The enthalpy change $\left(\Delta \mathrm{H}_{\mathrm{r}}{ }^{\circ}\right)$ 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 $\Delta \mathrm{H}$.
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 $\Delta \mathrm{H}$ by that same number.

$$
\text { Left } \rightarrow \text { Right }
$$

Ex.1) Given: $2 \mathrm{HF}_{(\mathrm{g})} \rightarrow \mathrm{H}_{2(\mathrm{~g})}+\mathrm{F}_{2(\mathrm{~g})} \quad \Delta \mathrm{H}=+537 \mathrm{~kJ} \quad$ (1 $1^{\text {st }}$ reaction)

$$
\begin{array}{lll}
1 / 2 \mathrm{C}_{(\mathrm{s})}+\mathrm{F}_{2(\mathrm{~g}} \rightarrow 1 / 2 \mathrm{CF}_{4(\mathrm{~g})} & \Delta \mathrm{H}=-340 . \mathrm{kJ} & \left(2^{\text {nd }} \text { reaction }\right) \\
2 \mathrm{C}_{(\mathrm{s})}+2 \mathrm{H}_{2(\mathrm{~g})} \rightarrow \mathrm{C}_{2} \mathrm{H}_{4(\mathrm{~g})} & \Delta \mathrm{H}=52 \mathrm{~kJ} & \left(3^{\mathrm{rd}}\right. \text { reaction) }
\end{array}
$$

Find $\Delta \mathrm{H}_{\mathrm{r}}{ }^{\mathrm{o}}$ for: $\mathrm{C}_{2} \mathbf{H}_{\mathbf{4 ( g )}}+\mathbf{6} \mathrm{F}_{2(\mathrm{~g})} \rightarrow \mathbf{2} \mathbf{C F}_{\mathbf{4 ( \mathrm { g } )}}+\mathbf{4} \mathbf{H F}_{(\mathrm{g})}$
Look at the first reaction to see, if the compounds are on the correct sides.
*The HF is on the left side of the $1^{\text {st }}$ 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 $\mathrm{H}_{2}$ is on the right side of the $1^{\text {st }}$ reaction, but it is not in the blue reaction, so that does not help. *The $\mathrm{F}_{2}$ is on the right side of the $1^{\text {st }}$ 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 $\Delta \mathrm{H}$ sign will flip as well. The positive 537 will now be negative.

$$
\mathrm{H}_{2(\mathrm{~g})}+\mathrm{F}_{2(\mathrm{~g})} \rightarrow 2 \mathrm{HF}_{(\mathrm{g})} \quad \Delta \mathrm{H}=-537 \mathrm{~kJ} \quad\left(\mathrm{~F}_{2} \& \mathrm{HF} \text { now on correct sides , now }-537\right)
$$

Look at the second reaction.
*The C is on the left side of the $2^{\text {nd }}$ reaction, but it is not in the blue reaction, so that does not help. $*$ The $\mathrm{F}_{2}$ is on the left side of the $2^{\text {nd }}$ reaction and it is on the left side of the blue reaction, so that is OK.
*The $\mathrm{CF}_{4}$ is on the right side of the $2^{\text {nd }}$ reaction and it is on the right side of the blue reaction, so that is OK. The $2^{\text {nd }}$ reaction stays the way it is written, since $\mathrm{F}_{2}$ and $\mathrm{CF}_{4}$ are already on the correct sides.

$$
1 / 2 \mathrm{C}_{(\mathrm{s})}+\mathrm{F}_{2(\mathrm{~g})} \rightarrow 1 / 2 \mathrm{CF}_{4(\mathrm{~g})} \quad \Delta \mathrm{H}=-340 . \mathrm{kJ} \quad\left(\mathrm{~F}_{2} \& \mathrm{CF}_{4} \text { on correct sides already }\right)
$$

