Q1. Methane and oxygen react together to produce carbon dioxide and water.

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

818 kJ of energy is given out to the surroundings for each formula mass (mole) of methane that reacts.

The methane gas will not burn in oxygen until a flame is applied, but once lit it continues to burn.

(a) Explain why energy must be supplied to start the reaction but it continues by itself once started.

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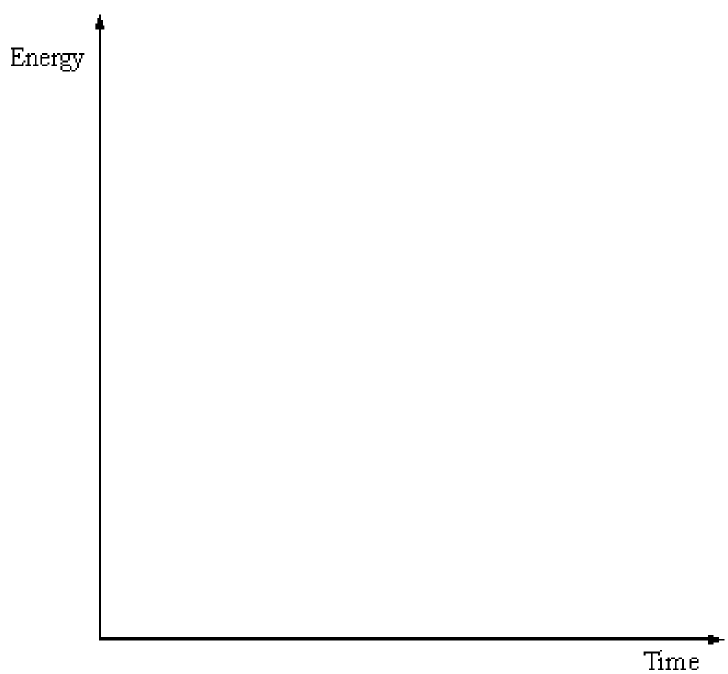
(4)

(b) Sketch an energy level diagram for the reaction and indicate on the diagram the nett energy released.

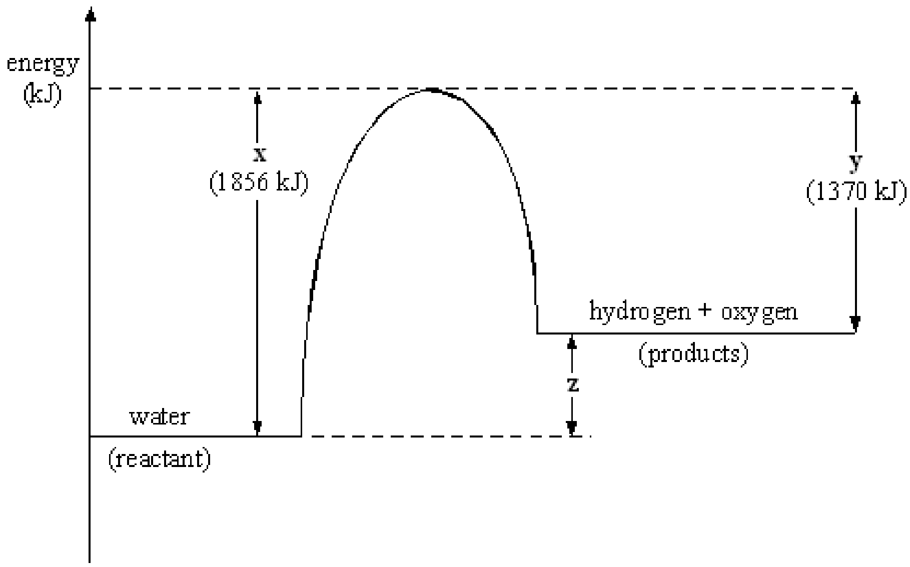


(3)
(Total 7 marks)

Q2. The symbol equation shows the decomposition of water.

$2H_2O \rightarrow 2H_2 + O_2$

An energy level diagram for this reaction is shown below.



Explain the significance of **x**, **y** and **z** on the energy level diagram in terms of energy transfers that occur in the reaction. You should make specific reference to the bonds broken and formed and to the nett energy transfer (energy transferred to or from the surroundings).

