Relationships involving ΔH_{rxn}

1. If a chemical equation is multiplied by some factor, then ΔH_{rxn} is multiplied by the same factor

$A + 2B \rightarrow C \quad \Delta H_1$

$2A + 4B \rightarrow 2C \quad \Delta H_2 = 2 \cdot \Delta H_1$

2. If a chemical reaction is reversed, then ΔH_{rxn} changes sign

$A + 2B \rightarrow C \quad \Delta H_1$

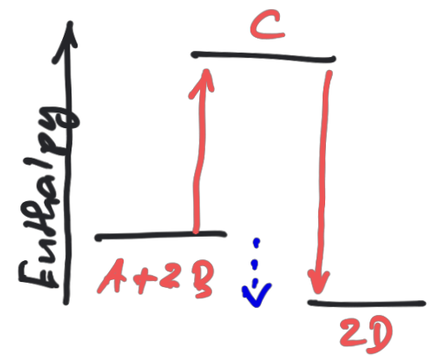
$C \rightarrow A + 2B \quad \Delta H_2 = -\Delta H_1$

3. If a chemical can be expressed as the sum of a series of steps, then ΔH_{rxn} for the overall is equation is the sum of the heats of reaction for each step (Hess Law)

$A + 2B \rightarrow \cancel{C} \quad \Delta H_1$

$\cancel{C} \rightarrow 2D \quad \Delta H_2$

$A + 2B \rightarrow 2D \quad \Delta H_3 = \Delta H_1 + \Delta H_2$



$$CO(g) + NO(g) \rightarrow CO_2(g) + \tfrac{1}{2}N_2 \quad \Delta H = ?$$

Given:

(A) $CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$ $\Delta H = -283.0\ kJ/mol$

(B) $N_2(g) + O_2(g) \rightarrow 2NO$ $\Delta H = 180.6\ kJ/mol$

- Equation A has the same amount of CO and CO_2 as in the target => leave a written
- Equation B has twice as much N_2 and NO as the target and they are on opposite sides => multiply with 1/2 and reverse

$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$ $\Delta H = -283\ kJ/mol$

$NO(g) \rightarrow \frac{1}{2}N_2(g) + \frac{1}{2}O_2$ $\Delta H = (-1)\cdot(\frac{1}{2})\cdot 180.6\ kJ/mol$
$= -90.3\ kJ/mol$

$CO(g) + NO(g) \rightarrow CO_2(g) + \frac{1}{2}N_2(g)$ $\Delta H_{rxn} = -373.3\ \frac{kJ}{mol}$

Standard States and Standard Enthalpy Changes

1. Standard State

   gas: pure gase @ 1 atm

   liquid / solid: pure substance in its most stable form at 1 atm and at the temp. of interest

   substance in solution: 1M

2. Standard Enthalpy: ΔH°

   The change of enthalpy for a process when all reactants and products are in their standard state

3. Standard Enthalpy of Formation ΔH_f°

   For a pure compound: The change in enthalpy when 1 mole of compound forms from its constituent elements in their standard states