Look at the third reaction.
*The C is on the left side of the $3^{\text {rd }}$ reaction, but it is not in the blue reaction, so that does not help. *The $\mathrm{H}_{2}$ is on the left side of the $3^{\text {rd }}$ reaction, but it is not in the blue reaction, so that does not help. *The $\mathrm{C}_{2} \mathrm{H}_{4}$ is on the right side of the $3^{\text {rd }}$ reaction, but it is on the left side of the blue reaction. The $\mathrm{C}_{2} \mathrm{H}_{4}$ is on the wrong side of the reaction. \{We cannot just move one compound, because then the chemistrynoteslecture.com © 2011
reaction will not balance, so we must flip the entire reaction and make it go backwards.\} If we flip the reaction, the $\Delta \mathrm{H}$ sign will flip as well. The positive 52 will now be negative.

$$
\mathrm{C}_{2} \mathrm{H}_{4(\mathrm{~g})} \rightarrow 2 \mathrm{C}_{(\mathrm{s})}+2 \mathrm{H}_{2(\mathrm{~g})} \quad \Delta \mathrm{H}=-52 \mathrm{~kJ} \quad\left(\mathrm{C}_{2} \mathrm{H}_{4} \text { was on wrong side, now }-52\right)
$$

So this is what we have so far:

$$
\begin{array}{ll}
\mathrm{H}_{2(\mathrm{~g})}+\mathrm{F}_{2(\mathrm{~g})} \rightarrow 2 \mathrm{HF}_{(\mathrm{g})} & \Delta \mathrm{H}=-537 \mathrm{~kJ} \\
1 / 2 \mathrm{C}_{(\mathrm{s})}+\mathrm{F}_{2(\mathrm{~g})} \rightarrow 1 / 2 \mathrm{CF}_{4(\mathrm{~g})} & \Delta \mathrm{H}=-340 . \mathrm{kJ} \\
\underline{\mathrm{C}}_{2} \underline{\mathrm{H}}_{4(\mathrm{~g})} \rightarrow 2 \mathrm{C}_{(\mathrm{s})}+2 \mathrm{H}_{2(\mathrm{~g})} & \Delta \mathrm{H}=-52 \mathrm{~kJ}
\end{array}
$$

Now we must completely cancel all of the compounds that were not in the blue reaction. Look up above: $\mathrm{H}_{2}$ and C were in the 3 top reactions, but were not in the blue reaction.
To make the $\mathrm{H}_{2}$ cancel we must multiply the $1^{\text {st }}$ reaction by 2 . The $\Delta \mathrm{H}$ will also be multiplied by 2 . To make the C cancel we must multiply the $2^{\text {nd }}$ reaction by 4 . The $\Delta \mathrm{H}$ 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!

$$
\left.2\left(\mathrm{H}_{2(\mathrm{~g})}+\mathrm{F}_{2(\mathrm{~g})} \rightarrow 2 \mathrm{HF}_{(\mathrm{g})}\right) \quad \Delta \mathrm{H}=-537 \mathrm{~kJ} \quad \mathrm{X} 2 \quad \text { (need to cancel } \mathrm{H}_{2}\right)=-1074 \mathrm{~kJ}
$$

$$
\left.4\left(1 / 2 \mathrm{C}_{(\mathrm{s})}+\mathrm{F}_{2(\mathrm{~g})} \rightarrow 1 / 2 \mathrm{CF}_{4(\mathrm{~g})}\right) \quad \Delta \mathrm{H}=-340 . \mathrm{kJ} \quad \mathrm{X} 4 \text { (need to cancel } \mathrm{C}\right)=-1360 \mathrm{~kJ}
$$

$$
\underline{\mathrm{C}}_{2} \underline{\mathrm{H}}_{4}(\mathrm{~g}) \rightarrow 2 \mathrm{C}(\mathrm{~s})+2 \mathrm{H}_{2}(\mathrm{~g}) \quad \Delta \mathrm{H}=-52 \mathrm{~kJ}
$$

$$
\mathbf{C}_{2} \mathrm{H}_{4(\mathrm{~g})}+6 \mathrm{~F}_{2(\mathrm{~g})} \rightarrow 2 \mathrm{CF}_{4(\mathrm{~g})}+4 \mathrm{HF}_{(\mathrm{g})} \quad \Delta \mathrm{H}=-2486 \mathrm{~kJ}
$$

