O-level chemistry

Calculations involving heat in reactions

Reaction involve energy change; exothermic reactions such as burning fire woods produce heat while endothermic reactions such as dissolution of ammonium chloride in water absorb heat.

The amount of heat absorbed or released in a reaction depend on

- Amounts of the reactants
- Temperature and
- Pressure at which a reaction is carried out.

When molar quantities are involved at 298K and 1 atmosphere, the resultant heat changes are referred to as standard heat/enthalpy changes given a symbol a symbol ΔH (delta H).

Enthalpy changes (ΔH) (for exothermic reactions carry a negative sign because heat is lost from the system while enthalpy changes (ΔH) for endothermic reaction carry a positive sign because heat is gained by the system.

Heat is measured in joules (J)

Each heat change is identified by names; the common ones are:

1. **Heat of combustion or enthalpy of combustion** of a substance is the heat change when 1 mole of substance is burnt completely in oxygen.

   Experiment to determine enthalpy of combustion

   A given mass (M_1g) of a substance of molecular mass, Mr, is burnt completely in excess oxygen. Heat liberated raises the temperature of (Mw g) of water through a temperature change of θ^0.

   Assumption

   Heat liberated by a burning substance = heat absorbed by water

   = MwCθ (where C = specific heat capacity of water)

   ⇨ M_1 g of the substance produce MwCθ J

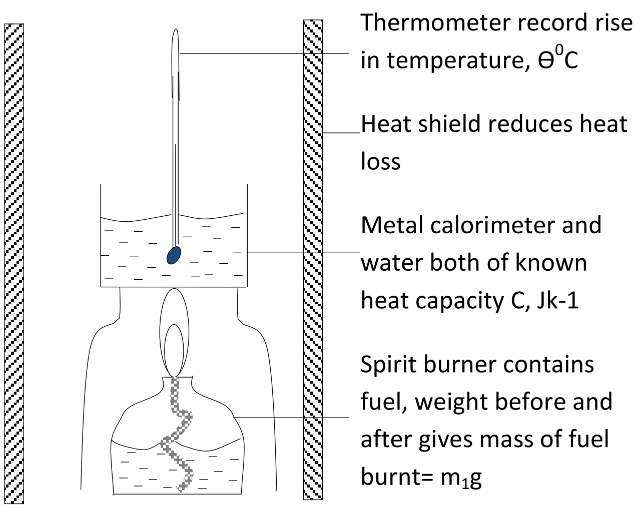
   ⇨ Mr g of substance produce $\frac{M_wC\theta \ x \ Mr}{M_1}$ $Jmol^{-1}$.

   Therefore, enthalpy of combustion of the substance = $\frac{M_wC\theta \ x \ Mr}{M_1}$ $Jmol^{-1}$

Experimental depends on whether a fuel is a liquid or a solid.

Experimental method for finding enthalpy of combustion a liquid fuel

The figure below shows a simple method for obtaining approximate value for the enthalpy of combustion of a fuel.



Calculations

Assumption

Heat produced by combusting fuel = Heat gained by calorimeter and water

Heat gained by calorimeter and water = Cϴ joules

It implies that

m_1g of fuel produce = Cϴ joules

Mr (mass equivalent to 1 mole of fuel) produces $= \frac{MrC\theta}{m_1}$ joulesmol^{-1}

Example 1

When 23g of ethanol completely burnt, 13600KJ of heat was produced.

Calculate the molar heat of combustion of ethanol (C = 12, H = 1, O = 16)

solution

Formula mass of ethanol (CH_3CH_2OH) = 12 x 2 + 6 + 16 = 46

23g of ethanol liberate 13600KJ

Then, 46g of ethanol liberate $\frac{13600 \ x\ 46}{23} = 27200kJ$

Therefore, the enthalpy of combustion of ethanol = 27200kJmol^{-1}.

