Do now:

Write equations for the following expressions:

$\Delta_f H^\circ (NH_3(g)) = -46 \text{ kJ mol}^{-1}$

$\Delta_f H^\circ (HCl(g)) = -92 \text{ kJ mol}^{-1}$

$\Delta_f H^\circ (NH_4Cl(s)) = -314 \text{ kJ mol}^{-1}$

$\frac{1}{2} N_{2(g)} + 1\frac{1}{2} H_{2(g)} \rightarrow NH_{3(g)}$ **$\Delta_f H^\circ(NH_{3(g)}) = -46 \text{ kJ.mol}^{-1}$**

$\frac{1}{2} H_{2(g)} + \frac{1}{2} Cl_{2(g)} \rightarrow HCl_{(g)}$ **$\Delta_f H^\circ(HCl_{(g)}) = -92 \text{ kJ.mol}^{-1}$**

$\frac{1}{2} N_{2(g)} + 2 H_{2(g)} + \frac{1}{2} Cl_{2(g)} \rightarrow NH_4Cl_{(s)}$ **$\Delta_f H^\circ(NH_4Cl_{(s)}) = -314 \text{ kJ.mol}^{-1}$**

Hess's Law

We use Hess's Law to work out an unknown enthalpy of reaction.

We do this by using other reactions where we do know the enthalpy change to work out the unknown enthalpy change.

For example: 2014 Exam Q2 c

(c) An equation for the reaction of ammonia gas with hydrogen chloride gas is:

$NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$ **unknown enthalpy, $\Delta_r H°$**

Calculate the standard enthalpy change, $\Delta_r H°$, for this reaction, using the following data.

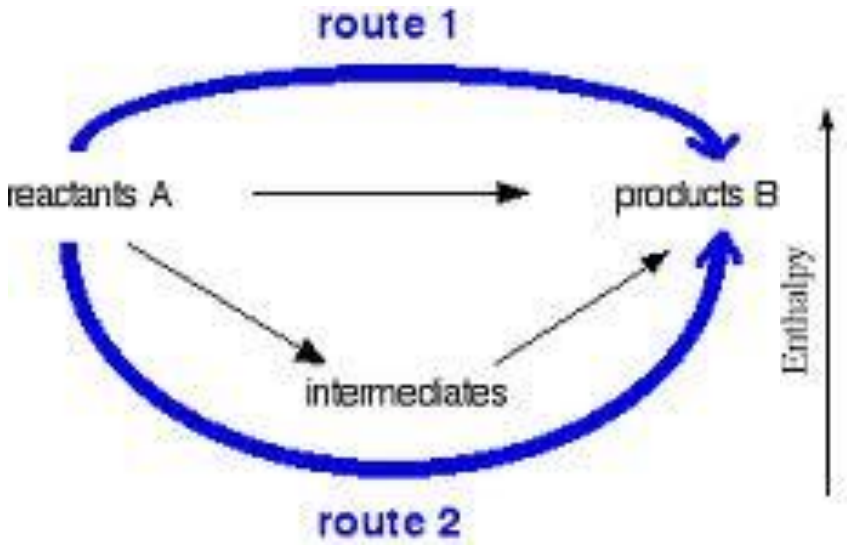
$\Delta_f H°\ (NH_3(g))$	=	–46 kJ mol^{-1}
$\Delta_f H°\ (HCl(g))$	=	–92 kJ mol^{-1}
$\Delta_f H°\ (NH_4Cl(s))$	=	–314 kJ mol^{-1}