When the reactions are added, we have $1 \mathrm{C}_{2} \mathrm{H}_{4}$ on the left side.
We have $2 \times 1 \mathrm{~F}_{2}$ ( $1^{\text {st }}$ reaction) added to $4 \times 1 \mathrm{~F}_{2}$ ( $2^{\text {nd }}$ reaction) $=6 \mathrm{~F}_{2}$. $\left\{\right.$ The $\mathrm{F}_{2}$ 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 $2 \mathrm{X} 2 \mathrm{HF}=4 \mathrm{HF}$ and $4 \mathrm{X} 1 / 2 \mathrm{CF}_{4}=2 \mathrm{CF}_{4}$.
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:

$$
\begin{array}{rll}
\mathrm{SO}_{3(\mathrm{~g})} & \rightarrow \mathrm{S}_{(\mathrm{s})}+3 / 2 \mathrm{O}_{2(\mathrm{~g})} & \Delta \mathrm{H}=+395 \mathrm{~kJ} \\
2 \mathrm{SO}_{2(\mathrm{~g})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow 2 \mathrm{SO}_{3(\mathrm{~g})} & \Delta \mathrm{H}=-198 \mathrm{~kJ} & \text { (14 } \text { ( }^{\text {td }} \text { reaction) } \\
\text { reaction })
\end{array}
$$

Calculate $\Delta \mathrm{H}$ for the reaction: $\mathrm{S}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{SO}_{2(\mathrm{~g})}$
Look at the $1^{\text {st }}$ reaction:
*The $\mathrm{SO}_{3}$ is on the left side of the $1^{\text {st }}$ reaction, but is it not in the blue reaction, so that does not help. *The S is on the right side of the $1^{\text {st }}$ reaction and on the left side of the blue reaction, so that is on the wrong side.
*The $\mathrm{O}_{2}$ is on the right side of the $1^{\text {st }}$ reaction and on the left side of the blue reaction, so that is also on the wrong side.
The $1^{\text {st }}$ reaction needs to be flipped, since S and $\mathrm{O}_{2}$ are on the wrong sides.

$$
\mathrm{S}_{(\mathrm{s})}+3 / 2 \mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{SO}_{3(\mathrm{~g})} \quad \Delta \mathrm{H}=-395 \mathrm{~kJ} \quad\{\text { now that it is flipped, }
$$ the $+\Delta \mathrm{H}$ will now be -.\}

Look at the $2^{\text {nd }}$ reaction:
*The $\mathrm{SO}_{2}$ is on the left side of the $2^{\text {nd }}$ reaction, but on the right side of the blue reaction. It is on the wrong side.
*The $\mathrm{O}_{2}$ is on the left side of the $2^{\text {nd }}$ reaction and on the left side of the blue reaction, so that is OK. *The $\mathrm{SO}_{3}$ is on the right side of the $2^{\text {nd }}$ reaction, but it is not in the blue reaction, so that does not help. We have a problem, because the $\mathrm{SO}_{2}$ is on the wrong side, but the $\mathrm{O}_{2}$ is on the correct side. We need to figure out which is the most important! The $\mathrm{SO}_{2}$ in that $2^{\text {nd }}$ reaction is the only $\mathrm{SO}_{2}$ in the first two reactions, but there is $\mathrm{O}_{2}$ in both reactions $\# 1$ and $\# 2$. The $\mathrm{SO}_{2}$ is the most important, since it is in only one location, so it must go on the correct side. The $2^{\text {nd }}$ reaction will need to be flipped to get the $\mathrm{SO}_{2}$ to the right side. \{The $\mathrm{O}_{2}$ will go on the wrong side, but there is $\mathrm{O}_{2}$ in the $1^{\text {st }}$ reaction, that will go on the correct side. After we add the reactions and cancel, there will hopefully be enough $\mathrm{O}_{2}$ on the correct side.\}

$$
2 \mathrm{SO}_{3(\mathrm{~g})} \rightarrow 2 \mathrm{SO}_{2(\mathrm{~g})}+\mathrm{O}_{2(\mathrm{~g})} \quad \Delta \mathrm{H}=+198 \mathrm{~kJ}
$$

