

ENTHALPY OF FORMATION

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Standard enthalpy of formation (ΔH_f°):

Also called the standard heat of formation of a substance

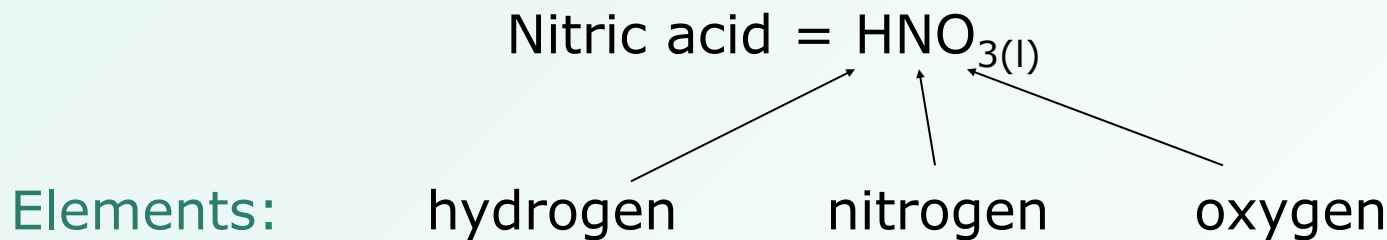
Standard heat of formation: The amount of heat absorbed or released when one mole of the substance is formed at 25°C and 100kPa (SATP) from its elements in their standard states

ΔH_f° units are always in kJ/mol

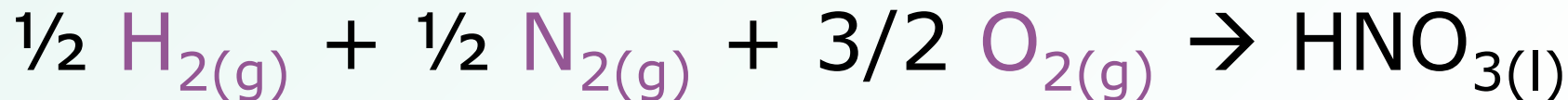
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Standard heat of formation: The amount of heat absorbed or released when one mole of the substance is formed at 25°C and 100kPa (SATP) from its **elements** in their standard states

Example: What equation represents the formation of nitric acid?



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



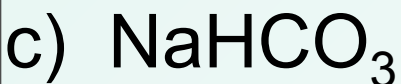
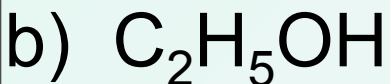
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The ΔH_f° for elements in their standard states are zero

Compound	$\Delta G_f^\circ / \text{kJ mol}^{-1}$	Compound	$\Delta G_f^\circ / \text{kJ mol}^{-1}$
AgCl(s)	-109.7	H ₂ O(g)	-228.6
AgN ₃ (s)	378.5	H ₂ O(l)	-237.2
Ag ₂ O(s)	-10.8	H ₂ O ₂ (l)	-114.0
Al ₂ O ₃ (s)	-1576.4	H ₂ S(g)	-33.0
Br ₂ (l)	0.0	HgO(s)	-58.5
Br ₂ (g)	3.1	I ₂ (s)	0.0
CaO(s)	-604.2	I ₂ (g)	19.4
CaCO ₃ (s)	-1128.8	KCl(s)	-408.3
C—graphite	0.0	KBr(s)	-393.1
C—diamond	2.9	MgO(s)	-569.6
CH ₄ (g)	-50.8	MgH ₂ (s)	76.1
C ₂ H ₂ (g)	209.2	NH ₃ (g)	16.7
C ₂ H ₄ (g)	68.2	NO(g)	86.7
C ₂ H ₆ (g)	-32.9	NO ₂ (g)	51.8
C ₆ H ₆ (l)	124.5	N ₂ O ₄ (g)	98.3
CO(g)	-137.3	NF ₃ (g)	-124.7
CO ₂ (g)	-394.4	NaCl(s)	-384.0
CuO(s)	-127.2	NaBr(s)	-347.6
Fe ₂ O ₃ (s)	-741.0	O ₃ (g)	163.4
HBr(g)	-53.2	SO ₂ (g)	-300.4
HCl(g)	-95.3	SO ₃ (g)	-370.4
HI(g)	1.3	ZnO(s)	-318.2

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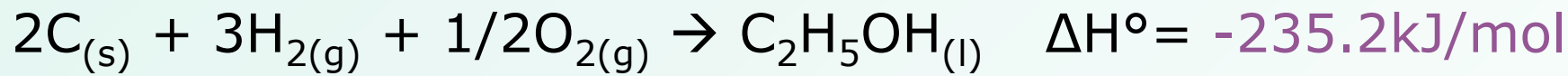
Determine the equations for the formation of:



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

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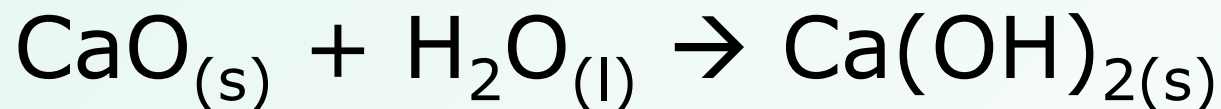
Now we can assign the ΔH°_f of the product as the ΔH° of the whole reaction



This additional equation may assist solving Hess' Law questions.

