Answer Scheme

Concept of Enthalpy

1 Hydrogen gas burns in air to form water:

$$2\,H_2\,(g) \;+\; O_2\,(g) \;\rightarrow\; 2\,H_2O\,(l) \quad \Delta H = -\,572\ kJ$$
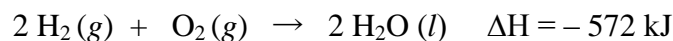
How much heat is given off if 10.0 kg of hydrogen gas is burnt in excess oxygen?

Based on the thermochemical equation; 2 moles of H_2 released 572 kJ
∴ If 10.0 kg of H_2 released ? kJ

no of mole of H_2 = 10,000 g / 2.0 g mol^{-1} = 5000 mol

2 moles of H_2 released 572 kJ
5000 mol of H_2 released = 5000 x 572 / 2 = 1.43 x 10^6 kJ

∴ Heat given off by 10.0 kg of H_2 = − 1.43 x 10^6 kJ

2 Ammonium nitrate, NH_4NO_3 decomposes by the following reaction:

$$2\,NH_4NO_3\,(g) \;\rightarrow\; 2\,N_2O\,(g) \;+\; 4\,H_2O\,(g) \qquad \Delta H^o = -\,74.8\ kJ$$

If 74.0 g of H_2O are formed from the reaction, how much heat was released?

Note: 4 mol of H_2O not 2 mol of H_2O

Based on the thermochemical equation; 4 moles of H2O released 74.8 kJ
∴ If 74.0 g of H_2O released ? kJ

no of mole of H_2O = 74.0 g / 18.0 g mol^{-1} = 4.111 mol

4 moles of H_2O released 74.8 kJ
4.111 mol released = 4.111 x 74.8 / 4 = 76.9 kJ

∴ Heat released by 74.0 g of H_2O = − 76.9 kJ

Calorimetry

1 When 18.70 g sodium chloride was dissolved in 400 cm^3 distilled water, the temperature
of the solution decreased by 1.0 °C.
[*Specific heat capacity of solution = 4.20 $Jg^{-1}\,°K^{-1}$, density of solution = 1.0 g cm^{-3}*]

   a) Calculate the heat of solution of sodium chloride.

$Q_{soln} = m_s c_s \Delta T$
= 400 g x 4.20 $Jg^{-1}\,°K^{-1}$ x 1.0 K
= 1680 J
= 1.68 kJ

∴ $Q_{soln\ of\ NaCl}$ = + 1.68 kJ

b) Determine the enthalpy of solution of sodium chloride.

Number of mole of NaCl $= 18.70$ g $/ 58.5$ g mol^{-1} $= 0.3197$ mol

Enthalpy of solution per mole of NaCl $= 4.60$ x 10^2 kJ $/ 0.3197$ mol
$= 1.44$ x 10^3 kJ mol^{-1}

∴ $\Delta H_{soln\ of\ NaCl} = + 1.44$ x 10^3 kJ mol^{-1}

2   A sample of 0.02 mol octane, C_8H_{18} (*l*) was burnt in a bomb calorimeter, the temperature of 1000 cm^3 water increased by 24.2 °C.
[*Specific heat capacity of solution $= 4.20$ Jg^{-1} °C^{-1}, density of solution $= 1.0$ g cm^{-3}*]
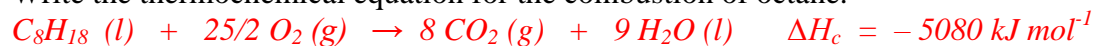
a)   What is the enthalpy of combustion of octane?

$Q_{comb} = m_w c_w \Delta T$
$= 1000$ g x 4.20 Jg^{-1} °C^{-1} x 24.2 °C
$= 1.016$ x 10^5 J
$= 1.016$ x 10^2 kJ

0.02 mol of octane, C_8H_{18} (l) released 1.016 x 10^2 kJ
1.00 mol of octane, C_8H_{18} (l) released $= 1.016$ x 10^2 kJ $/ 0.02$ mol $= 5080$ kJ

∴ $\Delta H_{comb\ of\ C8H18} = - 5080$ kJ mol^{-1}

b)   Write the thermochemical equation for the combustion of octane.
C_8H_{18} (l) $+ 25/2\ O_2$ (g) $\rightarrow 8\ CO_2$ (g) $+ 9\ H_2O$ (l) $\Delta H_c = - 5080$ kJ mol^{-1}