\{ now that it is flipped, the $-\Delta \mathrm{H}$ will now be + . $\}$
So far we have this:

$$
\begin{array}{ll}
\mathrm{S}_{(\mathrm{s})}+3 / 2 \mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{SO}_{3(\mathrm{~g})} & \Delta \mathrm{H}=-395 \mathrm{~kJ} \\
2 \mathrm{SO}_{3(\mathrm{~g})} \rightarrow 2 \mathrm{SO}_{2(\mathrm{~g})}+\mathrm{O}_{2(\mathrm{~g})} & \Delta \mathrm{H}=+198 \mathrm{~kJ}
\end{array}
$$

Now we need to cancel out any compounds that are not in the blue reaction. That means we need to cancel the $\mathrm{SO}_{3}$.

To cancel the $\mathrm{SO}_{3}$ we need to multiply the $1^{\text {st }}$ reaction by 2 , and multiply the $\Delta \mathrm{H}$ by 2 .

$$
\begin{array}{ll}
2\left(\mathrm{~S}_{(\mathrm{s})}+3 / 2 \mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{SO}_{3(\mathrm{~g})}\right) & \Delta \mathrm{H}=-395 \mathrm{~kJ} \mathrm{X} 2=-790 \mathrm{~kJ} \\
2 \mathrm{~S}_{(\mathrm{s})}+{\underline{2 \mathrm{SO}_{2(\mathrm{~g})}}}_{3(\mathrm{~g})} & \rightarrow 2 \mathrm{SO}_{2(\mathrm{~g})}+\mathrm{O}_{2(\mathrm{~g})}- \\
\rightarrow 2 \mathrm{SO}_{2(\mathrm{~g})} & \Delta \mathrm{H}=+198 \mathrm{~kJ} \\
\Delta \mathrm{H}=-592 \mathrm{~kJ}
\end{array}
$$

When the reactions are added we will get on the left side $2 \mathrm{X} \mathrm{S}=2 \mathrm{~S}$.
For the $\mathrm{O}_{2}$ : On the left there are $2 \mathrm{X} 3 / 2 \mathrm{O}_{2}$ which equals $3 \mathrm{O}_{2}$.
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On the right there is $\mathrm{O}_{2}$, so just $1 \mathrm{O}_{2}$.
If we have, $3 \mathrm{O}_{2}$ on the left and $1 \mathrm{O}_{2}$ on the right.

$$
3 \mathrm{O}_{2} \rightarrow 1 \mathrm{O}_{2}
$$

$$
2 \mathrm{O}_{2} \rightarrow \quad \text { We can subtract off } 1 \mathrm{O}_{2} \text { from each side, }
$$

$$
\text { leaving } 2 \mathrm{O}_{2} \text { on the left side. }
$$

And there are $2 \mathrm{SO}_{2}$ on the right side.

$$
2 \mathrm{~S}_{(\mathrm{s})}+2 \mathrm{O}_{2(\mathrm{~g})} \rightarrow 2 \mathrm{SO}_{2(\mathrm{~g})} \quad \Delta \mathrm{H}=-592 \mathrm{~kJ}
$$

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 $\Delta \mathrm{H}$ by 2 .

$$
\mathrm{S}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{SO}_{2(\mathrm{~g})} \quad \Delta \mathrm{H}=-296 \mathrm{~kJ}
$$

Supplemental Notes: $\mathbf{\Delta} \mathbf{H}_{\text {formation }}$ and why $\sum \mathbf{n} \Delta \mathbf{H}_{\text {products }}-\sum \mathbf{n} \Delta \mathbf{H}_{\text {reactants }}$ works.
$\Delta H_{\text {reaction }}=\sum \mathrm{n} \Delta \mathrm{H}_{\text {products }}-\sum \mathrm{n} \Delta \mathrm{H}_{\text {reactants }}$ can be explained by doing a Hess's Law problem with the $\Delta \mathrm{H}_{\text {formation }}$ reactions of the reactants and products in the overall reaction.

