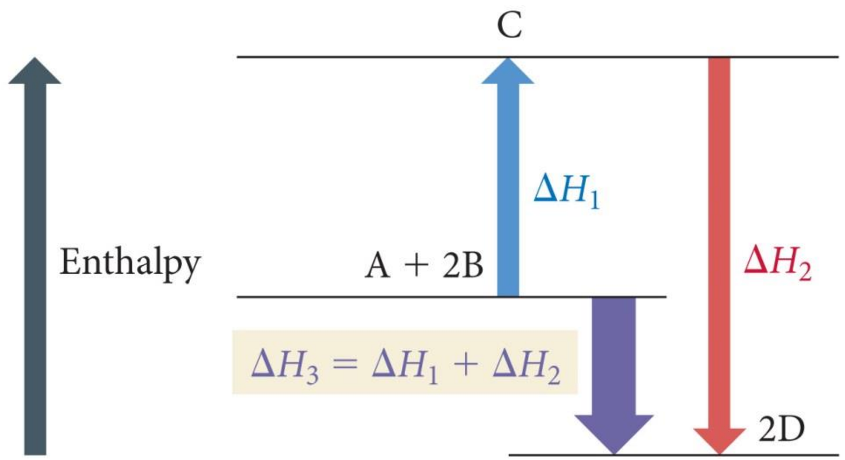
N3 - THERMOCHEMISTRY

Hess's Law

Hess's Law

"In going from a particular set of reactants to a particular set of products, the change in enthalpy is the same whether the reaction takes place in one step or a series of steps."

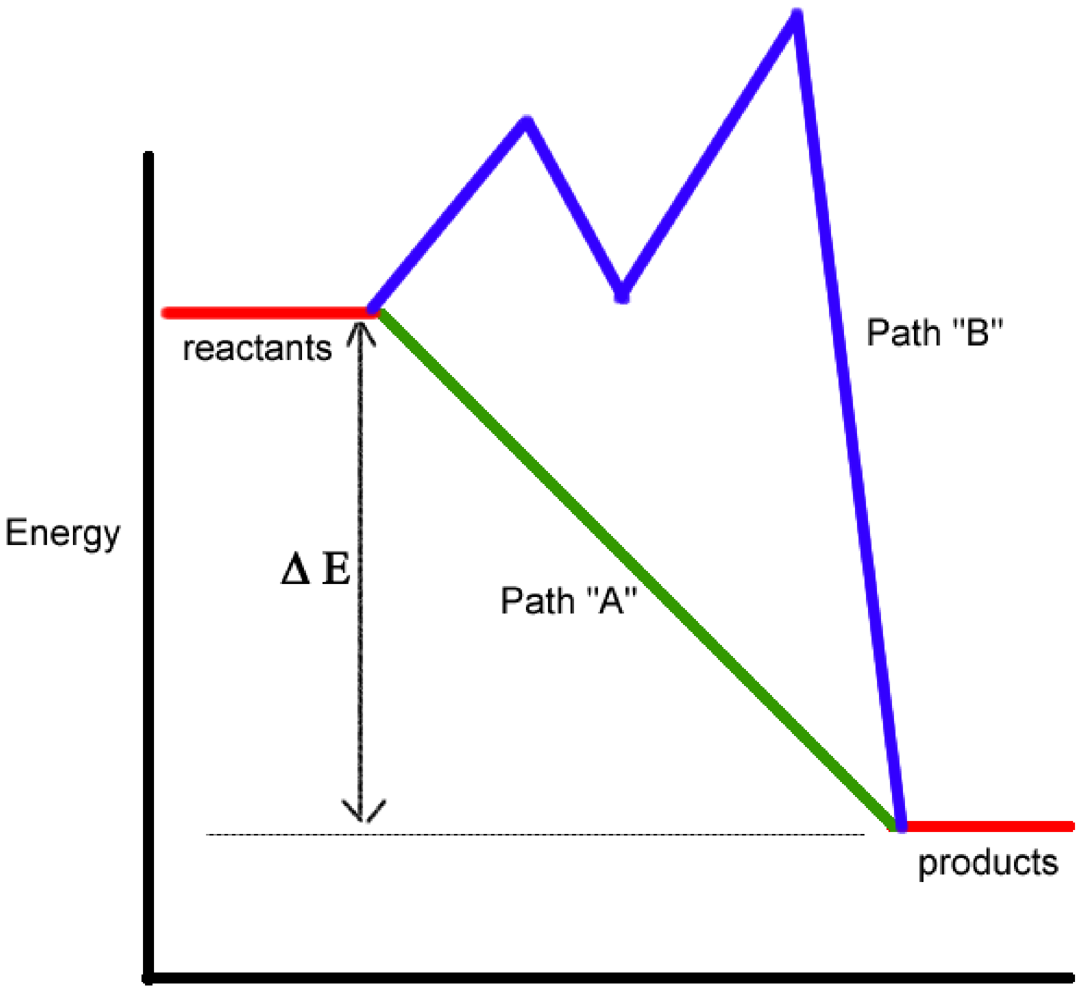
Hess's Law
The change in enthalpy for a stepwise process is the sum of the enthalpy changes of the steps.



