Hess's Law

- Instead of conducting a calorimetry experiment, alternative methods have been created to *calculate* the enthalpy change of a reaction
- Hess's Law is a way to calculate the enthalpy change of a chemical reaction by adding all the individual enthalpy changes of individual reactions together to get a desired net reaction
  - Hess's law is based off the idea that the same reactants can have different and multiple pathways to get to the same end products

the sum of all rxns

- To determine an enthalpy change of a desired reaction using Hess's Law, follow these steps:

  Step 1: Determine or create the desired net reaction

  Step 2: Manipulate the given/intermediate reactions so they add up to yield the net reaction
    - Ensure the chemicals found in the intermediate reactions are on the same side of the reaction as the chemicals found in the net/desired equation. This may require intermediate chemical reactions to be reversed (ie. flipped), which will reverse the ΔH sign.
    - Ensure that the moles of the chemicals in the intermediate reactions match the moles of the chemicals in the net/desired reaction. This may require the intermediate reactions to be altered by a constant factor (ie. multiply or divide by a factor), which will cause the ΔH to be altered by the same factor

  Step 3: Subtract/add the remaining reactants and products to yield the net equation
    - Chemicals on the same side of the reaction arrow add up
    - Chemicals on opposite sides of the reaction arrow subtract/cancel out

- * Usually use Hess's Law when a list of intermediate reactions are listed and you are trying to find the enthalpy change for a desired net reaction

EXAMPLES:

1. One of the methods that the steel industry uses to obtain metallic iron is to react iron (III) oxide, $Fe_2O_3(s)$, with carbon monoxide, $CO(g)$, as shown in the balanced equation below:

$$Fe_2O_{3(s)} + 3CO_{(g)} \rightarrow 3CO_{2(g)} + 2Fe_{(s)} \qquad \Delta H = ?$$

Determine the enthalpy change of this reaction, given the following equations and their enthalpy changes.

$$CO_{(g)} + \tfrac{1}{2} O_{2(g)} \rightarrow CO_{2(g)} \qquad \Delta H = -283.0 \text{ kJ}$$
$$4Fe_{(s)} + 3O_{2(g)} \rightarrow 2Fe_2O_{3(s)} \qquad \Delta H = -1648.4 \text{ kJ}$$

(x3) $3CO_{(g)} + \tfrac{3}{2}O_{2(g)} \rightarrow 3CO_{2(g)}$ $\Delta H = -283.0 \text{ kJ}$ (x3)

* 3/2 − 3/2 = 0

(÷2) $2Fe_2O_{3(s)} \rightarrow 4Fe_{(s)} + 3O_{2(g)}$ (÷2: 1, 2, 3/2) $\Delta H = \frac{+1648.4 \text{ kJ}}{2}$

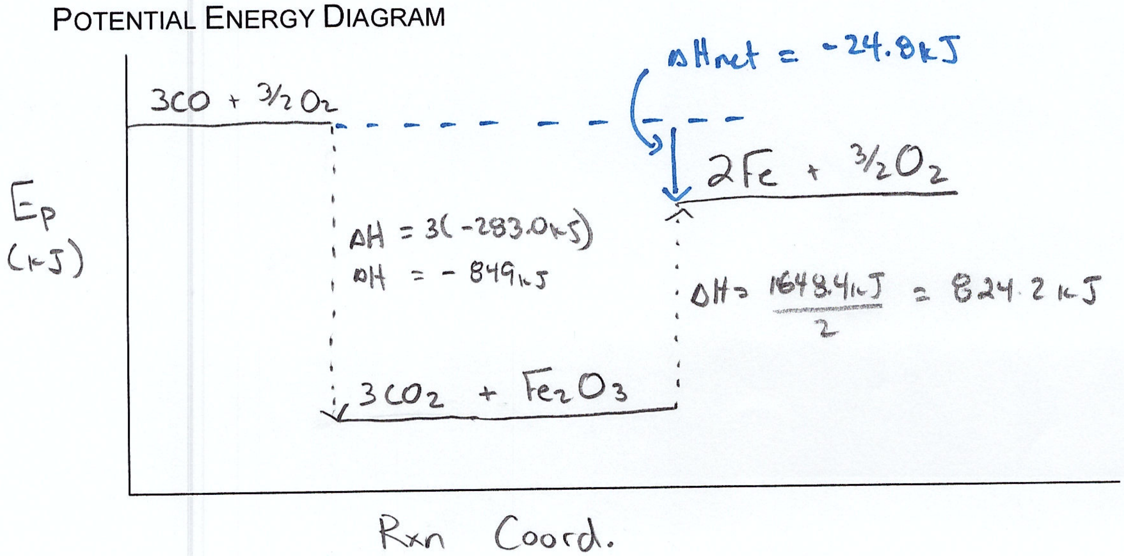
net: $Fe_2O_{3(s)} + 3CO_{(g)} \rightarrow 3CO_{2(g)} + 2Fe_{(s)}$ $\Delta H = ?$

$$\Delta H = (-283.0)(3) + \frac{(1648.4 \text{ kJ})}{2}$$

$$\boxed{\Delta H = -24.8 \text{ kJ}}$$

* O_2 subtract to zero ∴ don't appear in net rxn.

