

Step by Step: **Hess's Law** (see at end for supplemental notes on $\Delta H_{\text{formation}}$ with Hess's Law)

The enthalpy change (ΔH_r°) for a reaction is the sum of the enthalpy changes for a series of reactions, that add up to the overall reaction.

Steps:

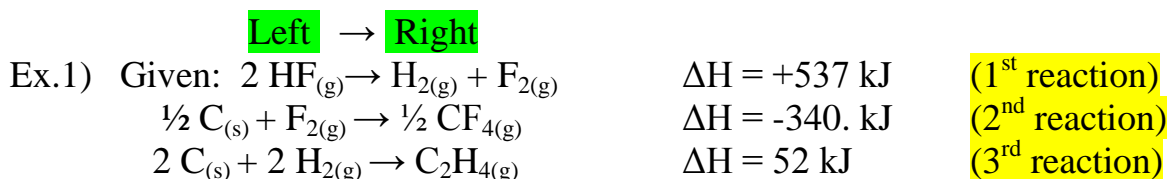
For each reaction:

1) Check to see, if the compounds are on the correct sides of the reaction.

**If not, reverse the entire reaction, and change the sign of ΔH .

2) Check to see, if all of the unwanted compounds will cancel completely.

**If not, multiply an entire reaction by a number so that they do cancel completely and multiply ΔH by that same number.



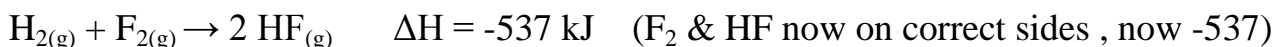
Find ΔH_r° for: $\text{C}_2\text{H}_{4(g)} + 6 \text{F}_{2(g)} \rightarrow 2 \text{CF}_{4(g)} + 4 \text{HF}_{(g)}$

Look at the first reaction to see, if the compounds are on the correct sides.

*The HF is on the left side of the 1st reaction and it is on the right side of the blue reaction, so that is not OK. We need to flip this reaction and make it go the other direction.

*The H₂ is on the right side of the 1st reaction, but it is not in the blue reaction, so that does not help.

*The F₂ is on the right side of the 1st reaction and it is on the left side of the blue reaction, so that is not OK. We need to flip this reaction and make it go the other direction. { We cannot just move one compound, because then the reaction will not balance, so we must flip the entire reaction and make it go backwards. } If we flip the reaction, the ΔH sign will flip as well. The positive 537 will now be negative.

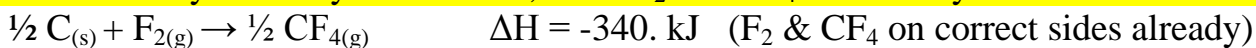


Look at the second reaction.

*The C is on the left side of the 2nd reaction, but it is not in the blue reaction, so that does not help.

*The F₂ is on the left side of the 2nd reaction and it is on the left side of the blue reaction, so that is OK.

*The CF₄ is on the right side of the 2nd reaction and it is on the right side of the blue reaction, so that is OK. The 2nd reaction stays the way it is written, since F₂ and CF₄ are already on the correct sides.



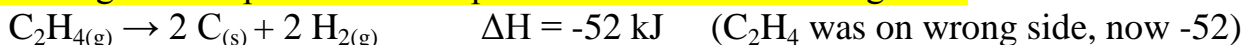
Look at the third reaction.

*The C is on the left side of the 3rd reaction, but it is not in the blue reaction, so that does not help.

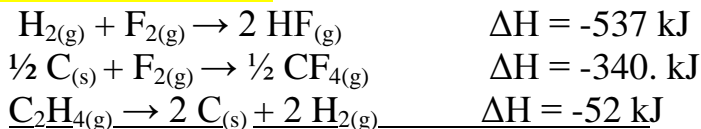
*The H₂ is on the left side of the 3rd reaction, but it is not in the blue reaction, so that does not help.

*The C₂H₄ is on the right side of the 3rd reaction, but it is on the left side of the blue reaction. The C₂H₄ is on the wrong side of the reaction. { We cannot just move one compound, because then the

reaction will not balance, so we must flip the entire reaction and make it go backwards.} If we flip the reaction, the ΔH sign will flip as well. The positive 52 will now be negative.



