

ENTHALPY OF FORMATION

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Standard enthalpy of formation (ΔH_f°):

Also called the standard heat of formation of a substance

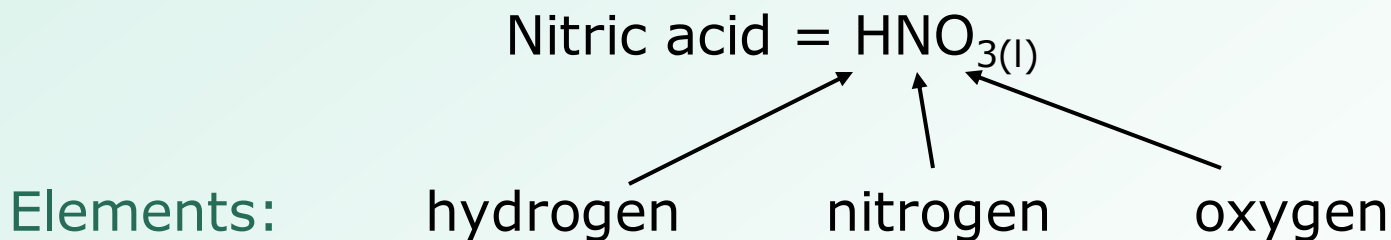
Standard heat of formation: The amount of heat absorbed or released when one mole of the substance is formed at 25°C and 100kPa (SATP) from its elements in their standard states

ΔH_f° units are always in kJ/mol

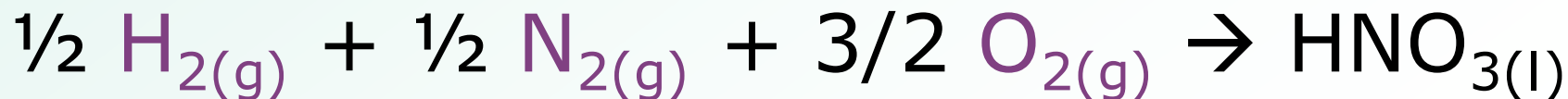
ENTHALPY OF FORMATION

Standard heat of formation: The amount of heat absorbed or released when one mole of the substance is formed at 25°C and 100kPa (SATP) from its **elements** in their standard states

Example: What equation represents the formation of nitric acid?



What are these elements in their standard (most common) states?



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The ΔH_f° for elements in their standard states are zero

Table A-6

Thermodynamic Properties (at standard states)