3   When 1.00 g of calcium chloride, $CaCl_2$, is added to 60.0 g of water in a coffee cup calorimeter, it dissolves:

$$CaCl_2\ (s)\ \rightarrow\ Ca^{2+}\ (aq)\ +\ 2Cl^-\ (aq)$$
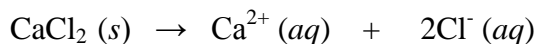
The temperature rises from 20.00 °C to 23.51 °C. Assuming that all the heat given off by the reaction is transferred to the water, calculate the heat for the reaction.
[Specific heat capacity of solution $= 4.18$ Jg^{-1}°C^{-1}]

$Q_{soln} = m_w c_w \Delta T$
$= 60.0$ g x 4.18 Jg^{-1} °C^{-1} x 3.51 °C
$= 880.3$ J
$= 0.880$ kJ @ 88.0 x 10^{-2} kJ

∴ Heat released by 1.00 g of calcium chloride, $CaCl_2 = - 88.0$ x 10^{-2} kJ

4   An amount of 120.0 mL of coffee in a well-insulated cup at 82.0 °C is too hot to drink. What volume of cold fresh milk at 15.0 °C need to be added to the coffee in order to achieve a temperature of 65.0 °C? Assume specific heat capacities and densities of coffee and milk are the same as water.

$$Q_{cold\ milk} = Q_{hot\ coffee}$$

heat absorb by cold milk $=$ *heat release from hot coffee*

$$m_{milk}\ x\ c\ x\ \Delta T = m_{coffee}\ x\ c\ x\ \Delta T$$
$$m_{milk}\ x\ 4.18\ x\ (65-15) = 120\ x\ 4.18\ (82-65)$$
$$m_{milk} = 40.8\ g$$

∴ Volume of cold milk = 40.8 mL

5   100.00 cm^3 of 2.0 mol dm^{-3} hydrochloric acid was added to excess 100.00 cm^3 of 3.0 mol dm^{-3} potassium hydroxide solution. Both solutions are at initial temperature of 30.0 °C are mixed in a calorimeter. The maximum temperature of the solution is 41.0 °C. [*Specific heat capacity of solution = 4.20 Jg^{-1} $°C^{-1}$*]

a)   Determine the limiting reagent.
     Hydrochloric acid

b)   Calculate the enthalpy of neutralization for the reaction.

$$Q_{rxn} = m_{soln}c_{soln}\Delta T$$
$$= 200.0\ g\ x\ 4.2\ J\ g^{-1}\ °C^{-1}\ x\ (41.0-30.0)\ °C$$
$$= 9240\ J$$

$$No.\ of\ mol\ of\ HCl = (2.0\ mol\ dm^{-3}\ x\ 100)/1000$$
$$= 0.20\ mol$$

$$HCl\ (aq)\ +\ KOH\ (aq)\ \rightarrow\ KCl\ (aq)\ +\ H_2O\ (l)$$

Based on the equation; no of mol of H_2O = no of mole of HCl
$$= 0.20\ mol\ H_2O$$

0.20 mol of H_2O produced 9240 J
1.0 mol of H_2O produced $= (1.0/0.2)\ x\ 9240\ J$
$$= 4.620\ x\ 10^4\ J$$
$$= 46.2\ kJ$$

∴ Enthalpy of neutralization = $-46.2\ kJ\ mol^{-1}$

c)   Write the thermochemical equation between hydrochloric acid and potassium hydroxide solution.

$$HCl\ (aq)\ +\ KOH\ (aq)\ \rightarrow\ KCl\ (aq)\ +\ H_2O\ (l)\quad \Delta H_n° = -46.2\ kJ\ mol^{-1}$$

6   150 cm^3 of potassium hydroxide solution of concentration 2.0 M and 250 cm^3 of 1.5 M hydroiodic acid were mixed in a calorimeter. If the temperature rise is 10.2 $^{\circ}$C, calculate heat evolved from the reaction.

$$KOH\ (aq)\ +\ HI\ (aq)\ \rightarrow\ KI\ (aq)\ +\ H_2O\ (aq)$$
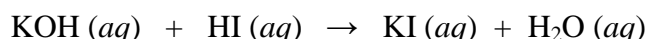
[*Specific heat capacity solution = 4.2 Jg^{-1o}C^{-1}; density of solution = 1.0 g cm^{-3}*]

Q_{rxn} = $m_s c_s \Delta T$
*   = (150 g + 250 g) x 4.2 Jg^{-1} $^{\circ}$C^{-1} x 10.2 $^{\circ}$C*
*   = 1.714 x 10^4 J*
*   = 17.14 kJ*