   For a pure element in its standard state

   $\Delta H_f^\circ = 0$ kJ/mol

Example $MgCO_3$

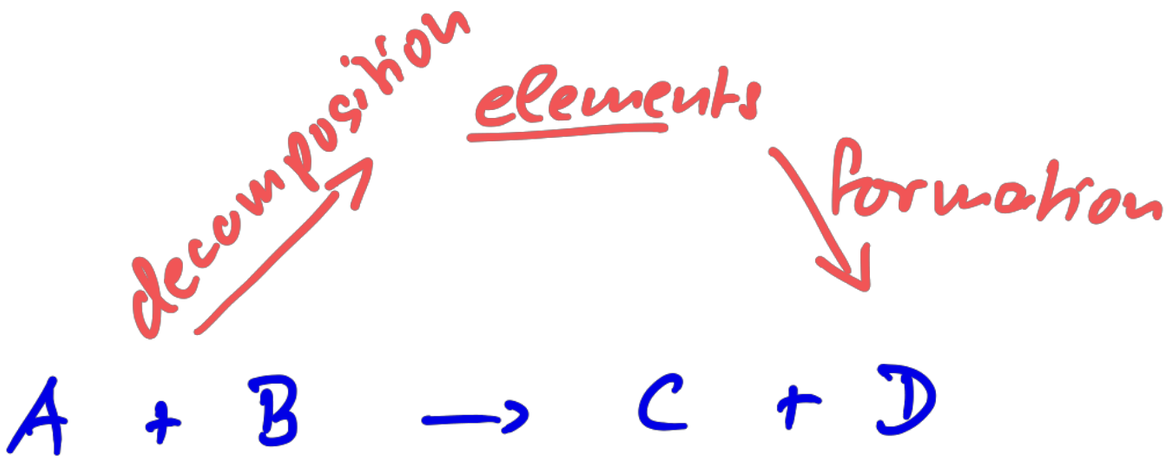
a). Write the equation with the elements in $MgCO_3$ in their standard states and 1 mole $MgCO_3$ as products

$$Mg(s) + C(s, \text{graphite}) + O_2(g) \rightarrow MgCO_3(s)$$

balance

$$Mg(s) + C(s, \text{graphite}) + \tfrac{3}{2} O_2(g) \rightarrow MgCO_3(s)$$

$\Delta H_f^\circ = -1095.8$ kJ/mole (table)



reactants → elements $\quad \Delta H_1 = -\Sigma \Delta H_f^\circ$

elements → products $\quad \Delta H_2 = +\Sigma \Delta H_f^\circ$

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reactants → products $\quad \Delta H_{rxn} = \Delta H_1 + \Delta H_2$

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$ $\quad \Delta H^\circ_{rxn} = ?$

$C(s,graphite) + 2H_2(g) + 2O_2(g)$

decomposition ↑ $\quad CH_4(g) + 2O_2(g)$

Formation of CO_2 ↓ $\quad CO_2(g) + 2H_2(g) + O_2(g)$

↓ $\quad CO_2(g) + 2H_2O(g)$

$C(s,graphite) + 2H_2(g) \rightarrow CH_4(g)$ $\quad \Delta H = -74.8\ kJ/mol$

reverse

$CH_4(g) \rightarrow C(s,graphite) + 2H_2(g)$ $\quad \Delta H = +74.8\ kJ/mol$!

Formation of $CO_2(g)$

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

Formation of $H_2O(g)$

$2 \cdot [H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g)]$ $\quad \Delta H = 2 \cdot \Delta H_f^\circ(H_2O(g))$

$= 2 \cdot -241.8\ kJ/mol$

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + H_2O(g)$ $\quad \Delta H_{rxn} = -802.5\ kJ/mol$

Standard enthalpies of formation at 25°C (kJ/mol) of compounds at 1 atm, aqueous ions at 1M