POTENTIAL ENERGY DIAGRAM



need to creat net rxn!

2. From the following information, calculate the enthalpy of formation of solid phosphorus pentachloride.

$P_{4(s)} + 6Cl_{2(g)} \rightarrow 4PCl_{3(l)}$ $\Delta H = -1272$ kJ

$PCl_{3(l)} + Cl_{2(g)} \rightarrow PCl_{5(s)}$ $\Delta H = -125$ kJ

6+4=10 $Cl_{2(g)}$ on reactanct side

$P_{4(s)} + 6Cl_{2(g)} \rightarrow 4PCl_{3(l)}$ $\Delta H = -1272$ kJ

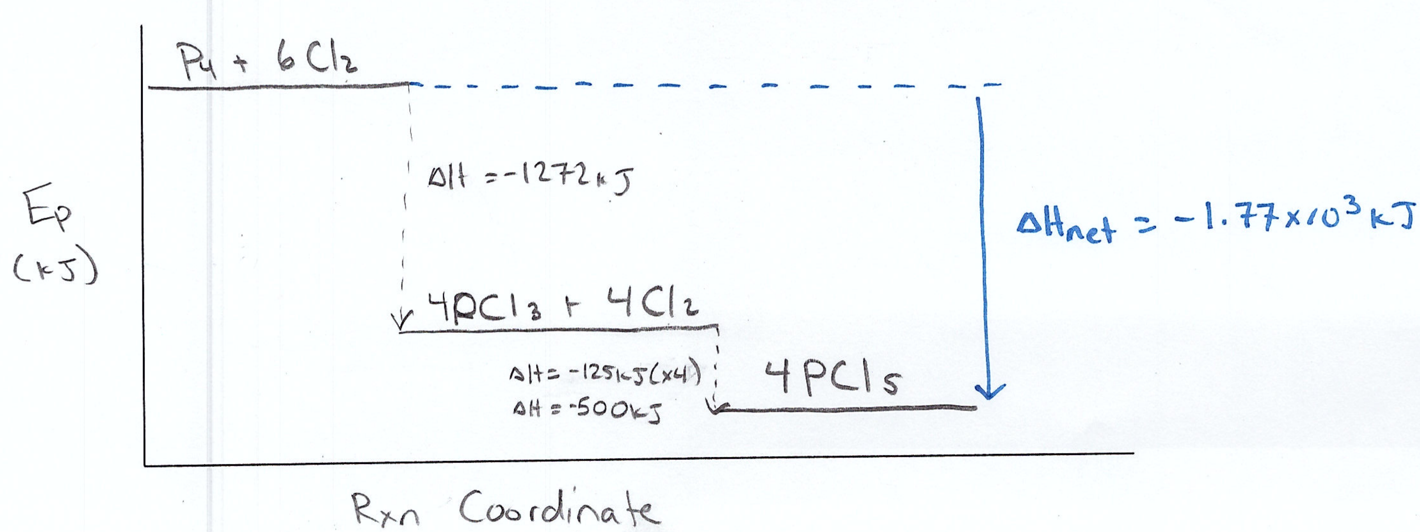
(x4) $4PCl_{3(l)} + 4Cl_{2(g)} \rightarrow 4PCl_{5(s)}$ $\Delta H = -125$ kJ (x4)

net: $P_{4(s)} + 10Cl_{2(g)} \rightarrow 4PCl_{5(s)}$ $\Delta H = ?$

$\Delta H = (-1272\text{ kJ}) + (-125\text{ kJ})(4)$

$\Delta H = -1.77 \times 10^3$ kJ or -1.77 MJ

POTENTIAL ENERGY DIAGRAM



3. Several reactions are listed below.

$C_2H_{2(g)} + 2\ H_{2(g)} \rightarrow C_2H_{6(g)}$ $\Delta H° = -94.5$ kJ

$2\ H_2O_{(g)} \rightarrow 2\ H_{2(g)} + O_{2\ (g)}$ $\Delta H° = 71.2$ kJ

$2\ C_2H_{6(g)} + 7\ O_{2(g)} \rightarrow 4\ CO_{2(g)} + 6H_2O_{(g)}$ $\Delta H° = -283$ kJ

Use the information above to calculate the standard enthalpy change for the following reaction:

$$4\ CO_{2(g)} + 2\ H_2O_{(g)} \rightarrow 2\ C_2H_{2(g)} + 5\ O_{2(g)}$$

(x2) ~~2~~ 4 ~~$H_{2(g)}$~~ + $2O_{2(g)}$ → ~~2~~ 4 $H_2O_{(g)}$ $\Delta H = -71.2$ kJ (x2)

