $\Delta H^{\ominus} = -3120$ |
| $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$ | $\Delta H^{\ominus} = -572$ |
| $C_2H_{4(g)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 2H_2O_{(l)}$ | $\Delta H^{\ominus} = -1411$ |

Calculate the *ΔH* for the following reaction:

$$C_2H_{6(g)} \rightarrow C_2H_{4(g)} + H_{2(g)}$$

# Hess's law

$$2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 4CO_{2(g)} + 6H_2O_{(l)} \quad \Delta H^{\ominus} = -3120$$

$$C_2H_{6(g)} + 3\tfrac{1}{2}\, O_{2(g)} \rightarrow 2CO_{2(g)} + 3H_2O_{(l)} \quad \Delta H^{\ominus} = -1560$$

+

+

$$C_2H_{6(g)} \rightarrow C_2H_{4(g)} + H_{2(g)}$$

$$\Delta H^{\ominus} = +137 \text{ kJ}$$

# Hess's law

$$2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 4CO_{2(g)} + 6H_2O_{(l)} \quad \Delta H^{\ominus} = -3120$$

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)} \quad \Delta H^{\ominus} = -572$$

$$C_2H_{4(g)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 2H_2O_{(l)} \quad \Delta H^{\ominus} = -1411$$

$$C_2H_{6(g)} + \cancel{3\tfrac{1}{2}O_{2(g)}} \rightarrow \cancel{2CO_{2(g)}} + \cancel{3H_2O_{(l)}} \quad \Delta H^{\ominus} = -1560$$

+

$$\cancel{H_2O_{(l)}} \rightarrow H_{2(g)} + \cancel{\tfrac{1}{2}O_{2(g)}} \quad \Delta H^{\ominus} = +286$$

+

$$\cancel{2CO_{2(g)}} + \cancel{2H_2O_{(l)}} \rightarrow C_2H_{4(g)} + \cancel{3O_{2(g)}} \quad \Delta H^{\ominus} = +1411$$

$$C_2H_{6(g)} \rightarrow C_2H_{4(g)} + H_{2(g)} \quad \Delta H^{\ominus} = +137\ \text{kJ}$$