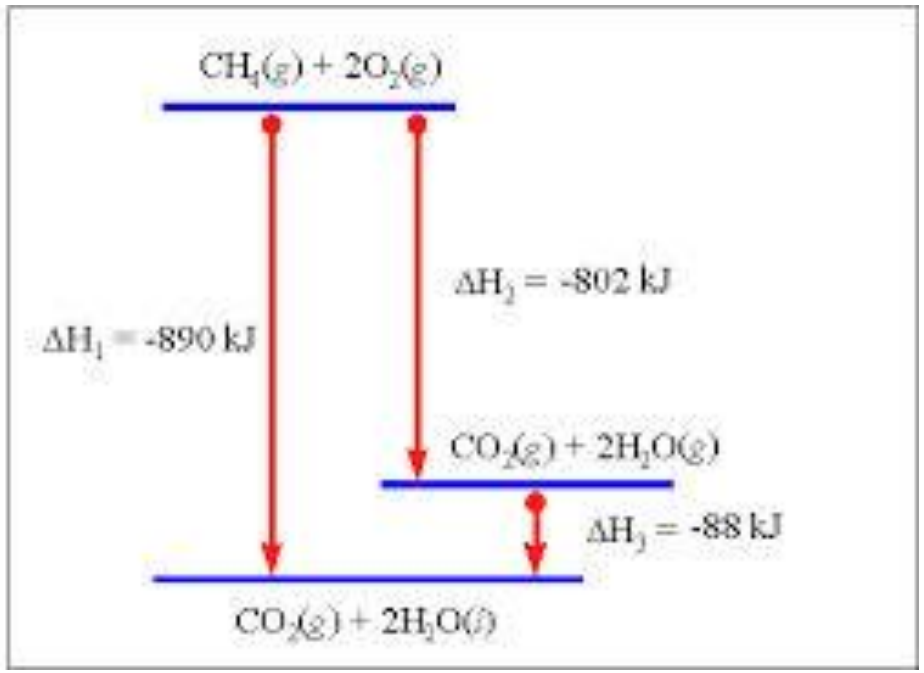
known enthalpys, $\Delta_r H°$

Hess's Law

'The enthalpy change for a reaction is independent of the way in which a reaction proceeds and depends only on the initial conditions of the reactants and the final conditions of products'

'The enthalpy change for a reaction is independent of the route taken'





Hess's Law example

Calculate the heat of formation of $CS_{2(l)}$ given that the heats of combustion of carbon, sulfur and carbon disulfide are -393, -297 and -1007 $kJ.mol^{-1}$ respectively

Step 1:
Write down the reaction for enthalpy you are trying to find

$C_{(s)} + 2\ S_{(s)} \rightarrow CS_2(l)$ **$\Delta_f H° = ?$**

Step 2:
Write down the reactions for enthalpy's you know

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ **$\Delta_c H° = -393\ kJ.mol^{-1}$**
$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$ **$\Delta_c H° = -297\ kJ.mol^{-1}$**
$CS_{2(l)} + 3\ O_{2(g)} \rightarrow CO_{2(g)} + 2\ SO_{2(g)}$ **$\Delta_c H° = -1007\ kJ.mol^{-1}$**

Hess's Law example

Step 3:

Rearrange the equations so that the products and reactants and correct amounts match the desired equation

$C_{(s)} + 2\ S_{(s)} \rightarrow CS_2(l)$ $\quad \Delta_f H° = ?$

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ $\quad \Delta_c H° = -393\ kJ.mol^{-1}$

$2\ S_{(s)} + 2\ O_{2(g)} \rightarrow 2\ SO_{2(g)}$ $\quad \Delta_c H° = -594\ kJ.mol^{-1}$

$CO_{2(g)} + 2\ SO_{2(g)} \rightarrow CS_{2(l)} + 3\ O_{2(g)}$ $\quad \Delta_c H° = +1007\ kJ.mol^{-1}$

Step 4:

Cancel

Step 5:

Calculate the desired enthalpy

-393 + -594 + 1007 =
+20 kJ.mol^{-1}

Another example

From the following equations and ΔH values

$H_{2(g)} + Br_{2(g)} \rightarrow 2\ HBr_{(g)}$ $\Delta_r H° = -72.8\ kJ.mol^{-1}$