Overall Reaction: $2 \mathrm{C}_{2} \mathrm{H}_{6(\mathrm{~g})}+7 \mathrm{O}_{2(\mathrm{~g})} \rightarrow 4 \mathrm{CO}_{2(\mathrm{~g})}+6 \mathrm{H}_{2} \mathrm{O}_{(\mathrm{g})}$
1t step: Write the $\Delta \mathrm{H}_{\text {formation }}$ 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: $\mathrm{Fe}_{(\mathrm{s})}, \mathrm{Na}_{(\mathrm{s})}$ etc., Metalloids: $\mathrm{Si}_{(\mathrm{s})}, \mathrm{Ge}_{(\mathrm{s})}$ etc., Non-metals: $\mathrm{C}_{(\mathrm{s})}, \mathrm{S}_{(\mathrm{s})}$ etc.)
b) Halogens and gases, that are not noble gases, are written as dimers (in two's).
(Halogens: $\mathrm{F}_{2(\mathrm{~g})}, \mathrm{Cl}_{2(\mathrm{~g})}, \mathrm{Br}_{2(\mathrm{l})}, \mathrm{I}_{2(\mathrm{~s})}$, Gases: $\left.\mathrm{H}_{2(\mathrm{~g})}, \mathrm{N}_{2(\mathrm{~g})}, \mathrm{O}_{2(\mathrm{~g})}\right)$
Noble gases have full orbital layers and are stable being alone: $\mathrm{He}_{(\mathrm{g})}, \mathrm{Ne}_{(\mathrm{g})}$ etc.
Balance the equation
$\mathrm{C}_{(\mathrm{s})}+\mathrm{H}_{2(\mathrm{~g})} \rightarrow \mathrm{C}_{2} \mathrm{H}_{6(\mathrm{~g})} \rightarrow \rightarrow 2 \mathrm{C}_{(\mathrm{s})}+3 \mathrm{H}_{2(\mathrm{~g})} \rightarrow \mathrm{C}_{2} \mathrm{H}_{6(\mathrm{~g})}$
$\Delta \mathrm{H}_{\text {reaction }}=\Delta \mathrm{H}_{\text {formation }}=-85 \mathrm{~kJ} / \mathrm{mol}$ $\uparrow$ of $\mathrm{C}_{2} \mathrm{H}_{6}$
You can find the $\Delta \mathrm{H}_{\text {formation }}$ of the compound from the $\Delta \mathrm{H}, \Delta \mathrm{G}$, and $\Delta \mathrm{S}$ Table in your textbook.
$\mathrm{O}_{2(\mathrm{~g})}$ is just $\mathrm{O}_{2(\mathrm{~g})}$, so there is no formation reaction.
$\mathrm{C}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{CO}_{2(\mathrm{~g})} \rightarrow \rightarrow \quad \mathrm{C}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{CO}_{2(\mathrm{~g})}$
$\Delta \mathrm{H}_{\text {reaction }}=\Delta \mathrm{H}_{\text {formation }}=-393 \mathrm{~kJ} / \mathrm{mol}$ of $\mathrm{CO}_{2}$
$\mathrm{H}_{2(\mathrm{~g})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{H}_{2} \mathrm{O}_{(\mathrm{g})} \rightarrow \rightarrow \quad 2 \mathrm{H}_{2(\mathrm{~g})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow 2 \mathbf{H}_{2} \mathrm{O}_{(\mathrm{g})} \quad \Delta \mathrm{H}_{\text {reaction }}=\mathbf{2 X} \Delta \mathrm{H}_{\text {formation }}=\mathbf{2 X}(-242 \mathrm{~kJ} / \mathrm{mol})=$
**Since there are 2 mols of $\mathrm{H}_{2} \mathrm{O}$ in the balanced reaction the $\quad$ of $\mathrm{H}_{2} \mathrm{O} \quad-\mathbf{4 8 4} \mathbf{~ k J} / \mathbf{m o l}$
$\Delta H_{\text {reaction }}$ will be two times the $\Delta \mathrm{H}_{\text {formation }}$ of $\mathrm{H}_{2} \mathrm{O}$. Or another way of thinking about it, is that the $\Delta H_{\text {formation }}$ will be half the $\Delta H_{\text {reaction }}$.
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## $\underline{\underline{2 n d}}$ step: Use the above reactions in a Hess's Law problem to solve for the overall reaction.