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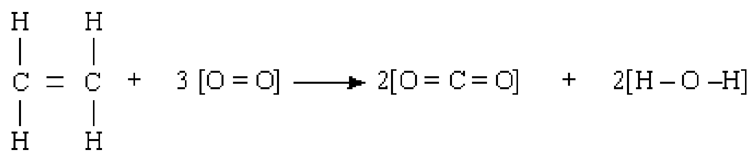
(Total 6 marks)

Q3. You will find the information on the Data Sheet helpful when answering this question.

This equation shows the reaction between ethene and oxygen.

$$C_2H_4 \quad + \quad 3O_2 \quad \rightarrow \quad 2CO_2 \quad + \quad 2H_2O$$

The structural formulae in the equation below show the bonds in each molecule involved.



Use the three stages shown at (a), (b) and (c) below to calculate the nett energy transfer when the formula mass (1 mole) of ethene reacts with oxygen.

(a) Write down the bonds broken and the bonds formed during the reaction. (Some have already been done for you.)

Bonds broken	
Number	Type
4	[C – H]
1	[C = C]

Bonds formed	
Number	Type
4	[C = O]

(2)

(b) Calculate the total energy changes involved in breaking and in forming all of these bonds. (Some have already been done for you.)

Total energy change in breaking bonds
[4 × 413] = 1652
[1 × 612] = 612
Total = kJ

Total energy change in forming bonds
4 × [805] = 3220
Total = kJ

(4)

(c) Describe, as fully as you can, what the figures in (b) tell you about the overall reaction.

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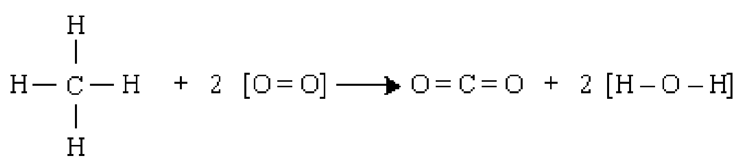
(2)
(Total 8 marks)

Q4. The symbol equation shows the reaction between methane and oxygen.

$$CH_4 \quad + \quad 2O_2 \quad \rightarrow \quad CO_2 \quad + \quad 2H_2O$$

methane oxygen carbon dioxide water

The structural formulae in the equation below show the bonds in each molecule involved.



In the three stages shown at (i), (ii) and (iii) below, calculate the net energy transfer when the formula mass (1 mole) of methane reacts with oxygen.

(i) Write down the bonds broken and the bonds formed during the reaction.

Bonds broken		**Bonds formed**	
number	**type**	**number**	**type**

(4)

(ii) Calculate the total energy changes involved in breaking and in forming each of these bonds.

Total energy change in breaking bonds	**Total energy change in forming bonds**

(4)

(iii) Describe, as fully as you can, what the above figures in (ii) tell you about the overall reaction.

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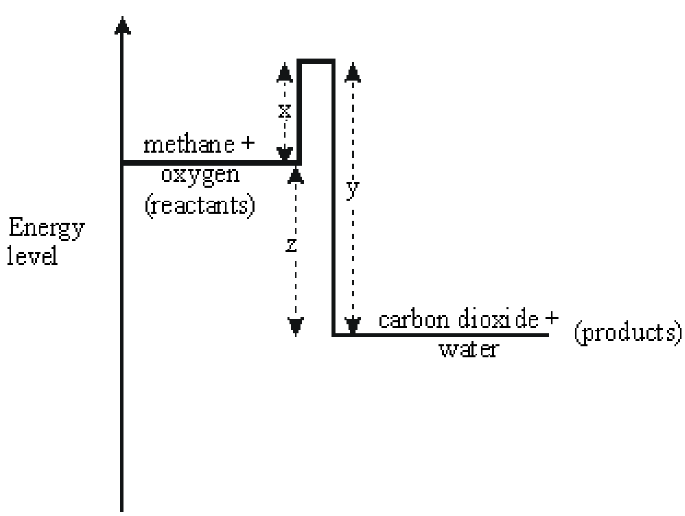
(2)
(Total 10 marks)

Q5. The symbol equation below shows the reaction when methane burns in oxygen.

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

An energy level diagram for this reaction is shown below.