∴ Heat evolved from the reaction = – 17.1 kJ

7   The enthalpy of combustion of benzoic acid is – 3226.8 kJ mol^{-1}. When 3.2 g benzoic acid, C_6H_5COOH is completely combusted in a bomb calorimeter containing 2.0 kg of water, the temperature of the water increased by 3.8 °C.
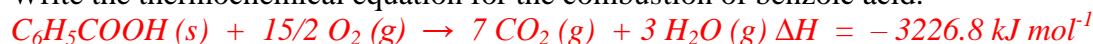   a)   Write the thermochemical equation for the combustion of benzoic acid.
    C_6H_5COOH (s) + 15/2 O_2 (g) $\rightarrow$ 7 CO_2 (g) + 3 H_2O (g) ΔH = – 3226.8 kJ mol^{-1}

    b)   Calculate the heat capacity of the calorimeter.

    no of mol of C_6H_5COOH = 3.2 g / 122 g mol^{-1} = 2.623 x 10^{-2} mol

    1.0 mol C_6H_5COOH released 3226.7 kJ
    2.623 x 10^{-2} mol C_6H_5COOH released = 2.623 x 10^{-2} x 3226.8 kJ
    *   = 84.60 kJ*
    *   = 8.460 x 10^4 J*

    Q_{comb} = Q_{water} + Q_{cal}
    8.460 x 10^4 = [2000 g x 4.184 J g^{-1} °C^{-1} x 3.8] + [C_{cal} x 3.8]
    * C_{cal} = 1.39 x 10^4 J °C^{-1}*

8   3.00 g of carbon was burned in a bomb calorimeter containing 2000 g of water at an initial temperature 20 $^{\circ}$C. The maximum temperature recorded was 31.3 $^{\circ}$C and the enthalpy of combustion of carbon is 402 kJ/mol. Calculate the heat capacity of bomb calorimeter. The specific heat for water is 4.184 J/g$^{\circ}$C.

    C (s) + O_2 (g) $\rightarrow$ CO_2 (g) + H_2O (l) ΔH = – 402 kJ mol^{-1}

    No of mol C = 3.00 g / 12.0 = 0.25 mol

    1.0 mol of C released 402 kJ mol^{-1}
    0.25 mol of C released = 0.25 mol x 402 kJ
    *   = 100.5 kJ = 1.005 x 10^5 J*

    Q_{comb} = Q_w + Q_{cal}
    *   = $m_w c_w \Delta T$ + $C_c \Delta T$*
    1.005 x 10^5 = [2000 g x 4.18 x (31.3 – 20.0)] + [C_c x (31.3 – 20.0)]
    *   = 5.34 x 10^2 J °C^{-1}*

Hess's Law

1   Standard enthalpy of formation of CO_2 (g), H_2O (l) and C_5H_{12} (g) are -394 kJ mol^{-1}, -286 kJ mol^{-1} and -173 kJ mol^{-1} respectively. Determine the heat of combustion of pentane, C_5H_{12} using standard enthalpies of formation given.

C_5H_{12} (g) + 8 O_2 (g) → CO_2 (g) + H_2O (l) $\Delta H_c = x$ kJ mol^{-1}

C (s) + O_2 (g)   → CO_2 (g) $\Delta H_f = -394$ kJ mol^{-1} ------ (1)
H_2 (g) + ½ O_2 (g)   → H_2O (l) $\Delta H_f = -286$ kJ mol^{-1} ------ (2)
5 C (s) + 6 H_2 (g)   → C_5H_{12} (g) $\Delta H_f = -173$ kJ mol^{-1} ------ (3)

Rev Eq (3): C_5H_{12} (g) → 5 C (s) + 6 H_2 (g) $\Delta H_f = +173$ kJ
Eq (1) x 5: 5 C (s) + 5 O_2 (g)   → 5 CO_2 (g) $\Delta H_f = -1970$ kJ
Eq (2) x 6: 6 H_2 (g) + 3 O_2 (g)   →   6 H_2O (l) $\Delta H_f = -1716$ kJ