Find $\Delta \mathrm{H}_{\text {reaction }}$ for : $\mathbf{2} \mathbf{C}_{\mathbf{2}} \mathbf{H}_{\mathbf{6 ( g )}}+\mathbf{7} \mathbf{O}_{\mathbf{2 ( g )}} \rightarrow \mathbf{4} \mathbf{C O}_{\mathbf{2 ( g )}}+\mathbf{6} \mathbf{H}_{\mathbf{2}} \mathrm{O}_{(\mathrm{g})}$
Using: $\quad 2 \mathrm{C}_{(\mathrm{s})}+3 \mathrm{H}_{2(\mathrm{~g})} \rightarrow \mathrm{C}_{2} \mathrm{H}_{6(\mathrm{~g})} \quad \Delta \mathrm{H}_{\text {formation }}=-85 \mathrm{~kJ} / \mathrm{mol}$

$$
\mathrm{C}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{CO}_{2(\mathrm{~g})} \quad \Delta \mathrm{H}_{\text {formation }}=-393 \mathrm{~kJ} / \mathrm{mol}
$$

$$
2 \mathrm{H}_{2(\mathrm{~g})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow 2 \mathrm{H}_{2} \mathrm{O}_{(\mathrm{g})} \quad \Delta \mathrm{H}_{\text {formation }}=-484 \mathrm{~kJ} / \mathrm{mol}
$$

$\mathrm{C}_{2} \mathrm{H}_{6(\mathrm{~g})} \rightarrow 2 \mathrm{C}_{(\mathrm{s})}+3 \mathrm{H}_{2(\mathrm{~g})} \quad \Delta \mathrm{H}_{\text {formation }}=+85 \mathrm{~kJ} / \mathrm{mol}$ (flipped, so $\mathrm{C}_{2} \mathrm{H}_{6}$ is on the left, like the reaction we are solving for, $\Delta \mathrm{H}$ changes sign, since now backwards)
$\mathrm{C}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{CO}_{2(\mathrm{~g})} \quad \Delta \mathrm{H}_{\text {formation }}=-393 \mathrm{~kJ} / \mathrm{mol}$ (stays, since $\mathrm{CO}_{2}$ is on the right, like the reaction we are solving for)
$2 \mathrm{H}_{2(\mathrm{~g})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow 2 \mathrm{H}_{2} \mathrm{O}_{(\mathrm{g})} \quad \Delta \mathrm{H}_{\text {formation }}=-484 \mathrm{~kJ} / \mathrm{mol}$ (stays, since $\mathrm{H}_{2} \mathrm{O}$ is on the right, like the reaction we are solving for)
**The energies are multiplied when the reactions are multiplied.

$$
\left.2\left(\mathrm{C}_{2} \mathrm{H}_{6(\mathrm{~g})} \rightarrow 2 \mathrm{C}_{(\mathrm{s})}+3 \mathrm{H}_{2(\mathrm{~g})}\right) \Delta \mathrm{H}_{\text {formation }}=+85(\mathbf{X 2})=\mathbf{1 7 0} \mathrm{kJ} / \mathrm{mol} \quad \text { (multiply by } 2 \text { to cancel } \mathrm{H}_{2} \text {, making } 6 \mathrm{H}_{2}\right)
$$

$4\left(\mathrm{C}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{CO}_{2(\mathrm{~g})}\right) \quad \Delta \mathrm{H}_{\text {formation }}=-393(\mathbf{X 4})=-1572 \mathrm{~kJ} / \mathrm{mol}$ (multiply by 4 to cancel C)
$\underline{3}\left(2 \mathrm{H}_{2(g)}+\mathrm{O}_{2(g)} \rightarrow 2 \mathrm{H}_{2} \mathrm{O}_{(g)}\right) \quad \Delta \mathrm{H}_{\text {formation }}=-484(\mathrm{XB})=-1452 \mathrm{~kJ} / \mathrm{mol}$ (multiply by 3 to cancel $\mathrm{H}_{2}$, making $6 \mathrm{H}_{2}$ )
$2 \mathrm{C}_{2} \mathrm{H}_{6(\mathrm{~g})}+7 \mathrm{O}_{2(\mathrm{~g})} \rightarrow 4 \mathrm{CO}_{2(\mathrm{~g})}+6 \mathrm{H}_{2} \mathrm{O}_{(\mathrm{g})} \quad \Delta \mathrm{H}=-2854 \mathrm{~kJ} / \mathrm{mol}$