ΔH_f° in kJ/mol			ΔG_f° in kJ/mol	S° in J/mol · K			
concentration of aqueous solutions is 1M							
Substance	ΔH_f°	ΔG_f°	S°	Substance	ΔH_f°	ΔG_f°	S°
Ag	0	0	42.7	H ₃ PO ₃	-972	—	—
AgCl	-127	-110	96.1	H ₃ PO ₄	-1280	-1120	110
AgCN	-146	-164	83.7	H ₂ S	-20.1	-33.0	206
Al	0	0	28.3	H ₂ SO ₃ (aq)	-614	-538	232
Al ₂ O ₃	-1670	-1580	51.0	H ₂ SO ₄ (aq)	-908	-742	17.2
BaCl ₂ (aq)	-873	-823	121	HgCl ₂	-230	-177	—
BaSO ₄	-1470	-1350	132	Hg ₂ Cl ₂	-265	-211	196
Be	0	0	9.54	Hg ₂ SO ₄	-742	-624	201
Be ₃ N ₂	-568	-512	—	I ₂	0	0	117
Bi	0	0	56.9	K	0	0	63.6
BiCl ₃	-379	-319	190	KBr	-392	-379	96.4
Bi ₂ S ₃	-183	-164	146	KMnO ₄	-813	-714	172
Br ₂	0	0	152	KOH	-426	—	—
CH ₄	-74.8	-50.8	186	LiBr	-350	—	—
C ₂ H ₄	+52.3	+68.1	219	LiOH	-487	-444	50.2
C ₂ H ₆	-84.7	-32.9	229	Mn	0	0	32.0
C ₄ H ₁₀	-125	-15.7	310	MnCl ₂ (aq)	-555	-491	38.9
CO	-111	-137	198	Mn(NO ₃) ₂ (aq)	-636	-451	218
CO ₂	-393.5	-394.4	214	MnO ₂	-521	-466	53.1
CS ₂	+87.9	+63.6	151	MnS	-214	—	—
Ca	0	0	41.6	N ₂	0	0	192
Ca(OH) ₂	-987	-897	—	NH ₃	-46.2	-16.6	193
Cl ₂	0	0	223	NH ₄ Br	-270	-175	113
CoCO ₃	-723	-650	—	NO	+90.4	—	211
CoO	-239	-213	43.9	NO ₂	+33.8	+51.8	240
Cr ₂ O ₃	-1130	-1050	81.2	Na	0	0	51.0
CsCl(aq)	-415	-371	188	NaBr	-360	—	—
Cs ₂ SO ₄ (aq)	-1400	-1310	283	NaCl	-411	-384	72.4
CuI	-67.8	-69.5	96.7	NaNO ₃ (aq)	-447	—	—
CuS	-53.1	-53.7	66.5	NaOH	-427	—	—
Cu ₂ S	-79.5	-86.2	121	Na ₂ S(aq)	-437	—	—
CuSO ₄	-770	-662	113	Na ₂ SO ₄	-1380	-1270	149
F ₂	0	0	203	O ₂	0	0	205
FeCl ₃	-405	—	—	P ₄ O ₆	-1640	—	—
FeO	-267	—	—	P ₄ O ₁₀	-2980	-2700	229
Fe ₂ O ₃	-822	-741	90.0	PbBr ₂	-277	-260	162
H	+218	—	115	PbCl ₂	-359	-314	136
H ₂	0	0	131	S	0	0	31.9
HBr	-36.2	-53.2	198	SO ₂	-297	-300	249
HCl	-92.3	-95.3	187	SO ₃	-438	-368	95.6
HCl(aq)	-167	-131	56.5	SrO	-590	-560	54.4
HCN(aq)	+151	+172	94.1	Ti	0	0	30.3
HF	-269	-271	174	TiO ₂	—	-853	50.2
HI	+25.9	+1.30	206	TiI	-50.2	-83.3	236
H ₂ O(l)	-286	-237	70.0	UCl ₄	-1050	-962	198
H ₂ O(g)	-242	-229	189	UCl ₅	-1100	-993	259
H ₂ O ₂	—	-118	110	Zn	0	0	41.6
H ₃ PO ₂	-609	—	—	ZnCl ₂ (aq)	-487	-410	3.72
				ZnSO ₄ (aq)	-1063	-892	-92.0

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Determine the equations for the formation of:

a) KBrO_3

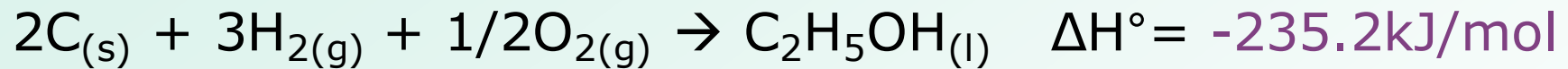
b) $\text{C}_2\text{H}_5\text{OH}$

c) NaHCO_3

Don't forget that the equation must result in the formation of **one** mole of the desired compound.

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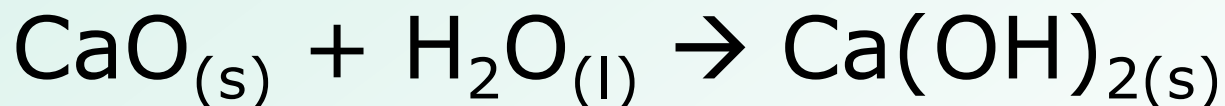
Now we can assign the ΔH°_f of the product as the ΔH° of the whole reaction



This additional equation may assist solving Hess' Law questions.