(a) Which chemical bonds are broken and which are formed during this reaction?

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(4)

(b) Explain the significance of x, y and z on the energy level diagram in terms of the energy transfers which occur when these chemical bonds are broken and formed.

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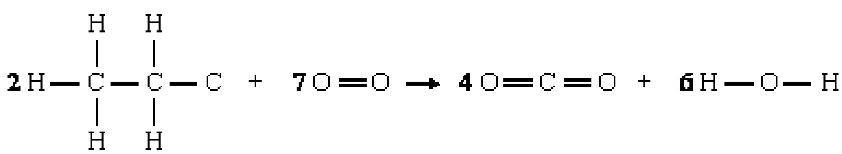
(5)

(Total 9 marks)

Q6. The balanced equation for the combustion of ethane is shown using structural formulae.



(a) Complete the table to show the number of bonds broken and made when two molecules of ethane react with seven molecules of oxygen.

Type of bond	**Number of bonds broken**	**Number of bonds made**
C — C		
C — H		
O ═ O		
C ═ O		
H — O		

(2)

(b) The combustion of ethane is a strongly exothermic process. Draw a labelled energy level diagram showing the endothermic and exothermic parts of the overall reaction. Indicate the activation energy on the diagram.

(4)

(c) Explain, in terms of particles and the activation energy of a reaction, how a catalyst is able to increase the rate of reaction.

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(2)
(Total 8 marks)

Q7. In the Haber process, nitrogen and hydrogen react to make ammonia.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

nitrogen + hydrogen $\rightleftharpoons$ ammonia

Pressure in atmospheres	% ammonia present at equilibrium				
	Temperature in °C				
	100	**200**	**300**	**400**	**500**
10	88.2	50.7	14.7	3.9	1.2
25	91.7	63.6	27.4	8.7	2.9
50	94.5	74.0	39.5	15.3	5.6
100	96.7	81.7	52.5	25.2	10.6
200	98.4	89.0	66.7	38.8	18.3
400	99.4	94.6	79.7	55.4	31.9
1000	99.9	98.3	92.6	79.8	57.5

The actual conditions used in the Haber process are usually 450 °C and 200 atmospheres.

(a) What effect does increasing the pressure have on the percentage of ammonia made? Use the balanced symbol equation to explain why.

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(2)

(b) A lower temperature of 100 °C gives high percentages of ammonia at most pressures. Why is this temperature **not** used in the Haber process?

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(1)

(c) Describe and explain the effect of an increase in the temperature on the reaction between nitrogen and hydrogen in the Haber process.

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(3)
(Total 6 marks)

Q8. Hydrogen chloride is made by reacting hydrogen with chlorine.

$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

Bond	Bond energy in kJ
H – H	436
Cl – Cl	242
H – Cl	431

Is the reaction between hydrogen and chlorine exothermic or endothermic?
Use the bond energies to explain your answer.

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(Total 3 marks)

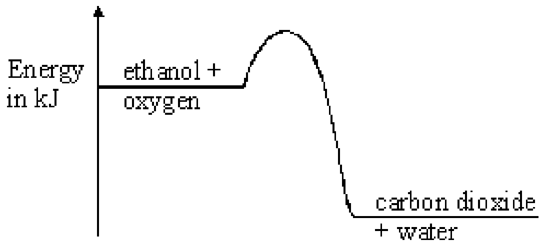
Q9. Ethanol is used as a fuel.

(a) Balance the symbol equation for the combustion reaction.

$C_2H_5OH + O_2 \rightarrow CO_2 + H_2O$

(1)

(b) The energy level diagram represents the combustion of ethanol.



Describe what must happen to the molecules of ethanol and oxygen to allow them to react.

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(3)

(c) We can use bond energies to calculate the energy change for the reaction between hydrogen and oxygen.

$$2H_2 + O_2 \rightarrow 2H_2O$$

Bond	**Bond energy in kJ**
H – H	436
O – H	464
O = O	498

(i) Calculate the total bond energy of the reactants.

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Total bond energy of reactants = ... kJ

(2)

(ii) Is the reaction between hydrogen and oxygen exothermic or endothermic? Use bond energies to explain your answer.