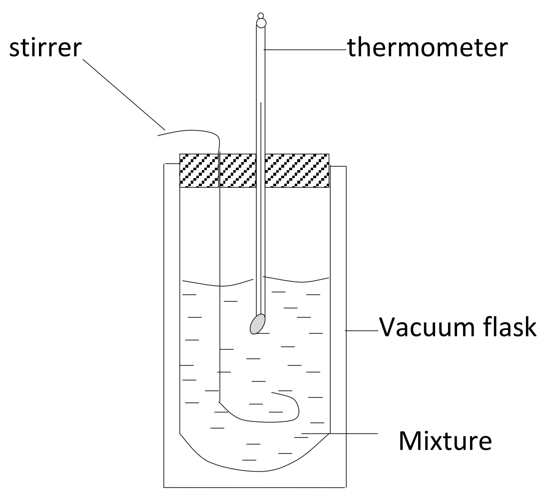
2. Enthalpy of neutralization

This refers to enthalpy change for the formation 1 mole of water from hydrogen and hydroxide ions

$H^+(g) + {}^-OH(aq) \rightarrow H_2O(l)$

Measurement of standard enthalpy of neutralization

The heat released when a known amount of water is formed is found by measuring the temperature produced in a calorimeter and its contents.



NB. A vacuum flask is used to minimize heat losses

Know volume of standard acid (V_1) and alkali (V_2) are added to calorimeter, and temperature change θ^0C is noted. The number of moles of water formed, M_w, is calculated

Calculations

Heat given out By water	=	Heat received by calorimeter of capacity, C.

Total volume = $(V_1 + V_2)$cm^3

Given that the density of solution = density of water (or 1gcm^{-1})

Mass of water, m = $(V_1 + V_2)$g

Heat = mcθ J (where c is the specific heat capacity

Amount of water formed = m_w moles

The standard enthalpy of neutralization is $(mc\theta)/m_w$ Jmol^{-1}.

Example 2

250 cm^3 of 0.40M NaOH were added to 250cm^3 of 0.40M HCl in the calorimeter. The temperature of the two solutions was 17.5^{0}C and rose to 20.1^{0}C

Calculate the enthalpy of neutralization assuming that the specific heat capacities of solution are the same as that of water = 4180J kg^{-1} K^{-1}.

Solution

Temperature rise = 20.1 – 17.5 = 2.6^{0}C

Mass of solution = total volume of solution

= (250 + 250) =500g

Heat liberated = mcθ

= 500 x 4.180 x 2.6

= 5434J

Mole of water produced = moles of NaOH or moles of HCl

$= \frac{250\ x\ 0.4}{1000} = 0.1 mole$

0.1mole of water require = 5434J

1 mole of water require = $\frac{5434\ x\ 1}{0.1} = 54340$ J

Therefore, enthalpy of neutralization of water = 54340Jmol^{-1}

Exercise

1	When 1 gram of methanol is burnt in excess air 22.6kJ of heat was liberated. What is the quantity of heat in kJ liberated when 1 mole of methanol was burnt under similar conditions A. 22.6 B. 32 C. 723.2 D. 777.8
2	5.3kJ of energy are required to vaporize 13g of a liquid X (molecular mass of X = 78) The molar heat of vaporization of X in kJ/mole is A. $\frac{5.3\ x\ 78}{13}$ B. $\frac{13\ x\ 78}{5.3}$ C. $\frac{5.3\ x\ 13}{78}$ D. 5.3 x 13 x 78
3	When 0.4g of ethanol was burnt, it raised the temperature of 0.1kg of water by 20^{0}C. the heat of combustion of ethanol is (specific heat capacity of water = 4.2kJ/kg/^{0}C, C_2H_5OH = 46) A. $\frac{4.2\ x\ 20\ x\ 46}{0.1\ x\ 0.4} kjmol^{-1}$ B. $\frac{0.14\ x\ 4.2\ x\ 20}{46\ x\ 0.1} kjmol^{-1}$ C. $\frac{0.1\ x\ 4.2\ x\ 20\ x\ 46}{0.4} kjmol^{-1}$ D. $\frac{0.1\ x\ 20\ x\ 46}{46\ x\ 0.4} kjmol^{-1}$