## Why this works:

The $1^{\text {st }}$ reaction of the three reactions in the Hess's Law problem breaks $\mathrm{C}_{2} \mathrm{H}_{6}$ apart to it's elements $\mathrm{C}_{(\mathrm{s})}$ and $\mathrm{H}_{2(\mathrm{~g})}$. This is the opposite of the $\Delta \mathrm{H}_{\text {formation, }}$, since $\mathrm{C}_{2} \mathrm{H}_{6}$ is broken apart and not formed. (The reaction was flipped and $\Delta \mathrm{H}$ changed sign.) Hess's Law has no reaction for the breaking down and forming of $\mathrm{O}_{2(\mathrm{~g})}$, since it is already in it's elemental state.

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

Broken Down Reformed
$\mathrm{C}_{2} \mathrm{H}_{6} \rightarrow \rightarrow \rightarrow \rightarrow \mathrm{C}+\mathrm{H}_{2} \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \mathrm{CO}_{2}+\mathrm{H}_{2} \mathrm{O}$
$\mathrm{O}_{2} \quad \ldots \ldots \ldots \ldots . \mathrm{O}_{2}$
The total of the energies for these changes was calculated in Hess's Law.
$\underline{3}^{\text {rd }}$ step: Prove that this equation works: $\Delta H_{\text {reaction }}=\sum \mathbf{n} \Delta H_{\text {products }}-\sum \mathbf{n} \Delta H_{\text {reactants }}$
(These $\Delta \mathrm{H}$ 's are $\Delta \mathrm{H}_{\text {formations }}$ of the compounds.)
$2 \mathrm{C}_{2} \mathrm{H}_{6(\mathrm{~g})}+7 \mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathbf{4} \mathrm{CO}_{2(\mathrm{~g})}+6 \mathrm{H}_{2} \mathrm{O}_{(\mathrm{g})}$
$\downarrow \Delta \mathrm{H}_{\text {formation }}$ of $\mathrm{H}_{2} \mathrm{O}$
$\Delta \mathrm{H}_{\text {reaction }}=\left[\left(4 \mathrm{~mol} \mathrm{CO}_{2}\right)(-393 \mathrm{~kJ} / \mathrm{mol})+(6 \mathrm{~mol} \mathrm{H} \mathrm{H})(-242 \mathrm{~kJ} / \mathrm{mol})\right]-$
[ $\left.\left(2 \mathrm{~mol} \mathrm{C} 2 \mathrm{H}_{6}\right)(-85 \mathrm{~kJ} / \mathrm{mol})+(7 \mathrm{~mol} \mathrm{O} 2)(0 \mathrm{~kJ} / \mathrm{mol})\right]$
$\Delta \mathbf{H}_{\text {reaction }}=\mathbf{- 1 5 7 2 - 1 4 5 2 + 1 7 0 = - 2 8 5 4 \mathbf { k J } / \mathbf { m o l } , ~}$

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

Other Sample $\Delta \mathbf{H}_{\text {formations }}$ :