So this is what we have so far:

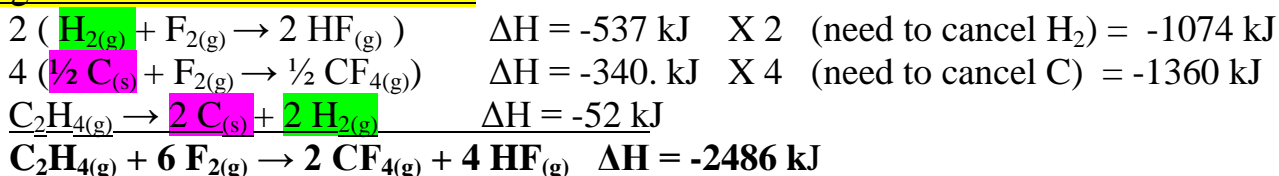


Now we must completely cancel all of the compounds that were not in the blue reaction. Look up above: H_2 and C were in the 3 top reactions, but were not in the blue reaction.

To make the H_2 cancel we must multiply the 1st reaction by 2. The ΔH will also be multiplied by 2.

To make the C cancel we must multiply the 2nd reaction by 4. The ΔH will also be multiplied by 4.

Just like the redox reactions, if the compounds are on opposite sides of the arrows, we can cancel them by subtracting from both sides of the arrow!



When the reactions are added, we have 1 C_2H_4 on the left side.

We have 2 X 1 F_2 (1st reaction) added to 4 X 1 F_2 (2nd reaction) = 6 F_2 . {The F_2 in the 2 reactions are added, since they are on the same side of the reactions. Remember they only cancel, if they are on opposite sides.}

On the right side there are 2 X 2 HF = 4 HF and 4 X $\frac{1}{2}$ CF_4 = 2 CF_4 .

This summation reaction should match the blue reaction, which it does. Then add all of the energies together to get the total energy of -2486 kJ.

Ex. 2) Given the following data:



Calculate ΔH for the reaction: $\text{S}_{(s)} + \text{O}_{2(g)} \rightarrow \text{SO}_{2(g)}$

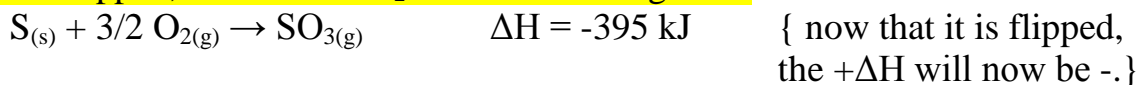
Look at the 1st reaction:

*The SO_3 is on the left side of the 1st reaction, but is it not in the blue reaction, so that does not help.

*The S is on the right side of the 1st reaction and on the left side of the blue reaction, so that is on the wrong side.

*The O_2 is on the right side of the 1st reaction and on the left side of the blue reaction, so that is also on the wrong side.

The 1st reaction needs to be flipped, since S and O_2 are on the wrong sides.



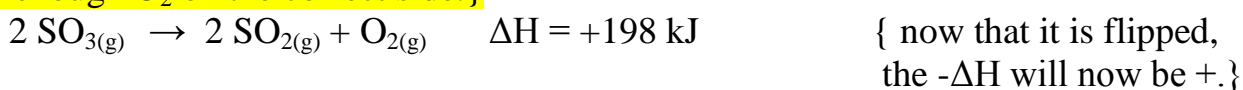
Look at the 2nd reaction:

*The SO_2 is on the left side of the 2nd reaction, but on the right side of the blue reaction. It is on the wrong side.

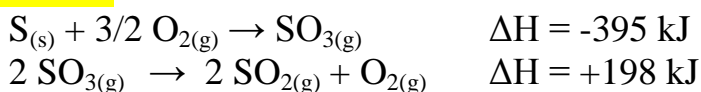
*The O_2 is on the left side of the 2nd reaction and on the left side of the blue reaction, so that is OK.

*The SO_3 is on the right side of the 2nd reaction, but it is not in the blue reaction, so that does not help.