Hess's Law

Path A – Mrs. Farmer cleaning the house.

Path B – Mr. Farmer cleaning the house.



Regardless of the path taken, you still get to the same place.

Although Path B drives Mrs. Farmer bonkers – Ha!

Relationships Involving ΔH_{rxn}

Multiplying Rxn by a # to Change Coefficients

ΔH_{rxn} is multiplied by that factor.

- Because ΔH_{rxn} is *extensive* – depends on the amount of substance

$C(s) + O_2(g) \rightarrow CO_2(g) \quad \Delta H = -393.5$ kJ

$2\ C(s) + 2\ O_2(g) \rightarrow 2\ CO_2(g) \quad \Delta H = 2 \times (-393.5$ kJ$) = -787.0$ kJ.

Reversing a rxn to flip which side the products/reactants are on

Flip the sign of ΔH, if positive now negative, if negative, now positive

$C(s) + O_2(g) \rightarrow CO_2(g) \quad \Delta H = -393.5$ kJ

$CO_2(g) \rightarrow C(s) + O_2(g) \quad \Delta H = -(-393.5) = +393.5$ kJ

Standard Conditions

Standard State

The state of a material at a defined set of conditions.

- Pure gas at 1 atm pressure
- Pure solid or liquid in its most stable form at 1 atm pressure and temperature of interest (usually 25°C)
- Substances in a solution with a 1M concentration

Standard Enthalpy Change

Standard Enthalpy Change

$\Delta H°$ - the Enthalpy change when all reactants and products are in their standard states.

That's what the ° symbol means – that it is under the standard conditions. You can have ΔH values that are not at standard conditions, then you leave the ° off.

Standard Enthalpy of Formation

Standard Enthalpy of Formation

$\Delta H°_f$ - the Enthalpy change for the reaction forming *1 mole* of a pure compound from its constituent elements.

- Elements must be in their standard states
- $\Delta H°_f$ for a pure element in its standard state = 0 kJ/mol

That includes diatomic gases! They are still pure elements!

Hess's Law Example Problem #1

Calculate ΔH for the combustion of methane, CH_4:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

#	Reaction	ΔH^o
1	$C + 2H_2 \rightarrow CH_4$	-74.80 kJ
2	$C + O_2 \rightarrow CO_2$	-393.50 kJ
3	$H_2 + ½ O_2 \rightarrow H_2O$	-285.83 kJ

Step #1:

CH_4 must appear on the reactant side, so we reverse reaction #1 and change the sign on ΔH.

- rxn 1 **$CH_4 \rightarrow C + 2H_2$** **+74.80 kJ**

Hess's Law Example Problem #1

Calculate ΔH for the combustion of methane, CH_4:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

#	Reaction	ΔHº
1	$C + 2H_2 \rightarrow CH_4$	-74.80 kJ
2	$C + O_2 \rightarrow CO_2$	-393.50 kJ
3	$H_2 + ½\, O_2 \rightarrow H_2O$	-285.83 kJ

Step #2:

Keep reaction #2 unchanged, because CO_2 belongs on the product side

- rxn 1	**$CH_4 \rightarrow C + 2H_2$**	**+74.80 kJ**
rxn 2	**$C + O_2 \rightarrow CO_2$**	**-393.50 kJ**

Hess's Law Example Problem #1

Calculate ΔH for the combustion of methane, CH_4:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

#	Reaction	ΔHº
1	$C + 2H_2 \rightarrow CH_4$	-74.80 kJ
2	$C + O_2 \rightarrow CO_2$	-393.50 kJ
3	$H_2 + ½ O_2 \rightarrow H_2O$	-285.83 kJ

Step #3:

Use reaction #3 to get water as a product, but multiply it by 2 since you have 2 H_2O

- rxn 1	$CH_4 \rightarrow C + 2H_2$	+74.80 kJ
rxn 2	$C + O_2 \rightarrow CO_2$	-393.50 kJ
2 x rxn 3	$2H_2 + O_2 \rightarrow 2H_2O$	2 x (-285.83 kJ)

Hess's Law Example Problem #1

Calculate ΔH for the combustion of methane, CH_4:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

#	Reaction	ΔHº
1	$C + 2H_2 \rightarrow CH_4$	-74.80 kJ
2	$C + O_2 \rightarrow CO_2$	-393.50 kJ
3	$H_2 + ½ O_2 \rightarrow H_2O$	-285.83 kJ

Step #4:

Cross out things that show up on both sides, then sum up your ΔH values

- rxn 1	$CH_4 \rightarrow \cancel{C} + \cancel{2H_2}$	**+74.80 kJ**
rxn 2	$\cancel{C} + O_2 \rightarrow CO_2$	**-393.50 kJ**
2 x rxn 3	$\cancel{2H_2} + O_2 \rightarrow 2H_2O$	**2 x (-285.83 kJ)**
	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	**-890.36 kJ**

Hess's Law Example Problem #2

$2\ NOCl\ (g) \rightarrow N_2\ (g) + O_2\ (g) + Cl_2\ (g) \quad \Delta H = \ ?$

Rxn #1) $\frac{1}{2}\ N_2\ (g) + \frac{1}{2}\ O_2\ (g) \rightarrow NO\ (g)$	$\Delta H =$	90.3 kJ
Rxn #2) $NO\ (g) + \frac{1}{2}\ Cl_2\ (g) \rightarrow NOCl\ (g)$	$\Delta H =$	–38.6 kJ

- A -51.7 kJ
- B 51.7 kJ
- C -103.4 kJ
- D 103.4 kJ
- E 142.0 kJ

Hess's Law Example Problem #2

$2\ NOCl\ (g) \rightarrow N_2\ (g) + O_2\ (g) + Cl_2\ (g)$ $\Delta H =$?

Rxn #1) $\frac{1}{2} N_2\ (g) + \frac{1}{2} O_2\ (g) \rightarrow NO\ (g)$	$\Delta H =$ 90.3 kJ
Rxn #2) $NO\ (g) + \frac{1}{2} Cl_2\ (g) \rightarrow NOCl\ (g)$	$\Delta H =$ –38.6 kJ

A -51.7 kJ

B 51.7 kJ

C **-103.4 kJ**

D 103.4 kJ

E 142.0 kJ

Rxn #	How to change it	Rxn	ΔH
2	- and x 2	$2\ NOCl \rightarrow \cancel{2NO} + Cl_2$	-2 (-38.6)
1	- and x 2	$\cancel{2NO} \rightarrow N_2 + O_2$	- (90.3)
		$2NOCl \rightarrow N_2 + O_2 + Cl_2$	-103.4 kJ

Hess's Law Example Problem #3

$FeO(s) + CO(g) \rightarrow Fe(s) + CO_2(g)$ **Calculate standard enthalpy change**

Rxn #1)	$3Fe_2O_3 + CO\ (g) \rightarrow 2Fe_3O_4 + CO_2\ (g)$	$\Delta H° = -47$ kJ
Rxn #2)	$Fe_2O_3 + 3CO\ (g) \rightarrow 2Fe\ (s) + 3CO_2\ (g)$	$\Delta H° = -25$ kJ
Rxn #3)	$Fe_3O_4 + CO\ (g) \rightarrow 3FeO\ (s) + CO_2\ (g)$	$\Delta H° = 19$ kJ

A. -53 kJ

B. -3 kJ

C. -41 kJ

D. 22 kJ

E. -11 kJ

Hess's Law Example Problem #3

$FeO(s) + CO(g) \rightarrow Fe(s) + CO_2(g)$ **Calculate standard enthalpy change**

Rxn #1) $3Fe_2O_3 + CO\ (g) \rightarrow 2Fe_3O_4 + CO_2\ (g)$ $\Delta H° = -47$ kJ
Rxn #2) $Fe_2O_3 + 3CO\ (g) \rightarrow 2Fe\ (s) + 3CO_2\ (g)$ $\Delta H° = -25$ kJ
Rxn #3) $Fe_3O_4 + CO\ (g) \rightarrow 3FeO\ (s) + CO_2\ (g)$ $\Delta H° = 19$ kJ

A -53 kJ

B -3 kJ

C -41 kJ

D 22 kJ

E **-11 kJ**

Rxn #	How to change it	Rxn	ΔH
3	- and x 1/3	$FeO + \cancel{{}^{1}/_{3}CO_2} \rightarrow {}^{1}/_{3}\cancel{Fe_3O_4} + \cancel{{}^{1}/_{3}CO}$	$-{}^{1}/_{3}\,(19)$
1	- and x 1/6	$\cancel{{}^{1}/_{3}Fe_3O_4} + \cancel{{}^{1}/_{6}CO_2} \rightarrow \cancel{{}^{1}/_{2}Fe_2O_3} + \cancel{{}^{1}/_{6}CO}$	$-{}^{1}/_{6}\,(-47)$
2	x 1/2	$\cancel{{}^{1}/_{2}Fe_2O_3} + \cancel{{}^{3}/_{2}CO} \rightarrow Fe + \cancel{{}^{3}/_{2}CO_2}$	${}^{1}/_{2}\,(-25)$
		$FeO + CO \rightarrow Fe + CO_2$	**-11 kJ**

Its just a puzzle!

Sometimes it’s a really hard puzzle…
but it’s still just a puzzle!

All the pieces are there,
you just have to figure out how to put them together…

Unfortunately no real “tricks” for how to figure out which parts to put together.