4	Glucose burn according to the following equation below giving out 2802kJmol^{-1} of heat energy. $C_6H_{12}O_6(s) + 6O_2(g) \longrightarrow 6CO_2(g) + 6H_2O(l)$ The amount of heat produced when 18g of glucose is burnt in oxygen at the same temperature is (H = 1, C = 12, O =16) A. $\frac{2802 \; x \; 18}{180 \; x \; 25}$ B. $\frac{180}{2802 \; x \; 18}$ C. $\frac{180 \; x \; 25 \; 18}{2802}$ D. $\frac{2802 \; x \; 18}{180}$
5	Graphite burns in oxygen according to he following equation $C(s) + O_2(g) \longrightarrow CO_2(g)$ $\Delta H = -390kJmol^{-1}$ When 48g of graphite is burnt in oxygen the heat produced is A. -97.5kJ B. -195kJ C. -780kJ D. -1560kJ (C = 12, O = 16, H = 1)
6	The formation of methanol from hydrogen and carbon monoxide is represented by equation $2H_2(g) + CO(g) \longrightarrow CH_3OH\ (g)$ $\Delta H = -\ 92kJmol\text{-}1$ What would be the energy released, in kJ, when 3.2g of methanol is formed? A. 2.9 B. 3.6 C. 9.2 D. 10.2
7	When 2.0g of substance X were burnt the heat produced raised the temperature of 1000g of water by 15.6^{0}C. The molar heat of combustion of X in joules is (the specific heat capacity of water is 4.2Jg^{-10}C, relative molecular mass of X is 60) A. $\frac{1000 \; x \; 4.2 \;\; x \; 15.6 \; x \; 20}{6o}$ B. $\frac{15.6 \; x \; 60 \; x1000}{2.0 \; x \; 4.2}$ C. $\frac{15.6 \; x \; 2.0 \; x \; 1000}{4.2 \; x \; 60}$ D. $\frac{4.2 \; x \; 15.6 \; x \; 60}{2}$
8	Methanol burns in excess air according to the equation $2CH_3OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 4H_2O(l)$ $\Delta H = -\ 730kJmol$ The amount of heat liberated when 3.2g of methanol (Mr = 32) is burnt completely is A. 73kJ B. 730kJ C. 1416kJ D. 2929kJ
9	Carbon reacts with sulphur according to the following equation $C(s) + 2S(s) \longrightarrow CS_2(s)$ $\Delta H = 116kJ$ The amount of heat absorbed when 16g of sulphur reacts with excess carbon is (C = 12, S = 32) A. 7kJ B. 29kJ C.58kJ D. 116kJ

10	When 8g of salt was dissolved in 100g of water the temperature decreased by 10^0C. The drop in temperature when 2g of the salt is dissolved in 100g of water would be (H = 1, O = 16) A. 10^0C B. 8.5^0C C. 5.0^0C D. 2.5^0C
11	Ethanol burns in oxygen according to the following equation $C_2H_5OH\ (l) + \frac{7}{2}\ O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l)\ \Delta H - 1185kJ$ Calculate heat given out when 0.2moles of ethanol is burnt completely A. -237kJ B. -592kJ C. -1185kJ D. -2370kJ
12	Carbon monoxide reacts with hydrogen according to the equation $CO(g) + 2H_2(g) \longrightarrow CH_3OH(l)\ \Delta H = +91kJmol^{-1}$ What mass of carbon monoxide would cause heat change of +188.2kJ (H = 1, C =12, O = 16) A. 2g B. 28g C. 58g D. 273g
13	13.7kJ of heat was evolved when 4.0g of copper was displaced from copper (II) sulphate solution by zinc. The amount heat evolved when one mole of copper was displaced is A. $\frac{63.5\ x\ 4}{13.7}$ B. $\frac{13.7\ x\ 63.5}{4}$ C. $\frac{13.7\ x\ 4}{63.5}$ D. $\frac{63.5}{13.7\ x\ 4}$
14	Carbon burns in excess oxygen according to the equation $C(s) + O_2(g) \longrightarrow CO_2(g)\ \Delta H\ -393kJ$ What mass of carbon in grams would produce750kJ of energy A. $\frac{393\ x\ 12}{750}$ B. $\frac{750\ x\ 12}{393000}$ C. $\frac{750\ 12}{393}$ D. $\frac{750\ x\ 393}{12}$
15	10g of methanol, CH_3OH, burns in air to liberate 226kJ of heat. The amount of heat liberated when 1 mole of methanol is burn in air is (H=1, C = 12) A. $\frac{32\ x\ 226}{10}$ B. $\frac{10\ x\ 32}{226}$ C. $\frac{10}{32\ 226}$ D. $\frac{10\ x\ 226}{32}$
16	When 1.0g of carbon is burnt in excess oxygen, the heat produced raises the temperature of 400g of water by 19^0C. the heat of combustion of carbon is (C =12, specific heat capacity of water is $4.2kJkg^{-1}K^{-1}$) A. $0.4 \times 4.2 \times 19 \times 12kJmol^{-1}$ B. $\frac{0.4\ x\ 4.2}{12\ x\ 19}\ kJmol^{-1}$ C. $400 \times 4.2 \times 19 \times 12kJmol^{-1}$