We have a problem, because the SO_2 is on the wrong side, but the O_2 is on the correct side. We need to figure out which is the most important! The SO_2 in that 2nd reaction is the only SO_2 in the first two reactions, but there is O_2 in both reactions #1 and #2. The SO_2 is the most important, since it is in only one location, so it must go on the correct side. The 2nd reaction will need to be flipped to get the SO_2 to the right side. {The O_2 will go on the wrong side, but there is O_2 in the 1st reaction, that will go on the correct side. After we add the reactions and cancel, there will hopefully be enough O_2 on the correct side.}

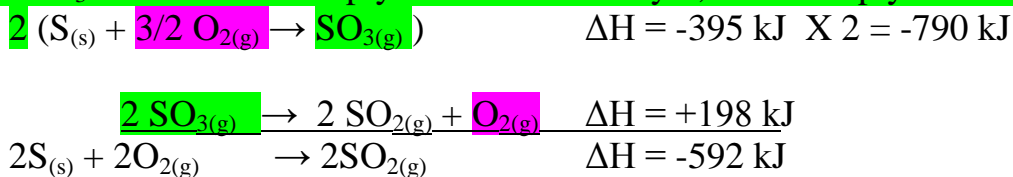


So far we have this:



Now we need to cancel out any compounds that are not in the blue reaction. That means we need to cancel the SO_3 .

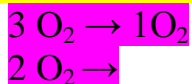
To cancel the SO_3 we need to multiply the 1st reaction by 2, and multiply the ΔH by 2.



When the reactions are added we will get on the left side $2 \times \text{S} = 2 \text{S}$.

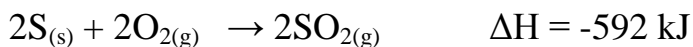
For the O_2 : On the left there are $2 \times 3/2 \text{O}_2$ which equals 3O_2 .

On the right there is O₂, so just 1 O₂.
 If we have, 3 O₂ on the left and 1 O₂ on the right.



We can subtract off 1 O₂ from each side,
 leaving 2 O₂ on the left side.

And there are 2 SO₂ on the right side.

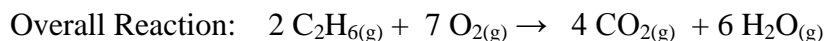


One last problem: Our reaction does not match the blue reaction, because it is two times too big. So we must divide by 2. Also divide the ΔH by 2.



Supplemental Notes: ΔH_{formation} and why ∑nΔH_{products} - ∑nΔH_{reactants} works.

ΔH_{reaction} = ∑nΔH_{products} - ∑nΔH_{reactants} can be explained by doing a Hess's Law problem with the ΔH_{formation} reactions of the reactants and products in the overall reaction.



1st step: Write the ΔH_{formation} reactions for each of the reactants and products.

a) When you do this, every metal, metalloid and non-metal is written as a single element, except for the gases and halogens.

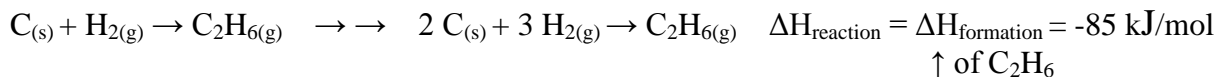
(Metals: Fe_(s), Na_(s) etc., Metalloids: Si_(s), Ge_(s) etc., Non-metals: C_(s), S_(s) etc.)

b) Halogens and gases, that are not noble gases, are written as dimers (in two's).

(Halogens: F_{2(g)}, Cl_{2(g)}, Br_{2(l)}, I_{2(s)}, Gases: H_{2(g)}, N_{2(g)}, O_{2(g)})

Noble gases have full orbital layers and are stable being alone: He_(g), Ne_(g) etc.

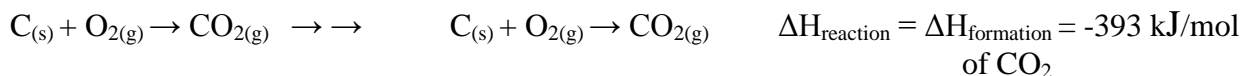
Balance the equation



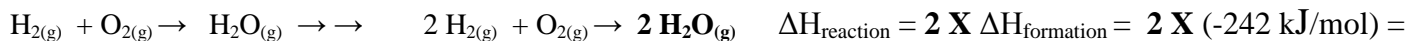
↑ of C₂H₆

You can find the ΔH_{formation} of the compound from the ΔH, ΔG, and ΔS Table in your textbook.