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How are these equations and ΔH°_f values useful?



By knowing the ΔH°_f of each of the chemicals in the above reaction, you can calculate the ΔH° of the reaction without using thermochemical equations and Hess' Law

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Formation reactions and their ΔH°_f values may be manipulated to determine balanced equation and the ΔH° value of chemical reactions.

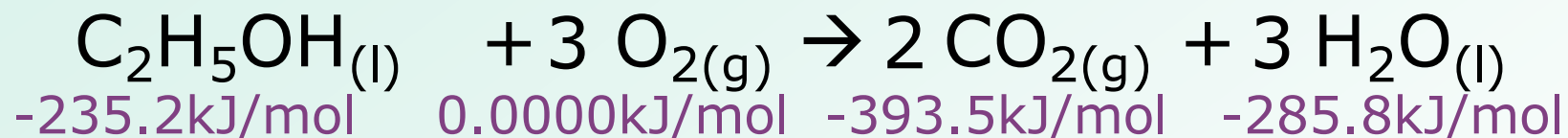
$$\Delta H^\circ = \sum \Delta H^\circ_{f(\text{products})} - \sum \Delta H^\circ_{f(\text{reactants})}$$

Σ = "sum of"

Don't forget that the equations should be multiplied by the appropriate factor, as necessary.

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Using ΔH°_f values, calculate the ΔH° of combustion of one mole of ethanol to produce carbon dioxide gas and liquid water.



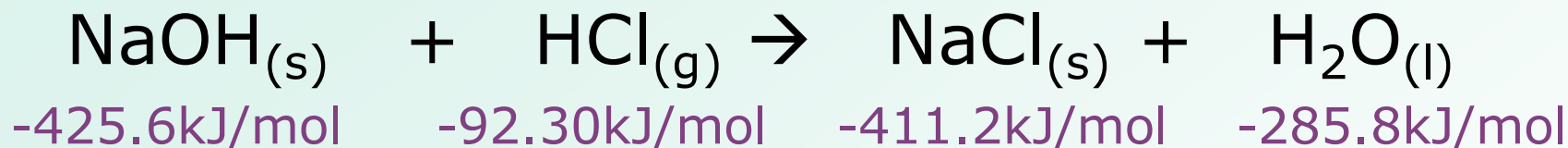
$$\begin{aligned} \Delta H^\circ &= \sum \Delta H^\circ_{\text{f(products)}} - \sum \Delta H^\circ_{\text{f(reactants)}} \\ &= [(2 \text{ mol} \times -393.5\text{kJ/mol}) + (3 \text{ mol} \times -285.8\text{kJ/mol})] \\ &\quad - [(1 \text{ mol} \times -235.2\text{kJ/mol}) + (3 \text{ mol} \times 0.0000\text{kJ/mol})] \\ &= -1644.4\text{kJ} - (-235.2\text{kJ}) \\ &= -1409.2\text{kJ} \end{aligned}$$

Since this equation already combusts 1 mole of ethanol, then the final answer is:

Therefore the heat of combustion is -1409kJ/mol of ethanol

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Using ΔH°_f values, calculate the ΔH° for the following reaction:



$$\begin{aligned} \Delta H^\circ &= \sum \Delta H^\circ_{f(\text{products})} - \sum \Delta H^\circ_{f(\text{reactants})} \\ &= [(1 \text{ mol} \times -411.2\text{kJ/mol}) + (1 \text{ mol} \times -285.8\text{kJ/mol})] \\ &\quad - [(1 \text{ mol} \times -425.6\text{kJ/mol}) + (1 \text{ mol} \times -92.30\text{kJ/mol})] \\ &= -697.0\text{kJ} - (-517.9\text{kJ}) \\ &= -179.1\text{kJ} \end{aligned}$$

Therefore the heat of the reaction is -179.1kJ

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Enthalpy of Combustion:

What is the reaction to produce $\text{C}_6\text{H}_{12}\text{O}_6$?



Where does this naturally occur?

How do we measure it?