	D. $\frac{12\ 19\ x\ 19}{0.4x\ 4.2} kJmol^{-1}$
17	Ethanol burns in oxygen according to the following equation CH_3CH_2OH (l) + $3O_2$(g) ⟶ $2CO_2$(g) + $3H_2O$(l) Calculate the amount of heat evolved when 45g of oxygen is used for complete combustion of ethanol. (C= 12, H = 1, O + 16, the molar heat of combustion of ethanol is 1370.0kJmol^{-1}) A. 642.2kJ B. 1284.4kJ C. 1340.2kJ D. 1926.6kJ
18	When 1 mole of ammonium chloride was dissolved in a certain volume of water, 2.94kJ of heat was absorbed. The amount heat absorbed when 5.35g of ammonium chloride is dissolved in the same volume of water is (NH_4Cl = 53.5) A. $\frac{53.5}{2.94\ x\ 5.53} kJ$ B. $\frac{2.94\ x\ 5.35}{53.5}$ kJ C. $\frac{29.4\ x\ 53.5}{5.35}$ D. $\frac{53.5\ x\ 5.35}{2.94}$
19	When 2.3g of ethanol was completely burnt in oxygen, heat evolved raised the temperature of 100g of water by 30^{0}C. the molar heat of combustion f ethanol is [The molar heat of combustion of ethanol in joule is (the molar mass of ethanol = 46 and the specific heat capacity of water = 4.2Jg^{-1}K^{-1}) A. $\frac{100\ x\ 4.2\ x\ 30\ x\ 46}{2.3}$ B. $\frac{30\ x\ 4.2\ x\ 2.3\ x\ 100}{46}$ C. $\frac{20\ x\ 4.2\ 2.3\ x\ 100}{46}$ D. $\frac{20\ x\ 4.2\ x\ 46\ 100}{2.3}$
20	When 2.4gof magnesium was reacted with 200cm^3 of 2M hydrochloric acid, 13.6kJ of heat was evolved. The molar heat of reaction of magnesium with the acid is (Mg = 24) A. $\frac{13.6\ x\ 200}{24\ x\ 2.4} kJ$ B. $\frac{13.6\ x\ 24}{2.4\ x\ 200}$ c. $\frac{2.4\ x\ 24}{13.6} kJ$ D. $\frac{24\ x\ 13.6}{2.4} kJ$
21	Butane undergoes combustion according to the following equation: $2C_4H_{10}$(g) + $13O_2$(g) ⟶ $8CO_2$(g) + $10H_2O$(l) + heat The mass of butane required to produce 950kJ of heat is (H = 1, C = 12, 1 mole of butane produces 2877kJ of heat) A. $\frac{950\ c\ 58}{2\ x\ 2877} g$ B. $\frac{950\ x\ 58}{2877}$ C. $\frac{950\ x\ 52\ x\ 2}{2877}$ D. $\frac{2877\ x\ 58}{950}$