O_{2(g)} is just O_{2(g)}, so there is no formation reaction.



of CO₂

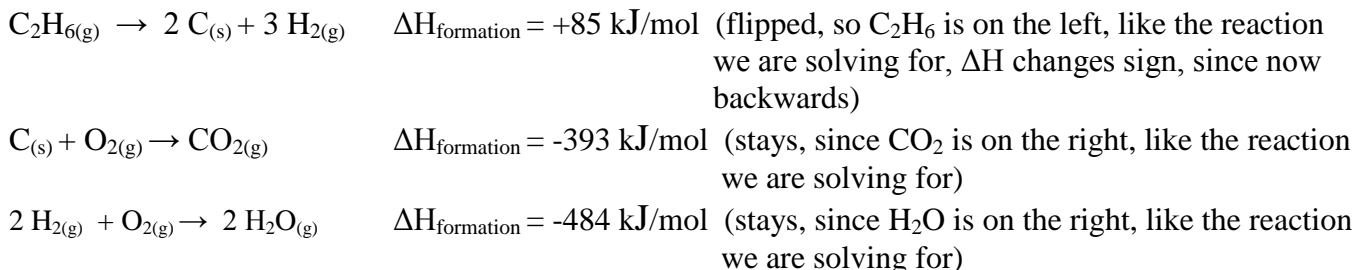
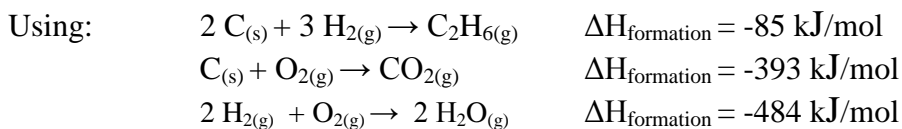


****Since there are 2 mols of H₂O in the balanced reaction the ΔH_{reaction} will be two times the ΔH_{formation} of H₂O. Or another way of thinking about it, is that the ΔH_{formation} will be half the ΔH_{reaction}.**

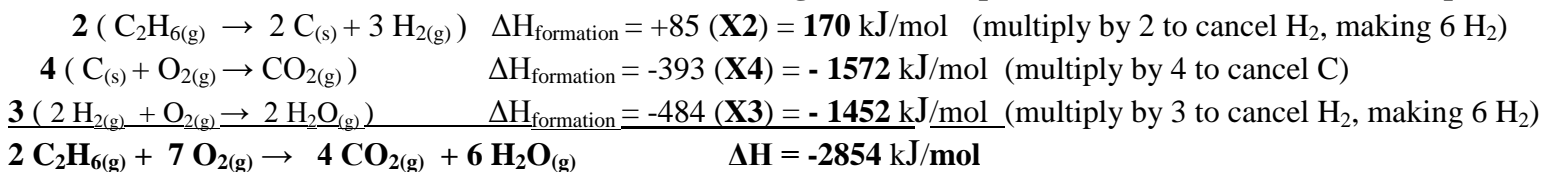
-484 kJ/mol

2nd step: Use the above reactions in a Hess's Law problem to solve for the overall reaction.

Find $\Delta H_{\text{reaction}}$ for : $2 \text{C}_2\text{H}_6(\text{g}) + 7 \text{O}_2(\text{g}) \rightarrow 4 \text{CO}_2(\text{g}) + 6 \text{H}_2\text{O}(\text{g})$



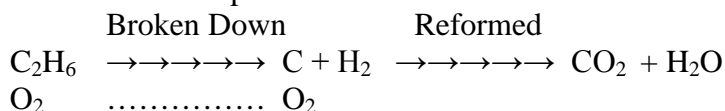
****The energies are multiplied when the reactions are multiplied.**



Why this works:

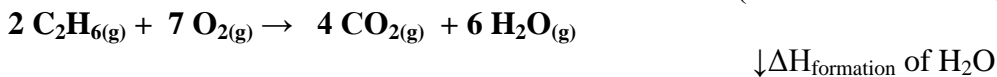
The 1st reaction of the three reactions in the Hess's Law problem breaks C_2H_6 apart to its elements $\text{C}_{(\text{s})}$ and $\text{H}_{2(\text{g})}$. This is the opposite of the $\Delta H_{\text{formation}}$, since C_2H_6 is broken apart and not formed. (The reaction was flipped and ΔH changed sign.) Hess's Law has no reaction for the breaking down and forming of $\text{O}_{2(\text{g})}$, since it is already in its elemental state.