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How are these equations and ΔH°_f values useful?

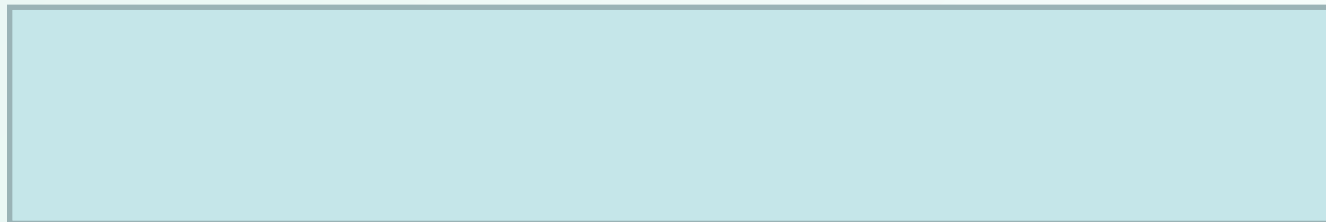


By knowing the ΔH°_f of each of the chemicals in the above reaction, you can calculate the ΔH° of the reaction without using thermochemical equations and Hess' Law

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

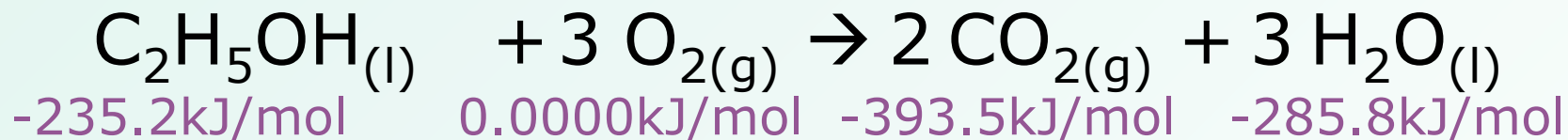
Formation reactions and their ΔH°_f values may be manipulated to determine balanced equation and the ΔH° value of chemical reactions.



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

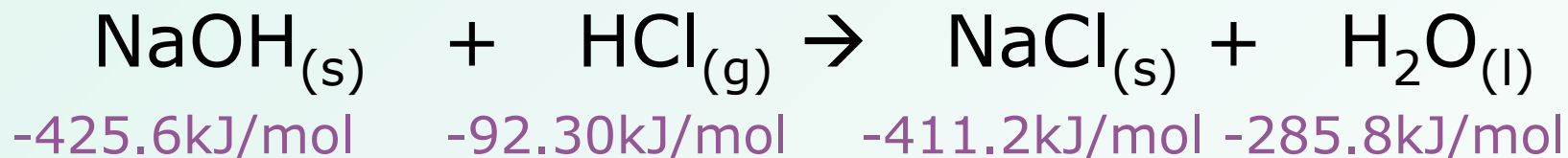
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Using ΔH°_f values, calculate the ΔH° of combustion of one mole of ethanol to produce carbon dioxide gas and liquid water.



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



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Enthalpy of Combustion:

What is the reaction to produce $C_6H_{12}O_6$?

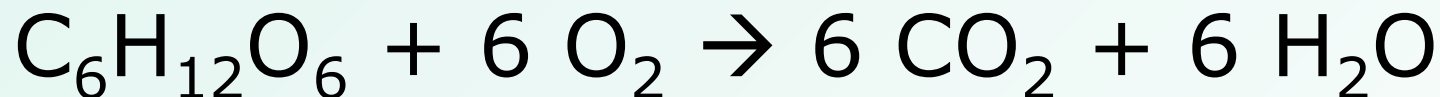


Where does this naturally occur?
How do we measure it?

In plant chloroplasts; it is not easy to measure.

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Enthalpy of Combustion:



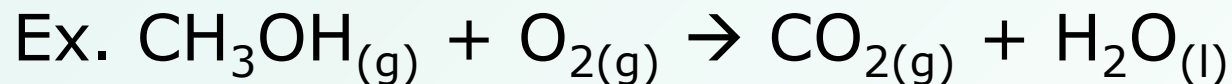
For complex organics, such as $\text{C}_6\text{H}_{12}\text{O}_6$, it is difficult to directly measure its formation. Instead, the compound is combusted and the products analyzed to determine ΔH°_f for the original compound.

