Thermochemistry & Hess's Law 2.15

1. What is meant by the following :
(a) first law of thermodynamics
(b) enthalpy change
(c) exothermic and endothermic reactions?

2. (a) Use your data-book to find the standard enthalpy of combustion of methanoic acid (HCOOH).
(b) 3 grams of methanoic acid was burned, and the energy released used to warm a quantity of water. Given that the water temperature increased by 5°C, calculate the mass of water used in the experiment.

3. The following equations of formation are all incorrect. Rewrite the equations correctly.

(a) $H_2(g) + O_2(g)$ ----------> $H_2O(l)$

(b) $1/2N_2 + 3/2H_2$ ----------> NH_3

(c) $Ca(s) + CO(g) + O_2(g)$ --------> $CaCO_3(s)$

(d) $C(g) + 4H(g)$ --------> $CH_4(g)$

(e) $Ca(s) + 2Br(l)$ -----> $CaBr_2(s)$

4. The enthalpy of combustion of benzene is -3268 kJ mol^{-1}. The enthalpies of combustion of carbon and hydrogen are -394 and -286 kJ mol^{-1} respectively.

(a) Write a balanced equation for the formation of benzene
(b) Use the information above (showing working) to calculate the enthalpy of formation of benzene.

5. (a) Write balanced equations for the combustion of ethene, ethane, and hydrogen.
(b) Use the data book to find the enthalpies of combustion of the above reactions.
(c) Use the information above (showing working), to calculate the enthalpy of reaction for the hydrogenation of ethene.

6. The enthalpy change for the following reaction which occurs in thermal cracking

$$C_4H_{10} \text{ ---> } C_2H_6 + C_2H_4$$

can be determined from the enthalpies of formation of butane, ethane, and ethene which are in the data booklet.
Calculate the enthalpy change for the reaction.

7. Three moles of ethyne, C_2H_2, can react to form one mole of benzene.

$$3C_2H_2 \text{ ----> } C_6H_6$$

Use information on enthalpies of formation in the data booklet to calculate the enthalpy change for this reaction.

2.15

1. (a) energy cannot be created or destroyed

(b) The heat energy given out or taken in during a chemical reaction.

(c) An exothermic reaction is a reaction in which heat energy is given out to the surroundings
An endothermic reaction is a reaction which takes in heat energy from the surroundings or a heat source.

2. (a) ΔH_c $(HCOOH)$ $= -255$ kJ/mol

(b) $\Delta H = -255 \times \frac{3}{46}$

$= -16.6$ kJ

1 mol $HCOOH$ = 46 g

$\Delta H = c\,m\,\Delta t$

$m = \frac{\Delta H}{c\,\Delta t} = \frac{16.6}{4.18 \times 5} = 0.794$ kg

3. (a) $H_{2(g)} + \frac{1}{2}O_{2(g)} \longrightarrow H_2O_{(l)}$

(b) $\frac{1}{2}N_{2(g)} + \frac{3}{2}H_{2(g)} \longrightarrow NH_{3(g)}$

(c) $Ca_{(s)} + C_{(s)} + 1\frac{1}{2}O_{2(g)} \longrightarrow CaCO_{3(s)}$

(d) $C_{(s)} + 2H_{2(g)} \longrightarrow CH_{4(g)}$

(e) $Ca_{(s)} + Br_{2(l)} \longrightarrow CaBr_{2(s)}$

4. (a) $6C_{(s)} + 3H_{2(g)} \longrightarrow C_6H_{6(l)}$

(b) Target equation

$$\boxed{6C_{(s)} + 3H_{2(g)} \longrightarrow C_6H_{6(l)}} = \Delta H_?$$

Known enthalpies

① $C_6H_{6(l)} + 7\frac{1}{2}O_{2(g)} \longrightarrow 6CO_{2(g)} + 3H_2O_{(g)} = \Delta H_1$

② $C + O_2 \longrightarrow CO_2 = \Delta H_2$

③ $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O = \Delta H_3$

adding above equations to get required equation

$6 \times (C + O_2 \longrightarrow CO_2)$ gives 6 mole C on LHS

$3 \times (H_2 + \frac{1}{2}O_2 \longrightarrow H_2O)$ gives 3 mole H_2 on LHS

$3H_2O + 6CO_2 \longrightarrow 7\frac{1}{2}O_2 + C_6H_6$ reverse equ ① to get 1 mole C_6H_6 on RHS

$6C + 6O_2 + 3H_2 + \frac{3}{2}O_2 + 3H_2O + 6CO_2 \longrightarrow 6CO_2 + 3H_2O + 7\frac{1}{2}O_2 + C_6H_6$

therefore

$\Delta H_? = (6 \times \Delta H_2) + (3 \times \Delta H_3) + (-\Delta H_1) = (6 \times -394) + (3 \times -286) + (-(-3268))$

