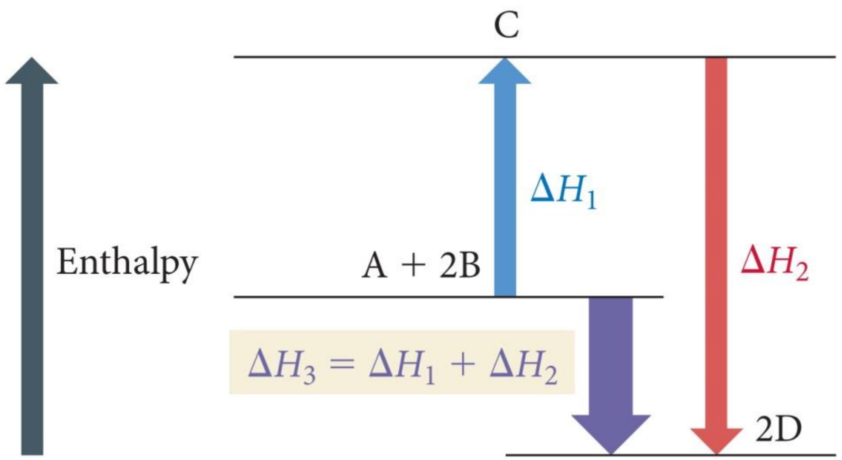
THERMOCHEMISTRY

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."

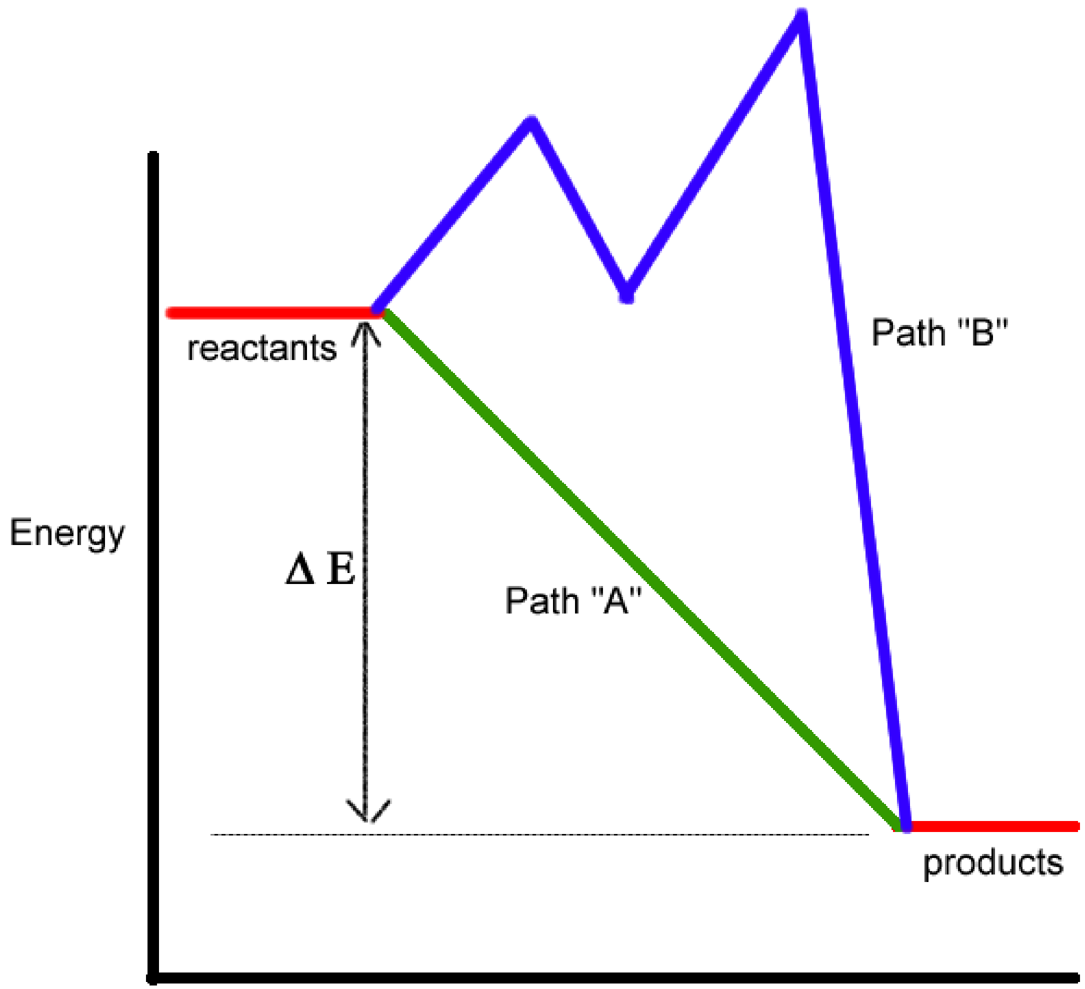
Hess's Law
The change in enthalpy for a stepwise process is the sum of the enthalpy changes of the steps.