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Enthalpy of Combustion:

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

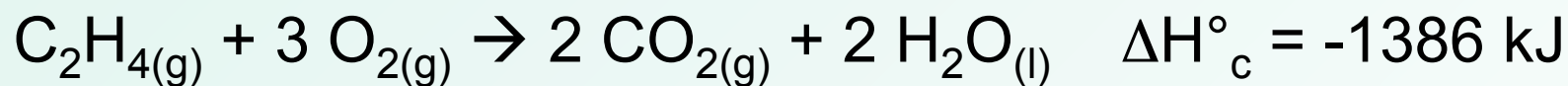
standard heat of combustion - the ΔH° for the combustion of one mole of compound



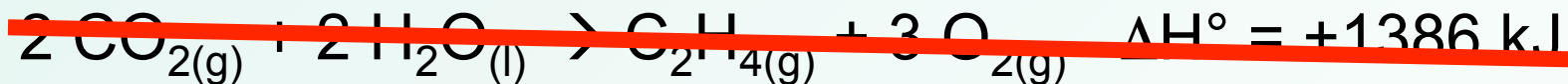
$$\Delta H^{\circ}_c = -727\text{kJ}$$

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Enthalpy of Combustion:



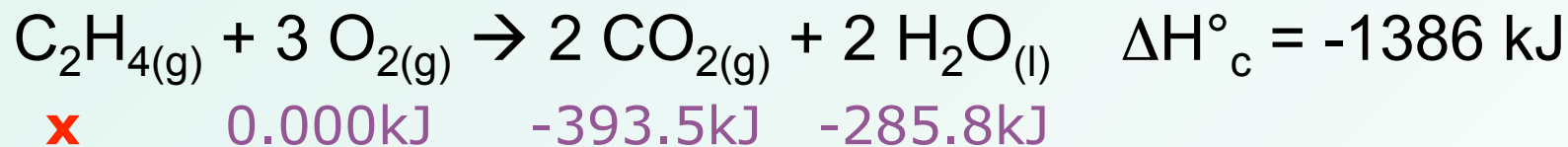
Calculate the ΔH°_f for C_2H_4 .



Can't simply reverse this equation.

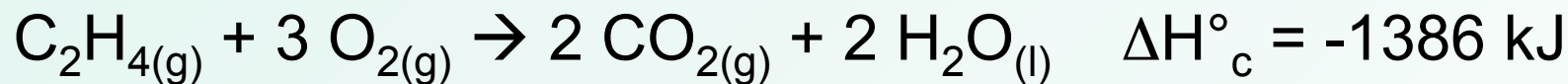
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Calculate the ΔH°_f for C_2H_4 .



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Enthalpy of Combustion:



Calculate the ΔH°_f for C_2H_4 .

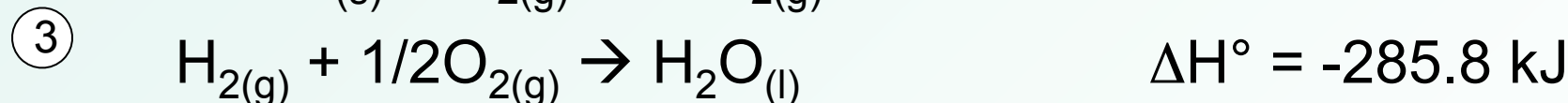
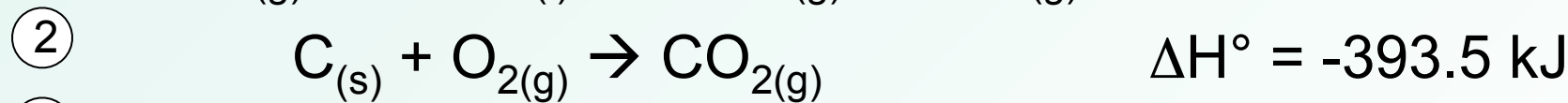
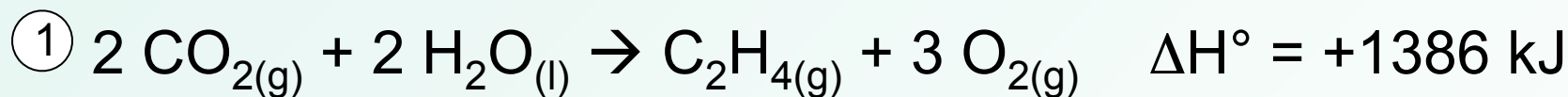


Table A-6

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	—	—
Cu ₂ SO ₄	-770	-662	113	Na ₂ SO ₄	-1380	-1270	149

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