$4CO_{2(g)} + 6H_2O_{(g)} \rightarrow 2\ C_2H_{6(g)} + 7O_{2(g)}$ $\Delta H = +283$ kJ

(x2) $2\ C_2H_{6(g)} \rightarrow 2C_2H_{2(g)}$ + ~~2~~ 4 ~~$H_{2(g)}$~~ $\Delta H = +94.5$ kJ (x2)

net: $4CO_{2(g)} + 2H_2O_{(g)} \rightarrow 2C_2H_{2(g)} + 5O_{2(g)}$ $\Delta H = ?$

* 6-4=2 H_2O on reactant side

* 7-2=5 O_2 on product side

$\Delta H = (-71.2\text{ kJ})(2) + (283\text{ kJ}) + (94.5\text{ kJ})(2)$

$\Delta H = 329.6$ kJ

$\boxed{\Delta H = 330\text{ kJ}}$

*****Now try pg. 374 #2, 4-6 & Practice Problems*****

Practice Problems

1. Use the following reactions and enthalpy changes to calculate the standard molar enthalpy change for $NO_{2(g)}$ when involved in the reaction $2NO_2(g) + 2H_2O(g) \rightarrow 3O_2(g) + N_2H_4(g)$.

$N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)$ $\Delta H° = +66.4$ kJ

$H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(g)$ $\Delta H° = -241.8$ kJ

$N_2(g) + 2H_2(g) \rightarrow N_2H_4(g)$ $\Delta H° = +47.6$ kJ

2. Use the following reactions to calculate the amount of energy (in MJ) required to produce 200g of hydrogen gas when produced in the reaction $CH_{4(g)} + NH_{3(g)} \longrightarrow HCN_{(g)} + 3H_{2(g)}$.

$N_{2\,(g)} + 3H_{2\,(g)} \longrightarrow 2NH_{3\,(g)}$ $\Delta H = -91.8$ kJ

$C_{(s)} + 2H_{2\,(g)} \longrightarrow CH_{4\,(g)}$ $\Delta H = -74.9$ kJ

$H_{2\,(g)} + 2C_{(s)} + N_{2\,(g)} \longrightarrow 2HCN_{(g)}$ $\Delta H = +270.3$ kJ

3. Find the mass of $N_2H_{4(l)}$ consumed when 950kJ of energy is released from the reaction $N_2H_4(l) + CH_4O(l) \rightarrow CH_2O(g) + N_2(g) + 3H_2(g)$, given the following information:

$2NH_3(g) \rightarrow N_2H_4(l) + H_2(g)$ $\Delta H = +22.5$ kJ

$2NH_3(g) \rightarrow N_2(g) + 3H_2(g)$ $\Delta H = +57.5$ kJ

$CH_2O(g) + H_2(g) \rightarrow CH_4O(l)$ $\Delta H = +81.2$ kJ

Answers

1. +232.4 kJ/mol
2. +8.45 MJ
3. 659 g

Hess's Law Review

1. Use the following reactions to calculate the standard molar enthalpy change for the complete combustion of cycloheptane (C_7H_{14}) in a closed system.

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$	$\Delta H° = -393.5$ kJ
$H_{2(g)} + \frac{1}{2} O_{2(g)} \rightarrow H_2O_{(g)}$	$\Delta H° = -241.8$ kJ
$7C_{(s)} + 7H_{2(g)} \rightarrow C_7H_{14(l)}$	$\Delta H° = +115.0$ kJ
$H_2O_{(l)} \rightarrow H_2O_{(g)}$	$\Delta H° = +40.7$ kJ

(x14) $14H_{2(g)} + 7O_{2(g)} \rightarrow 14H_2O_{(g)}$ $\Delta H = -241.8$ kJ (x14)

(x14) $14H_2O_{(g)} \rightarrow 14H_2O_{(l)}$ $\Delta H = -40.7$ kJ (x14)

(x14) $14C_{(s)} + 14O_{2(g)} \rightarrow 14CO_{2(g)}$ $\Delta H = -393.5$ kJ (x14)

(x2) $2C_7H_{14(l)} \rightarrow 14C_{(s)} + 14H_{2(g)}$ $\Delta H = -115.0$ kJ (x2)

net: $2C_7H_{14(l)} + 21O_{2(g)} \rightarrow 14H_2O_{(l)} + 14CO_{2(g)}$ $\Delta H = ?$

* $14 + 7 = 21\ O_2$

$\Delta H = (-241.8\text{ kJ})(14) + (-40.7\text{ kJ})(14) + (-393.5\text{ kJ})(14) + (-115.0\text{ kJ})(2)$

$\Delta H = -9694$ kJ

$\therefore \Delta_r H = \frac{\Delta H}{n} = \frac{-9694\text{ kJ}}{2\text{ mol}} = -4847$ kJ/mol

$\Delta_r H = -4847.0$ kJ/mol