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

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

$2\ C(s) + 2\ O_2(g) \rightarrow 2\ CO_2(g)$ $\Delta H = 2 \times (-393.5\text{ kJ}) = -787.0$ 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 posititve

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

$CO_2(g) \rightarrow C(s) + O_2(g)$ $\Delta H = -(-393.5) = +393.5$ 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**
  ΔH°_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
  - ΔH°_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	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 #1:

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

$CH_4 \rightarrow C + 2H_2$ +74.80 kJ

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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

$CH_4 \rightarrow C + 2H_2$ **+74.80 kJ**

$C + O_2 \rightarrow CO_2$ **-393.50 kJ**

Hess's Law Example Problem #1

Calculate ΔH for the combustion of methane, CH_4:

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Step #3:

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

$CH_4 \rightarrow C + 2H_2$ **+74.80 kJ**

$C + O_2 \rightarrow CO_2$ **-393.50 kJ**

$2H_2 + O_2 \rightarrow 2H_2O$ **2 x (-285.83 kJ)**

Hess's Law Example Problem #1

Calculate ΔH for the combustion of methane, CH_4:

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

$CH_4 \rightarrow \cancel{C} + \cancel{2H_2}$	+74.80 kJ
$\cancel{C} + O_2 \rightarrow CO_2$	-393.50 kJ
$\cancel{2H_2} + O_2 \rightarrow 2H_2O$	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) → N_2 (g) + O_2 (g) + Cl_2 (g) ΔH = ?

Rxn #1) ½ N_2 (g) + ½ O_2 (g) → NO (g)	ΔH =	90.3 kJ
Rxn #2) NO (g) + ½ Cl_2 (g) → NOCl (g)	ΔH =	–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*) ΔH = ?

Rxn #1) ½ N_2 (*g*) + ½ O_2 (*g*) $\rightarrow$ NO (*g*) ΔH = 90.3 kJ

Rxn #2) NO (*g*) + ½ Cl_2 (*g*) $\rightarrow$ NOCl (*g*) ΔH = –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 → ~~2NO~~ + Cl_2	-2 (-38.6)
1	- and x 2	~~2NO~~ → N_2 + O_2	- (90.3)
		2NOCl → 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	$FeO + {}^{1}/_{3}CO_2 \rightarrow {}^{1}/_{3}Fe_2O_4 + {}^{1}/_{3}CO$	$-{}^{1}/_{3}\ (19)$
1	- and x 1/6	${}^{1}/_{3}Fe_3O_4 + {}^{1}/_{6}CO_2 \rightarrow {}^{1}/_{2}Fe_2O_3 + {}^{1}/_{6}CO$	$-{}^{1}/_{6}\ (-47)$
2	x 1/2	${}^{1}/_{2}Fe_2O_3 + {}^{3}/_{2}CO \rightarrow Fe + {}^{3}/_{2}CO_2$	${}^{1}/_{2}\ (-25)$
		$FeO + CO \rightarrow Fe + CO_2$	**-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.