In plant chloroplasts; it is not easy to measure.

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Enthalpy of Combustion:



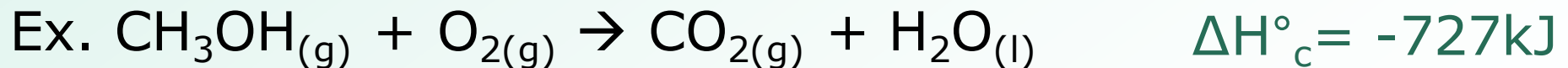
For complex organics, such as $\text{C}_6\text{H}_{12}\text{O}_6$, it is difficult to directly measure its formation. Instead, the compound is combusted and the products analyzed to determine ΔH°_f for the original compound.

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Enthalpy of Combustion:

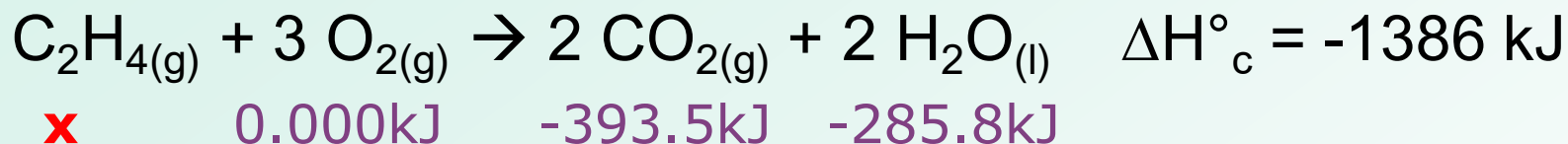
$$\Delta H^{\circ}_c$$

standard heat of combustion - the ΔH° for the combustion of one mole of compound



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Calculate the ΔH°_f for C_2H_4 .



$$\Delta H^\circ = \sum \Delta H^\circ_{f(\text{products})} - \sum \Delta H^\circ_{f(\text{reactants})}$$

$$-1386\text{kJ} = [(2 \text{ mol} \times -393.5\text{kJ/mol}) + (2 \text{ mol} \times -285.8\text{kJ/mol})] \\ - [(1 \text{ mol} \times \textcolor{red}{x}) + (3 \text{ mol} \times 0.000\text{kJ/mol})]$$

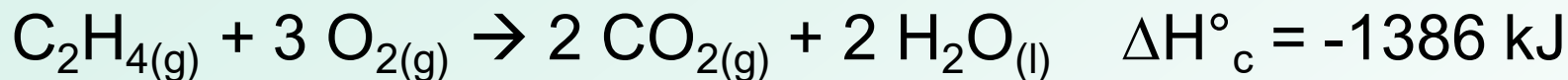
$$-1386\text{kJ} = -1358.6\text{kJ} - \textcolor{red}{x}$$

$$\textcolor{red}{x} = 27.4\text{kJ}$$

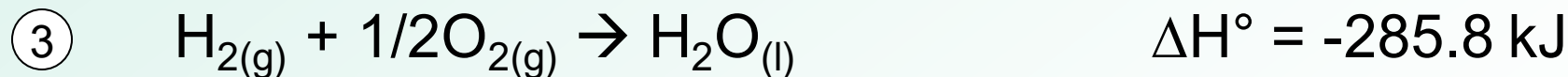
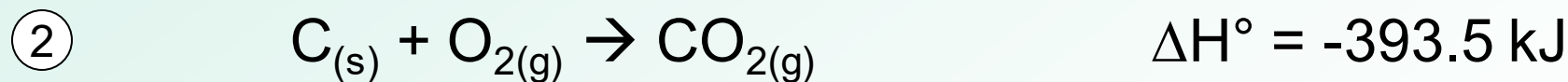
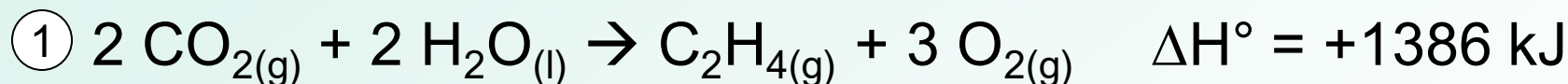
Therefore the heat of formation is 27.4kJ/mol