$= -2364 - 858 + 3268 = +46$ kJ/mol

5. (a) $C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$

$C_2H_6 + 3\frac{1}{2}O_2 \rightarrow 2CO_2 + 3H_2O$

$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

(b) ΔH_c (C_2H_4) $= -1411$ kJ/mol

ΔH_c (C_2H_6) $= -1560$ kJ/mol

ΔH_c (H_2) $= -286$ kJ/mol

(c) Target equation

$$C_2H_{4(g)} + H_{2(g)} \rightarrow C_2H_{6(g)}$$

adding equations from 5(a) to achieve target equation

$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$ $= \Delta H_c$ (ethene)

$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ $= \Delta H_c$ (hydrogen)

$2CO_2 + 3H_2O \rightarrow C_2H_6 + 3\frac{1}{2}O_2$ reverse ΔH_c (ethane)

$C_2H_4 + 3O_2 + H_2 + \frac{1}{2}O_2 + 2CO_2 + 3H_2O \rightarrow 2CO_2 + 2H_2O + H_2O + C_2H_6 + 3\frac{1}{2}O_2$

therefore $\Delta H_{\text{hydrogenation}} = \Delta H_c$ (ethene) $+ \Delta H_c$ (hydrogen) $+ (-\Delta H_c$ (ethane))

$= (-1411) + (-286) + (-(-1560))$

$= \underline{-137 \text{ kJ/mol}}$

6.

$$\Delta H^\circ = \Sigma \Delta H_f^\circ (\text{products}) - \Sigma \Delta H_f^\circ (\text{reactants})$$

$$= (-85 + 52) - (-125) \text{ kJ mol}^{-1}$$

$$= -33 + 125$$

$$= +92 \text{ kJ mol}^{-1}$$

7.

$$\Delta H^\circ = \sum \Delta H_f^\circ (\text{products}) - \sum \Delta H_f^\circ (\text{reactants})$$

$$= 49 - (3 \times 227)$$

$$= 49 - 681$$

$$= -632 \text{ kJ/mol}$$

Bond Enthalpies & Hess's Law 2.16

1. The mean bond enthalpy of the C-H bond is 414 kJ mol^{-1}.

(a) Why is the word mean used here ?

(b) Write balanced equations to represent the following energy changes:-

(i) Breaking all bonds in 1 mole of methane.

(ii) Breaking all bonds in 1 mole of ethane

(iii) Breaking all bonds in 1 mole of hexane

(iv) Breaking all bonds in 1 mole of ammonia

(v) Breaking all bonds in 1 mole of water

(vi) Breaking all bonds in 1 mole of chlorine

(vii) Breaking all bonds in 1 mole of bromine

2. As a good approximation, the overall ΔH of a reaction can be found by considering the energy of bonds broken during the reaction, and bonds formed. Use bond energy data to estimate the ΔH of the reactions below.

(a) Ethene reacting with water to form ethanol.

(b) Methane reacting with chlorine(Cl_2) to form chloromethane (CH_3Cl) and HCl.

1. (a) The C–H bond enthalpy is calculated by taking the average C–H bond enthalpy obtained from several different molecules.

(b)

(i) $CH_{4(g)} \longrightarrow C_{(g)} + 4H_{(g)}$

(ii) $C_2H_{6(g)} \longrightarrow 2C_{(g)} + 6H_{(g)}$

(iii) $C_6H_{14(g)} \longrightarrow 6C_{(g)} + 14H_{(g)}$

(iv) $NH_{3(g)} \longrightarrow N_{(g)} + 3H_{(g)}$

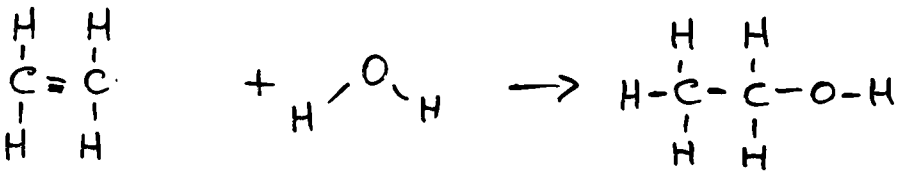
(v) $H_2O_{(g)} \longrightarrow 2H_{(g)} + O_{(g)}$