C_5H_{12} (g) + 8 O_2 (g) → CO_2 (g) + H_2O (l) $\Delta H_c = -3513$ kJ mol^{-1}
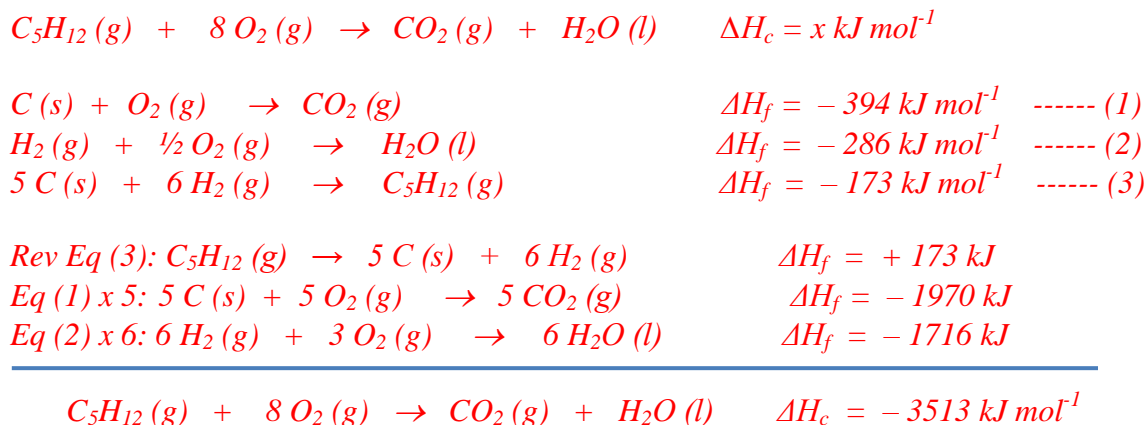
2   Calculate the heat of combustion of methane using standard heats of formation below:

$\Delta H_f\ CO_2$ (g) $= -394$ kJ mol^{-1}
$\Delta H_f\ H_2O$ (l) $= -286$ kJ mol^{-1}
$\Delta H_f\ CH_4$ (g) $= -75$ kJ mol^{-1}

CH_4 (g) + 2 O_2 (g) → CO_2 (g) + 2 H_2O (l) $\Delta H_c = x$ kJ mol^{-1}

C (s) + 2 H_2 (g)   → CH_4 (g) $\Delta H_f = -75$ kJ mol^{-1} ------ (1)
C (s) + O_2 (g)   → CO_2 (g) $\Delta H_f = -394$ kJ mol^{-1} ------ (2)
H_2 (g) + ½ O_2 (g)   → H_2O (l) $\Delta H_f = -286$ kJ mol^{-1} ------ (3)

Maintain (1): C (s) + 2 H_2 (g)   → CH_4 (g) $\Delta H_f = -75$ kJ
Maintai (2): C (s) + O_2 (g)   → CO_2 (g) $\Delta H_f = -394$ kJ
(2) x 2:   2 H_2 (g) + ½ O_2 (g)   → 2 H_2O (l) $\Delta H_f = -572$ kJ

CH_4 (g) + 2 O_2 (g) → CO_2 (g) + 2 H_2O (l) $\Delta H_c = -891$ kJ mol^{-1}

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CH_4 (g) + 2 O_2 (g)   → CO_2 (g) + 2 H_2O (l)
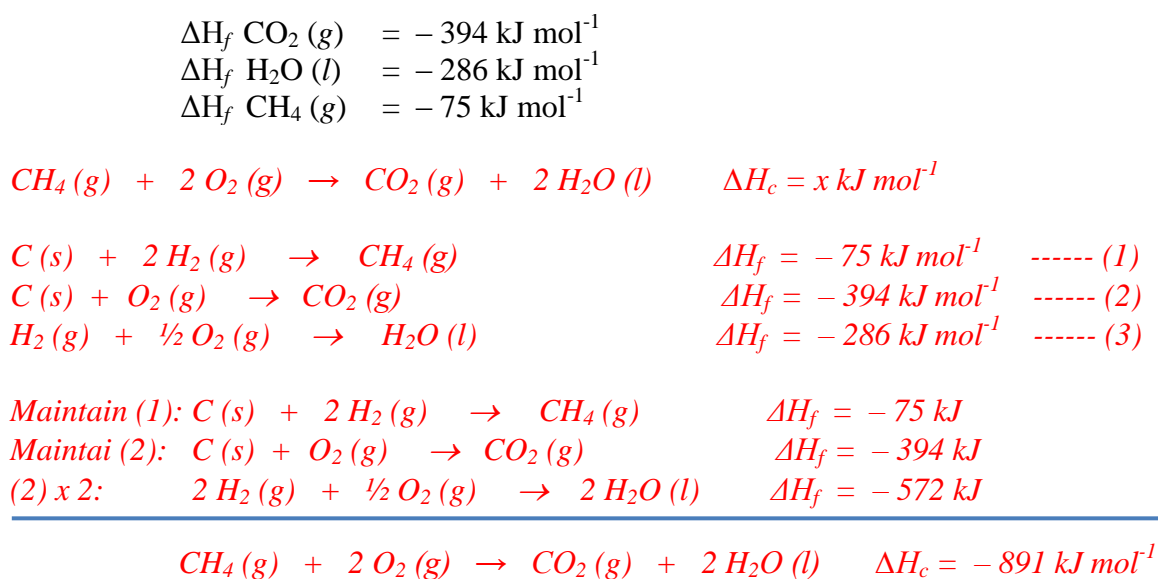
$\Delta H_f = \Sigma n\Delta H$ product $- \Sigma n\Delta H$ reactant
$\Delta H_c\ CH_4$ (g) $= -394 + (2\ x - 286) + 75$
                $= -891$ kJ mol^{-1}