Once the reactants are broken apart to their elements, they can be reformed into their products. So the $\text{C}_{(\text{s})}$, $\text{H}_{2(\text{g})}$, and $\text{O}_{2(\text{g})}$ are formed into the products in the 2nd and 3rd reactions of the Hess's Law problem.



The total of the energies for these changes was calculated in Hess's Law.

3rd step: Prove that this equation works: $\Delta H_{\text{reaction}} = \sum n\Delta H_{\text{products}} - \sum n\Delta H_{\text{reactants}}$
(These ΔH 's are $\Delta H_{\text{formations}}$ of the compounds.)

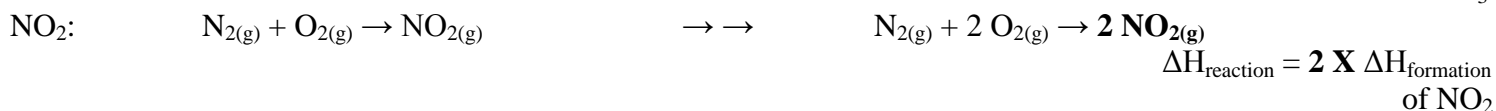
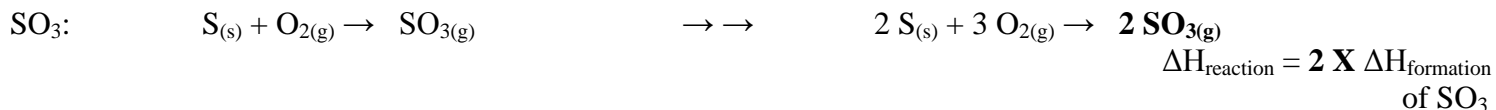
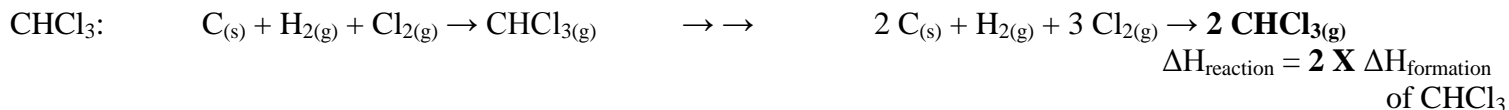


$$\Delta H_{\text{reaction}} = [(4 \text{ mol CO}_2) (-393 \text{ kJ/mol}) + (6 \text{ mol H}_2\text{O}) (-242 \text{ kJ/mol})] - [(2 \text{ mol C}_2\text{H}_6) (-85 \text{ kJ/mol}) + (7 \text{ mol O}_2) (0 \text{ kJ/mol})]$$

$$\Delta H_{\text{reaction}} = -1572 - 1452 + 170 = \mathbf{-2854 \text{ kJ/mol}}$$

The above equation has $\Delta H_{\text{products}} - \Delta H_{\text{reactants}}$, because the **product $\Delta H_{\text{formations}}$ remain positive** in the Hess's Law problem and the **reactant $\Delta H_{\text{formations}}$ are negative**, since they are flipped in the Hess's Law problem.

Other Sample $\Delta H_{\text{formations}}$:



Remember: Every **metal, metalloid and non-metal is written as a single element, except** for the gases and halogens.
(Metals: $\text{Fe}_{(s)}$, $\text{Na}_{(s)}$ etc., Metalloids: $\text{Si}_{(s)}$, $\text{Ge}_{(s)}$ etc., Non-metals: $\text{C}_{(s)}$, $\text{S}_{(s)}$ etc.)

Halogens and gases, that are not noble gases, are written as dimers (in two's).

(Halogens: $\text{F}_{2(g)}$, $\text{Cl}_{2(g)}$, $\text{Br}_{2(l)}$, $\text{I}_{2(s)}$ Gases: $\text{H}_{2(g)}$, $\text{N}_{2(g)}$, $\text{O}_{2(g)}$)

Noble gases have full orbital layers and are happy as loners: $\text{He}_{(g)}$, $\text{Ne}_{(g)}$ etc.

End of Notes