(vi) $Cl_{2(g)} \longrightarrow 2Cl_{(g)}$

(vii) $Br_{2(g)} \longrightarrow 2Br_{(g)}$

(2)(a) Required equation

$$C_2H_{4(g)} + H_2O_{(g)} \rightarrow C_2H_5OH_{(g)}$$



Bonds broken (+ve)

in ethane

4 × C-H = 1656
1 × C=C = 602

in water

2 × O-H = 916

TOTAL = +3174

Bonds formed (-ve)

in ethanol

5 × C-H = 2070
1 × C-C = 346
1 × C-O = 358
1 × O-H = 458

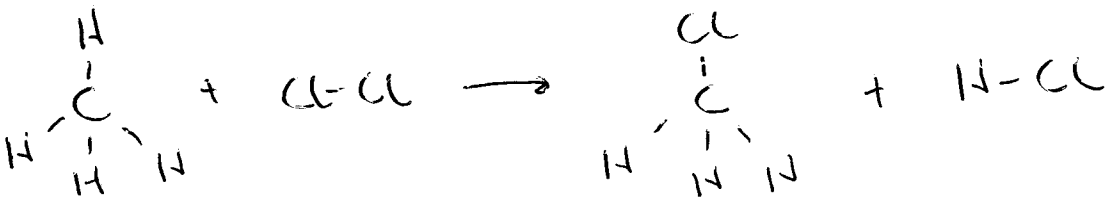
TOTAL = -3232

Heat of reaction = +3174 - 3232

= -58 KJ

2 (b) Target equation

$CH_4 + Cl_2 \longrightarrow CH_3Cl + HCl = \Delta H_{reaction}$



Bonds to be broken

4 x C–H = 4 x C–H bond enthalpy = 4 x 414 = 1656 KJ

1 x Cl–Cl = 1 x Cl–Cl bond enthalpy = 243 KJ/mol

total energy required = 1656 + 243 = +1899 KJ

Bonds to be made

3 x C–H = 3 x C–H bond enthalpy = 3 x 414 = 1242 KJ

1 x C–Cl = 1 x C–Cl " " = 326 KJ

1 x H–Cl = 1 x H–Cl " " = 428 KJ

Total energy released = 1242 + 326 + 428 = 1996 KJ

ΔH for reaction = 1899 + (−1996)

= −97 KJ

3 (a)

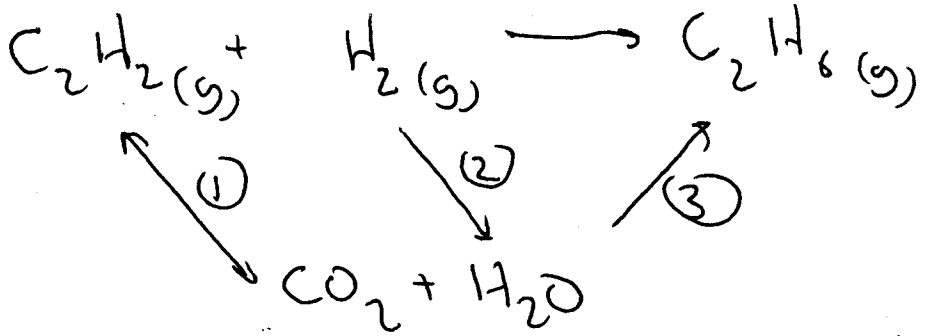
bond breaking		bond making	
1 × C-C =	kJ	1 × C-C	= -346
2 × C-H	= 2×414 kJ	6 × C-H	= -6×414
× H-H	= ×432		
total =	+ 828 +	total =	-346 + (-2484)
= +			= -2830

ΔH = Σ bond breaking + Σ bond making

= -2830

= ∴ kJ

(b)



from the above diagram it can be seen that to go an alternative route you require is use enthalpy of combustion of C_2H_2 ①, the enthalpy of combustion of H_2 ② and the reverse of the enthalpy of combustion of C_2H_6 ③.

(c)

$$C_2H_{2(g)} + 2\tfrac{1}{2}O_{2(g)} \longrightarrow 2CO_{2(g)} + H_2O_{(g)}$$

$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \longrightarrow H_2O_{(g)}$$

$$C_2H_6 + 3\tfrac{1}{2}O_{2(g)} \longrightarrow 2CO_2 + 3H_2O$$

3. (cont.)

now balance and add equations to get target equation. ($C_2H_{2(g)} + 2H_{2(g)} \rightarrow C_2H_{6(g)}$)

need 1 mole C_2H_2 on LHS therefore use eqn ①
need mole H_2 on LHS therefore use × eqn ②
need 1 mole C_2H_6 on RHS therefore use rev of eqn ③

$$\Delta H = -1300 + (2\times -286) + (+1560)$$
$$= -1300 - 572 + 1560$$
$$= -1872 + 1560$$
$$= \underline{-312 \text{ kJ/mol}}$$

(C) Method (a) uses mean bond enthalpies which are an average of the bond strength from several molecules.