| $\mathrm{CHCl}_{3}$ : | $\mathrm{C}_{(\mathrm{s})}+\mathrm{H}_{2(\mathrm{~g})}+\mathrm{Cl}_{2(\mathrm{~g})} \rightarrow \mathrm{CHCl}_{3(\mathrm{~g})}$ | $\rightarrow \rightarrow$ | $\begin{aligned} & 2 \mathrm{C}_{(\mathrm{s})}+\mathrm{H}_{2(\mathrm{~g})}+3 \mathrm{Cl}_{2(\mathrm{~g})} \rightarrow \mathbf{2 ~ C H C l}_{3(\mathrm{~g})} \\ & \Delta \mathrm{H}_{\text {reaction }}=\mathbf{2} \mathbf{X} \Delta \mathrm{H}_{\text {formation }} \\ & \text { of } \mathrm{CHCl}_{3} \end{aligned}$ |
| :---: | :---: | :---: | :---: |
| $\mathrm{SO}_{2}$ : | $\mathrm{S}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{SO}_{2(\mathrm{~g})}$ | $\rightarrow \rightarrow$ | $\mathrm{S}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{SO}_{2(\mathrm{~g})}$ |
| $\mathrm{SO}_{3}$ : | $\mathrm{S}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{SO}_{3(\mathrm{~g})}$ | $\rightarrow \rightarrow$ | $2 \mathrm{~S}_{(\mathrm{s})}+3 \mathrm{O}_{2(\mathrm{~g})} \rightarrow 2 \underset{\Delta \mathrm{H}_{\text {reaction }}}{\mathbf{S O}_{3(\mathbf{g})}}=\mathbf{2 \mathrm { X }} \Delta \underset{\substack{\text { formation } \\ \text { of } \mathrm{SO}_{3}}}{ }$ |
| $\mathrm{NO}_{2}$ : | $\mathrm{N}_{2(\mathrm{~g})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{NO}_{2(\mathrm{~g})}$ | $\rightarrow \rightarrow$ | $\begin{array}{r} \mathrm{N}_{2(\mathrm{~g})}+2 \mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathbf{2} \mathbf{N O}_{2(\mathrm{~g})} \\ \Delta \mathrm{H}_{\text {reaction }} \end{array}=\mathbf{2 \mathbf { X } \Delta \mathrm { H } _ { \text { formation } }} \begin{array}{r} \text { of } \mathrm{NO}_{2} \end{array}$ |
| $\mathrm{H}_{2} \mathrm{SO}_{4}$ : | $\mathrm{H}_{2(\mathrm{~g})}+\mathrm{S}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{H}_{2} \mathrm{SO}_{4(\mathrm{~g})}$ | $\rightarrow \rightarrow$ | $\mathrm{H}_{2(\mathrm{~g})}+\mathrm{S}_{(\mathrm{s})}+2 \mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{H}_{2} \mathrm{SO}_{4(\mathrm{~g})}$ |
| $\mathrm{KMnO}_{4}$ : | $\mathrm{K}_{(\mathrm{s})}+\mathrm{Mn}_{(\mathrm{s})}+\mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{KMnO}_{4(\mathrm{~s})}$ | $\rightarrow \rightarrow$ | $\mathrm{K}_{(\mathrm{s})}+\mathrm{Mn}_{(\mathrm{s})}+2 \mathrm{O}_{2(\mathrm{~g})} \rightarrow \mathrm{KMnO}_{4(\mathrm{~s})}$ |

Remember: Every metal, metalloid and non-metal is written as a single element, except for the gases and halogens.
(Metals: $\mathrm{Fe}_{(\mathrm{s})}, \mathrm{Na}_{(\mathrm{s})}$ etc., Metalloids: $\mathrm{Si}_{(\mathrm{s})}, \mathrm{Ge}_{(\mathrm{s})}$ etc., Non-metals: $\mathrm{C}_{(\mathrm{s})}, \mathrm{S}_{(\mathrm{s})}$ etc.)
Halogens and gases, that are not noble gases, are written as dimers (in two's).
(Halogens: $\mathrm{F}_{2(\mathrm{~g})}, \mathrm{Cl}_{2(\mathrm{~g})}, \mathrm{Br}_{2(\mathrm{l})}, \mathrm{I}_{2(\mathrm{~s})}$ Gases: $\mathrm{H}_{2(\mathrm{~g})}, \mathrm{N}_{2(\mathrm{~g})}, \mathrm{O}_{2(\mathrm{~g})}$ )
Noble gases have full orbital layers and are happy as loners: $\mathrm{He}_{(\mathrm{g})}, \mathrm{Ne}_{(\mathrm{g})}$ etc.
*End of Notes*