3   Determine the enthalpy of formation of hydrogen peroxide (H_2O_2) by using the data below.

	$\Delta H°$ (kJ/mol)	
$H_2\ (g)\ +\ ½\ O_2\ (g)\ \rightarrow\ H_2O\ (g)$	$-\ 241.82$	----- (1)
$2\ H\ (g)\ +\ O\ (g)\ \rightarrow\ H_2O\ (g)$	$-\ 926.92$	----- (2)
$2\ H\ (g)\ +\ 2\ O\ (g)\ \rightarrow\ H_2O_2\ (g)$	$-\ 1070.62$	----- (3)
$2\ O\ (g)\ \rightarrow\ O_2\ (g)$	$-\ 498.34$	----- (4)
$H_2O_2\ (l)\ \rightarrow\ H_2O_2\ (g)$	$+\ 51.46$	----- (5)

$H_2\ (g)\ +\ O_2\ (g)\ \rightarrow\ H_2O_2\ (l)$ $\qquad\qquad\qquad \Delta H_f = x\ kJ\ mol^{-1}$

$Rev\ Eq\ (5)\quad :\ H_2O_2\ (g)\ \rightarrow\ H_2O_2\ (l)$ $\qquad\qquad \Delta H = -\ 51.46\ kJ$
$Maintain\ Eq\ (3):\ 2\ H\ (g)\ +\ 2\ O\ (g)\ \rightarrow\ H_2O_2\ (g)$ $\qquad \Delta H = -\ 1070.62\ kJ$
$Maintain\ Eq\ (1):\ H_2\ (g)\ +\ ½\ O_2\ (g)\ \rightarrow\ H_2O\ (g)$ $\qquad \Delta H = -\ 241.82\ kJ$
$Rev\ Eq\ (2)\quad :\ H_2O\ (g)\ \rightarrow\ 2\ H\ (g)\ +\ O\ (g)$ $\qquad\qquad \Delta H = +\ 926.92\ kJ$
$Rev\ Eq\ (4)\ x\ ½:\ ½\ O_2\ (g)\ \rightarrow\ O\ (g)$ $\qquad\qquad\qquad \Delta H = +\ 249.17\ kJ$

$H_2\ (g)\ +\ O_2\ (g)\ \rightarrow\ H_2O_2\ (l)$ $\qquad\qquad\qquad \Delta H_f = -\ 187.81\ kJ\ mol^{-1}$
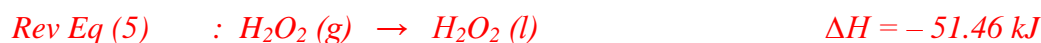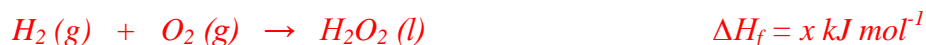
4   Draw the Born-Haber cycle for the formation of magnesium chloride, $MgCl_2$ from magnesium metal and chlorine gas. Calculate the enthalpy of formation of $MgCl_2$. Given:

Heat of sublimation of magnesium, $\Delta H_1\ =\ +\ 149\ kJ\ mol^{-1}$
First ionization energy of magnesium, $\Delta H_2\ =\ +\ 740\ kJ\ mol^{-1}$
Second ionization energy of magnesium, $\Delta H_3\ =\ +\ 1456\ kJ\ mol^{-1}$
Heat of atomization of chlorine, $\Delta H_4\ =\ +\ 240\ kJ\ mol^{-1}$
Electron affinity of chlorine, $\Delta H_5\ =\ -\ 369\ kJ\ mol^{-1}$
Lattice energy of $MgCl_2$, $\Delta H_6\ =\ -\ 3933\ kJ\ mol^{-1}$

Answer: $-\ 1846\ kJmol^{-1}$