Compounds

$AgBr(s)$	-100.4	$CaCl_2(s)$	-795.8	$H_2O(g)$	-241.8	$NH_3(g)$	-46.1
$AgCl(s)$	-127.1	$CaCO_3(s)$	-1206.9	$H_2O(l)$	-285.8	$N_2H_4(l)$	50.6
$AgNO_3(s)$	-124.4	$CaO(s)$	-635.1	$H_2O_2(l)$	-187.8	$N_2H_3CH_3(l)$	+54
$Al_2O_3(s)$	-1675.7	$Ca(OH)_2(s)$	-986.1	$H_2S(g)$	-20.6	$NH_4Cl(s)$	-314.4
$BaCl_2(s)$	-858.6	$CaSO_4(s)$	-1434.1	$H_2SO_4(l)$	-814.0	$NO(g)$	+91.3
$BaCO_3(s)$	-1216.3	$CdCl_2(s)$	-391.5	$HgO(s)$	-90.8	$N_2O_4(g)$	+9.2
$BaSO_4(s)$	-1473.2	$Cr_2O_3(s)$	-1139.7	$KCl(s)$	-436.7	$N_2O(g)$	+81.6
$CCl_4(l)$	-135.4	$CuO(s)$	-157.3	$KClO_3(s)$	-397.7	$NO_2(g)$	+33.2
$CHCl_3(l)$	-134.5	$CuSO_4(s)$	-771.4	$KNO_3(s)$	-494.6	$N_2O_4(l)$	-20.
$CH_4(g)$	-74.8	$FeCl_2(s)$	-341.8	$MgCl_2(s)$	-641.3	$NiCl_2(s)$	-305.3
$C_2H_4(g)$	+52.4	$Fe_2O_3(s)$	-824.2	$MgCO_3(s)$	-1095.8	$NiO(s)$	-239.7
$C_2H_6(g)$	-84.7	$Fe_3O_4(s)$	-1118.4	$MgF_2(s)$	-1124.2	$PbBr_2(s)$	-278.7
$C_6H_6(l)$	+49.1	$Fe(OH)_3(s)$	-823.0	$MgO(s)$	-601.7	$PCl_3(g)$	-287.0
$CH_3OH(l)$	-238.7	$HBr(g)$	-36.4	$Mg(OH)_2(s)$	-924.5	$SiO_2(s)$	-910.9
$C_2H_5OH(l)$	-277.7	$HF(g)$	-273.3	$MgSO_4(s)$	-1284.9	$SiCl_4(l)$	-687
$C_3H_6O(l)$ acetone	-284.4	$HCl(g)$	-92.3	$Na_2O(s)$	-416	$SnO_2(s)$	-580.7
$C_6H_{12}O_6(s)$ glucose	-1273.3	$HI(g)$	+26.5	$NaCl(s)$	-411.2	$SO_3(g)$	-395.7
$CO(g)$	-110.5	$HNO_3(l)$	-174.1	$NaHCO3(s)$	-950.8	$ZnO(s)$	-348.3
$CO_2(g)$	-393.5	$H_3PO_4(s)$	-1284.4	$NaOH(s)$	-425.6	$ZnS(s)$	-206.0

Cations				**Anions**			
$Ag^+(aq)$	+105.6	$K^+(aq)$	-252.4	$Br^-(aq)$	-121.6	$H_2PO_4^-(aq)$	-1296.3
$Al^{3+}(aq)$	-531.0	$Mg^{2+}(aq)$	-466.8	$CO_3^{2-}(aq)$	-677.1	$I^-(aq)$	-55.2
$Ba^{2+}(aq)$	-537.6	$Mn^{2+}(aq)$	-220.8	$Cl^-(aq)$	-167.2	$MnO_4^-(aq)$	-541.4
$Ca^{2+}(aq)$	-542.8	$Na^+(aq)$	-240.1	$ClO_3^-(aq)$	-104.0	$NO_2^-(aq)$	-104.6
$Cu^+(aq)$	+71.7	$NH_4^+(aq)$	-132.5	$ClO_4^-(aq)$	-129.3	$NO_3^-(aq)$	-205.0
$Cu^{2+}(aq)$	+64.8	$Ni^{2+}(aq)$	-54.0	$CrO_4^{2-}(aq)$	-881.2	$OH^-(aq)$	-230.0
$Fe^{2+}(aq)$	-89.1	$Pb^{2+}(aq)$	-1.7	$Cr_2O_7^{2-}(aq)$	-1490.3	$PO_4^{3-}(aq)$	-1277.4
$Fe^{3+}(aq)$	-48.5	$Sn^{2+}(aq)$	-8.8	$F^-(aq)$	-332.6	$S^{2-}(aq)$	+33.1
$H^+(aq)$	0.0	$Zn^{2+}(aq)$	-153.9	$HCO_3^-(aq)$	-692.0	$SO_4^{2-}(aq)$	-909.3