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Enthalpy of Combustion:

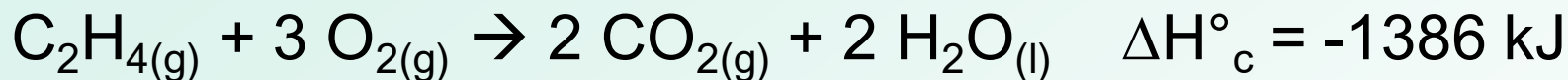


Calculate the ΔH°_f for C_2H_4 .



ENTHALPY OF FORMATION

Enthalpy of Combustion:



Calculate the ΔH°_f for C_2H_4 .

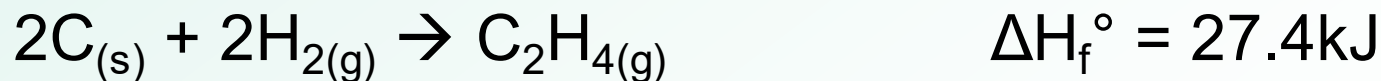
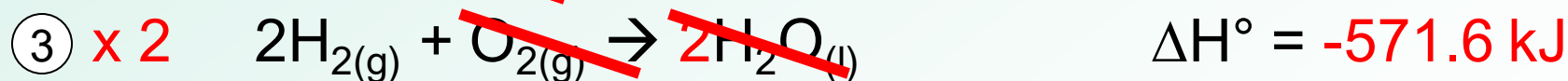
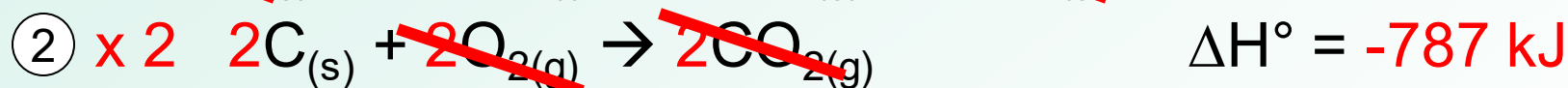
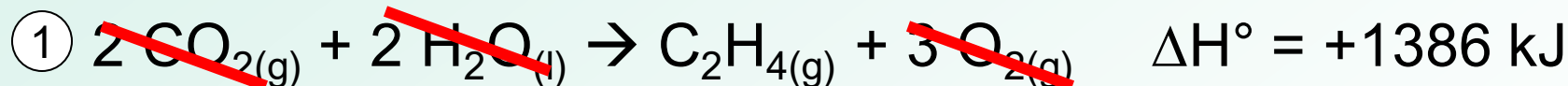


Table 6.2 • Selected Standard Molar Enthalpies of Formation at 298 K

Substance	Name	Standard Molar Enthalpy of Formation (kJ/mol)
C(graphite)	graphite	0
C(diamond)	diamond	+1.8
CH ₄ (g)	methane	−74.87
C ₂ H ₆ (g)	ethane	−83.85
C ₃ H ₈ (g)	propane	−104.7
C ₄ H ₁₀ (g)	butane	−127.1
C ₂ H ₄ (g)	ethene (ethylene)	+52.47
CH ₃ OH(<i>ℓ</i>)	methanol	−238.4
C ₂ H ₅ OH(<i>ℓ</i>)	ethanol	−277.0
C ₁₂ H ₂₂ O ₁₁ (s)	sucrose	−2,221.2
CO(g)	carbon monoxide	−110.53
CO ₂ (g)	carbon dioxide	−393.51
CaCO ₃ (s)*	calcium carbonate	−1207.6
CaO(s)	calcium oxide	−635.0
H ₂ (g)	hydrogen	0
HCl(g)	hydrogen chloride	−92.31
HCl(aq)*	hydrochloric acid (1 M)	−167.2