Section B

22.	(a)	What is meant by enthalpy of neutralization? (02marks)
	(b)	When $50.0cm^3$ of 1M sulphuric acid was added to $50cm^3$ of 2M sodium hydroxide, the temperature rose by 13.6^0C. (i) Write ionic equation for the reaction that took place (01 mark) (ii) Calculate the enthalpy of neutralization of sodium hydroxide. (specific heat capacity of water = $4.2Jmol^{-1}$, density of water $1g/cm^3$ (3marks)
23		Biogas contain mainly methane.
	(a)	Name two raw materials that can be used to produce biogas
	(b)	Methane burns in oxygen according to the following equation $CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l) \quad \Delta H = -890kJmol^{-1}$ Calculate the volume of methane at s.t.p that will produce 2670kJ.
24	(a)	$50cm^3$ of 2M HCl and $50cm^3$ of 2M NaOH each at 22^0C were mixed in a plastic beaker. The mixture was stirred and its maximum temperature was 35^0C. [heat capacity of solution is $4.2kJkg^{-1}\,{}^0C$, density of water = $1gcm^{-3}$] (i) Write ionic equation for the reaction. (ii) Calculate the heat of reaction
	(b)	$50cm^3$ of 2M ammonia was used instead of 2M NaOH in (a). State whether the heat of the reaction was greater than, equal to or less than the value obtained in (a)(ii) above. Explain your answer.
25	(a)	Write equation for complete combustion of methane
	(b)	A litre of methane gas costs 600/=. Calculate the cost of methane required to produce 1746×10^3J of heat. (1mole of a gas occupies $24dm^3$ at room temperature, heat of combustion of methane is $-882kJmol^{-1}$)
26	(a)	Define the term enthalpy of combustion (02marks)
	(b)	With the aid of a diagram describe an experiment you would carry out in a laboratory to determine the enthalpy of combustion of propanol (9marks)
	(c)	In an experiment to determine the enthalpy of combustion of propanol, 0.54g of propanol was burnt and the heat evolved caused the temperature of $150cm^3$ of water to rise by 21.5^0C (molar mass of propanol = 60, density of water is $1gcm^{-3}$, specific heat capacity of

		water = 4.1Jg^{-1}) Calculate heat capacity experiment value of enthalpy of combustion of propanol (3 ½ marks)
27		Ethane burns in oxygen according to the following equation $2C_2H_6(g) + 7O_2(g) \longrightarrow 4CO_2(g) + 6H_2O(l)$ When 2.0g of ethane was burnt in excess oxygen, 104kJ of heat was produced. Calculate
	(a)	Mass of water formed (03marks)
	(b)	Molar heat of combustion of ethane (02marks)
28	(a)	What is meant by the term enthalpy of combustion? (02mark)
	(b)	Ethanol burns in oxygen according to the following equation $C_2H_5OH(l) + 3O_2(g) \longrightarrow CO_2(g) + 3H_2O(l)$ $\Delta H - 1360 kJmol^{-1}$ Calculate the mass of ethanol that is required to raise the temperature of 1000cm^3 of water by 10.0^{0}C (03marks) (specific heat capacity of water = 4.2Jg^{-1}K^{-1})

Answers

1	C	Formula mass of methanol, CH_3OH = 12+3+16 +1 = 32 1g of methanol produce 22.6kJ 32g (1mole) produce 22.6 x 32 = 723.2kJ
2	B	5.3g of X require 5.3kJ 78g of X require $\frac{5,3\ x\ 78}{13}\ kJ$
3	C	Heat = mcθ = (0.1 x 4.2 x 20)kJ 0.4g of ethanol produce (0.1 x 4.2 x 20)kJ 46g of ethanol produce $\frac{0.1\ x\ 4.2\ x\ 20\ x\ 46}{0.4}$
4	D	Formula mass $C_6H_{12}O_6$ weigh 6 x 12 + 12 x 1 + 16 x 6 = 180 180g glucose produce 2802 kJ 18g of glucose produce $\frac{2802\ x\ 18}{180}\ kJ$
5	D	12g produce 390kJ 48g produce $\frac{390\ x\ 48}{12}$ =1560kJ
6	C	Formula mass of methanol, CH_3OH = 32 32g of CH_3OH produce 92kJ 3.2g of CH_3OHproduce $\frac{92\ x\ 3.2}{32} = 9.2kJ$
7	D	Heat = mcθ = (1000 x 4.2 x 15.6)J 2g of X produce (1000 x 4.2 x 15.6)J 60g of X produce $\frac{1000\ x\ 4.2\ x\ 15.6\ x\ 60}{2}$ $Jmol^{-1}$