$2\ H_2 + O_{2(g)+} \rightarrow 2\ H_2O_{(g)}$ $\Delta_r H° = -483.7\ kJ.mol^{-1}$

Calculate $\Delta_r H°$ for the following reaction:

$4\ HBr_{(g)} + O_{2(g)} \rightarrow 2\ Br_{2(l)} + 2\ H_2O_{(g)}$

Step 1:

Write down the reaction for enthalpy you are trying to find

Step 2:

Write down the reactions for enthalpy's you know

Step 3:

Rearrange the equations so that the products and reactants and correct amounts match the desired equation

Step 4: Cancel

Step 5: Calculate the desired enthalpy

Do now:

Write equations for the following expressions

Compound	kJ mol^{-1}
$\Delta_c H°$ (C(s))	–394
$\Delta_f H°$ ($H_2O(\ell)$)	–286
$\Delta_c H°$ ($C_2H_5OH(\ell)$)	–1367

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ $\Delta_c H°(C_{(s)}) = -394\ kJ.mol^{-1}$

$H_{2(g)} + ½\ O_{2(g)} \rightarrow H_2O_{(l)}$ $\Delta_f H°(H_2O_{(l)}) = -286\ kJ.mol^{-1}$

$C_2H_5OH_{(l)} + 3\ ½\ O_{2(g)} \rightarrow 2\ CO_{2(g)} + 3\ H_2O_{(l)}$

$\Delta_c H°(C_2H_5OH_{(s)}) = -394\ kJ.mol^{-1}$

Hess's Law

This is from the 2014 Exam Q3 d.

(d) (i)

Compound	kJ mol^{-1}
$\Delta_c H°$ (C(s))	–394
$\Delta_f H°$ ($H_2O(\ell)$)	–286
$\Delta_c H°$ ($C_2H_5OH(\ell)$)	–1367

$$3H_2O + 2CO_2 \rightarrow C_2H_5OH + 3O_2 \quad +1367$$
$$2C + 2O_2 \rightarrow 2CO_2 \quad -394 \times 2 \ (788)$$
$$3H_2 + 1½O_2 \rightarrow 3H_2O \quad -286 \times 3 \ (858)$$
$$½\ O_2 + 2C + 3H_2 \rightarrow C_2H_5OH \quad -279 \text{ kJ mol}^{-1}$$

Calculate the standard enthalpy of formation of liquid ethanol using the information given above.

$2\ C_{(s)} + 3\ H_{2(g)} + ½\ O_{2(g)} \rightarrow C_2H_5OH_{(l)}$ $\quad \Delta_f H°(C_2H_5OH_{(l)}) = ?$

Achieved	Merit	Excellence
• Uses a recognised process but errors made in the calculations.	• Correct process leading to an incorrect answer.	• Correct process leading to the correct answer with units.

Your turn

Calculate the heat of reaction for the water gas reaction:

$C_{(s)} + H_2O_{(g)} \rightarrow CO_{(g)} + H_{2(g)}$ $\Delta_r H° = ?$

$\Delta_f H°(CO_{2(g)}) = -394\ kJ.mol^{-1}$

$\Delta_f H°(H_2O_{(g)}) = -242\ kJ.mol^{-1}$

$\Delta_c H°(CO_{(g)}) = -282\ kJ.mol^{-1}$

Workbook pg 63, 64 Q1, Q2 and Q3

Q2: combustion equation: $B_2H_{6(g)} + 3\ O_{2(g)} \rightarrow B_2O_{3(s)} + 3\ H_2O_{(l)}$

Quick recap

Calculate the heat of reaction for the esterification of ethanol with ethanoic acid:

$CH_3COOH_{(l)} + C_2H_5OH_{(l)} \rightarrow CH_3COOC_2H_{5(l)} + H_2O_{(l)}$ $\Delta_rH° = ?$

$\Delta_fH°(CH_3COOH) = -487\ kJ.mol^{-1}$,
$\Delta_fH°(C_2H_5OH) = -278\ kJ.mol^{-1}$,
$\Delta_fH°(CH_3COOC_2H_5) = -481\ kJ.mol^{-1}$,
$\Delta_fH°(H_2O) = -286\ kJ.mol^{-1}$

$\Delta_rH = -2\ kJ.mol^{-1}$

It gets easier…

If $\Delta_f H°$ is given for all products and reactants we can use the following equation to calculate $\Delta_r H$.