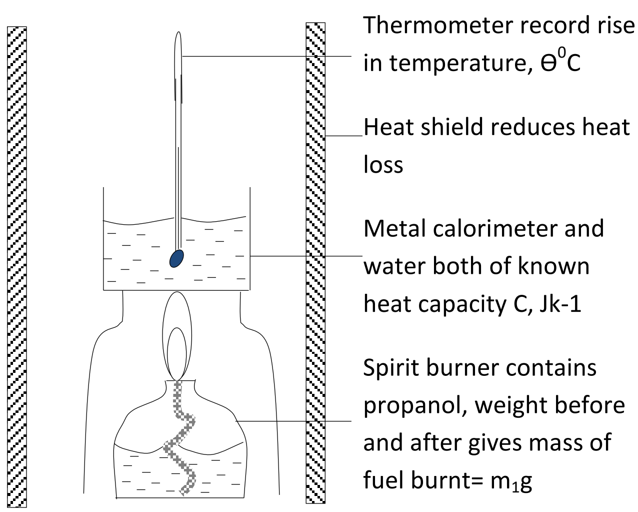
8	A	32g of methanol produce 730kJ 3.2 g of methanol produce $\frac{730\ x\ 3.2}{32} = 73kJ$
9	B	(2 x 32)g of sulphur produce 116kJ 16g of sulphur produce $\frac{116\ x\ 16}{64} = 29kJ$
10	D	8g cause a drop in temperature of 10^0C 2g will cause a drop in temperature of $\frac{2\ x\ 10^0}{8}$ 2.5^0C
11	A	1 mole of ethanol produce 1185 kJ 0.2mole produce 0.2 x 1185
12	C	Formula mass of CO = 12 + 16 = 28 91kJ is absorbed by 28g of CO 1882kJ is absorbed by $\frac{1882\ x\ 28}{91} = 57.9g$
13	B	4.0g of copper produce 13.7kJ 63.5g of copper produce $\frac{63.5\ x\ 13.7}{4}$g
14	C	393kJ are produced by 12g of carbon 750kJ require $\frac{750\ x\ 12}{393}g$
15	D	Formula mass of CH_3OH = 12 + 3 x 1+ 16 + 1 = 32g 10g of methanol produce 226kJ 32g (1mole) produce $\frac{226x\ 32}{10}kJ$
16	A	400g = $\frac{400}{1000} = 0.4kg$ Heat produced = mcθ = (0.4 x 4.2 x 19)kJ 1g of carbon produces (0.4 x 4.2 x 19)kJ 12g produce $\frac{(0.4 \text{ x } 4.2 \text{ x } 19 \text{ x } 12)}{1}\ kJ$

17	B	Formula mass of O_2 = 16 x 2 = 32 (3 x 32) g of oxygen produce 1370kJ 45g of oxygen produce = $\frac{1370\ x\ 45}{3\ x\ 32}$
18	B	Formula mass of NH_4Cl = 14 + 1 x 4 + 35.5 = 53.5 53.5gof NH_4Cl absorb 2.94kJ 5.35g of NH_4Cl absorb $\frac{5.35\ x\ 2.94}{53.5}$
19	A	Formula mass of ethanol, CH3CH2OH = 12 + 3 + 12 + 2 + 16 + 1 = 46 Heat = mcθ = (100 x 4.2 x 30)J 2.3g of ethanol produce (100 x 4.2 x 30)J 46g of ethanol produce $\frac{0.1\ x\ 4.2\ x\ 30\ x\ 46}{2.3}J$
20	D	2.4g of magnesium produce 13.6kJ 24g of magnesium produce $\frac{24\ x\ 13.6}{2.4}$
21	B	Formula mass of butane, C_4H_{10} = 4 x 12 + 1 x 10 =58 2877kJ is produced by 58g of butane 950kg is produced by $\frac{58\ x\ 950}{2877}$

Section B

22	(a)	Enthalpy of neutralization is enthalpy change when 1 mole of water is formed from aqueous hydrogen and hydroxyl ions.

	(b)	(i) $H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$ (ii) total volume of water = 50 + 50 = 100cm^3 Mass of water = 100 x 1 = 100g Heat liberated = mcθ = 100 x 4.2 x 13.6 = 5712J Mole of water formed = moles NaOH = $\frac{50\ x\ 2}{1000} = 0.1\ mole$ Production of 0.1mole of water produce 5712J 1mole of water produced $\frac{5712\ x\ 1}{0.1}$ $57120J = 57.12kJmol^{-1}$
23	(a)	Cow dung, water, plant remaining
	(b)	Formula mass of CH_4 = 12 + 4 = 16 890kJ areproduced by 16g of methane 2670kJ are produced by $\frac{16\ x\ 2670}{890} = 48g$
24	(a)	$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$
	(b)	total volume of water = 50 + 50 = 100cm^3 Mass of water = 100 x 1 = 100g Temperature change= 35 – 22 = 13^{0}C Heat liberated = mcθ = 100 x 4.2 x 13 = 5460J Mole of water formed = moles NaOH = $\frac{50\ x\ 2}{1000} = 0.1\ mole$ Production of 0.1mole of water produce 5460J 1mole of water produced $\frac{5460\ x\ 1}{0.1}$ $54600J = 54.6kJmol^{-1}$
(b)		It would be less because ammonia is a weak base

25	(a)	$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l)$
	(b)	Formula mass of CH_4 = 12 + 4 = 16 882kJ are produce by 24 l 1746kJ require $\frac{1746 \ x \ 24}{882} = 47.5l$ Cost of 47.5l of methane = 47.5 x 600 = 28500/=
26		Ethnalpy of combustion is entalpy change when 1 mole of a substance is completely burnt in oxygen.
		Experimental method for finding enthalpy of combustion a liquid fuel The figure below shows a simple method for obtaining approximate value for the enthalpy of combustion of a propanol.  Calculations Assumption Heat produced by combusting fuel = Heat gained by calorimeter and water Heat gained by calorimeter and water = CΘ joules It implies that m_1g of fuel produce = CΘ joules Mr (mass equivalent to 1 mole of fuel) produces = $\frac{MrC\Theta}{m_1}$ joulesmol^{-1}

	(b)	Mass of water = 150 x 1 = 150g Heat = mcθ = 150 x 4.2 x 21.5 = 13545J 0.54gof propanol produce 13545J 60g of propanol produce $\frac{13545\ x\ 60}{0.54}$ =1505kJ
27	(a)	Formula mass of ethane C_2H_6 = 2 x 12 + 6 x1 = 30 Formula mass of water, H_2O = 1x2 + 16= 18 (2 x 30) g of ethane produce (6 x 18) g of water 2g of ethane produce $\frac{2\ x\ 6\ x\ 18}{2\ x\ 30} = 3.6g\ of\ water$
	(b)	2g of ethane produce 104kJ 30g (1mole) of ethane produce $\frac{30\ x\ 104}{2}$ 1560kJ
28	(a)	Enthalpy of combustion is the enthalpy change when 1 mole of a substance is burnt completely in oxygen.
	(b)	Formula mass of ethanol C_2H_5OH = 2 x 12 + 6 + 16 = 46 Mass of water = volume of water = 1000g Heat = mcθ = 1000 x 10 x 4.2 = 42000J 2g of ethanol produce 42000 30g of ethanol produce $\frac{420000\ x\ 30}{2}\ 630kJ$