$\Delta_r H = \Sigma \Delta_f H°_{(products)} - \Sigma \Delta_f H°_{(reactants)}$

Remember that $\Delta_f H°$ of an element is 0 $kJ.mol^{-1}$.

For example:

Calculate the enthalpy of the following reaction

$4\ NH_{3(g)} + 5\ O_{2(g)} \rightarrow 6\ H_2O_{(g)} + 4\ NO_{(g)}$

$\Delta_f H°(NH_{3(g)}) = -46.11\ kJ.mol^{-1}$, $\Delta_f H°(NO_{(g)}) = 90.25\ kJ.mol^{-1}$,

$\Delta_f H°(H_2O_{(g)}) = -241.8\ kJ.mol^{-1}$

$\Delta_r H = \Sigma \Delta_f H°_{(products)} - \Sigma \Delta_f H°_{(reactants)}$

$\Delta_r H = (6 \times -241.8 + 4 \times 90.25) – (4 \times -46.11 + 5 \times 0)$

$\Delta_r H = (-1450.8 + 361) – (-184.44)$

$\Delta_r H = -1089.8 + 184.44 \qquad = -905.36\ kJ.mol^{-1}$

$\Delta_r H = \Sigma \Delta_f H°_{(products)} - \Sigma \Delta_f H°_{(reactants)}$

Your turn

Calculate the enthalpy of the following reaction :

$CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$

$\Delta_f H°(CaO) = -635.5\ kJ.mol^{-1}$, $\Delta_f H°(CO_2) = -393\ kJ.mol^{-1}$,
$\Delta_f H°(CaCO_3) = -1207\ kJ.mol^{-1}$

Find $\Delta_f H°(NaHCO_3)$ given the following data:

$2\ NaHCO_{3(s)} \rightarrow Na_2CO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$ $\quad \Delta_r H° = 129\ kJ.mol^{-1}$

$\Delta_f H°(Na_2CO_3) = -1131\ kJ.mol^{-1}$, $\Delta_f H°(CO_2) = -393\ kJ.mol^{-1}$,
$\Delta_f H°(H_2O) = -242\ kJ.mol^{-1}$

Your turn

Calculate $\Delta_f H°(C_3H_8)$ given the following information

$\Delta_c H°(CO_2) = -393\ kJ.mol^{-1}$,
$\Delta_c H°(H_2) = -286\ kJ.mol^{-1}$,
$\Delta_c H°(C_3H_8) = -2200\ kJ.mol^{-1}$

Find $\Delta_r H°$ for the hydrogenation of ethyne to ethene

$C_2H_{2(g)} + H_{2(g)} \rightarrow C_2H_{4(g)}$

$\Delta_c H°(C_2H_2) = -1301\ kJ.mol^{-1}$, $\Delta_c H°(C_2H_4) = -1411\ kJ.mol^{-1}$,
$\Delta_f H°(H_2O) = -286\ kJ.mol^{-1}$

2014 Exam Q2 c

(c) An equation for the reaction of ammonia gas with hydrogen chloride gas is:

$$NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$$

Calculate the standard enthalpy change, $\Delta_r H°$, for this reaction, using the following data.

$\Delta_f H°\ (NH_3(g)) = -46\ kJ\ mol^{-1}$
$\Delta_f H°\ (HCl(g)) = -92\ kJ\ mol^{-1}$
$\Delta_f H°\ (NH_4Cl(s)) = -314\ kJ\ mol^{-1}$