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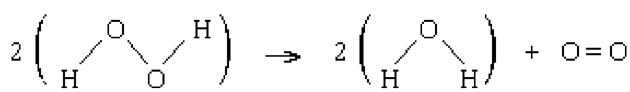
(2)
(Total 8 marks)

Q10. At room temperature, hydrogen peroxide decomposes very slowly to form water and oxygen.
The decomposition is speeded up when a catalyst is added.

(a) The following equation represents the decomposition of hydrogen peroxide.
The structural formulae of the chemicals involved are shown.



Use the following information about bond energies to answer this part of the question.

BOND	BOND ENERGY (kJ)
O = O	498
O – O	146
H – O	464

(i) Calculate the energy needed to break all the bonds in the reactants.

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.... kJ

(2)

(ii) Calculate the energy released when new bonds are formed in the products.

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.... kJ

(2)

(iii) Calculate the energy change for this reaction.

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.... kJ

(1)

(iv) Is the reaction exothermic or endothermic?

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Explain why.

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(1)

(b) (i) What is meant by 'activation energy'?

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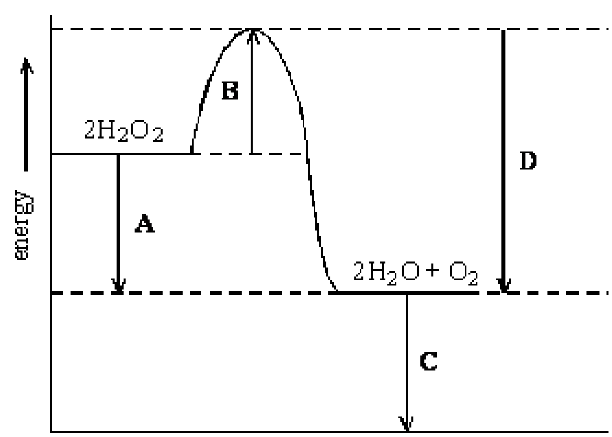
(1)

(ii) The energy level diagram for the decomposition of hydrogen peroxide into water and oxygen is shown below.



Which energy change, **A**, **B**, **C** or **D**, is the activation energy? ....

(1)

(iii) Explain, in terms of energy, how a catalyst makes hydrogen peroxide decompose more quickly.

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(1)

(Total 9 marks)

Q11. The relative amount of energy required to break the bond in each of the hydrogen halide molecules is shown below.

H – F	569
H – Cl	432
H – Br	366
H – I	298

One of the important properties of the hydrogen halides is that they dissolve in water to form acids. For example hydrogen chloride reacts with water to form hydrochloric acid.

To form an acid the bond between the hydrogen and the halogen atoms must be broken and ions are formed. The stronger the acid the more molecules that split up to form ions.

(i) Which ion must be formed to make a solution acidic?

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(1)

(ii) Which of the hydrogen halides would you expect to react with water to form the strongest acid? Explain your answer.

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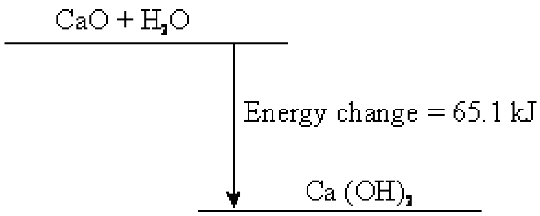
(3)

(Total 4 marks)

Q12. An energy diagram is shown below for the slaking of calcium oxide.



(i) Explain what the diagram tells you about the energy change which takes place in this reaction.

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(2)

(ii) Explain fully what the diagram tells you about the relative amount of energy required to break bonds and form new bonds in this reaction.

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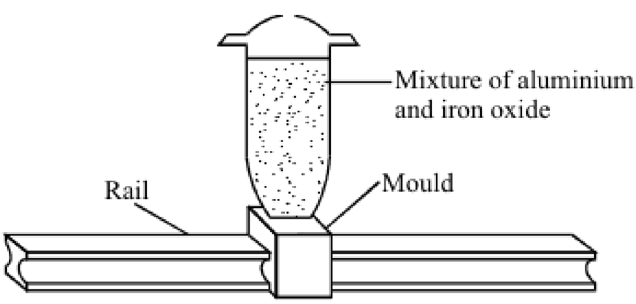
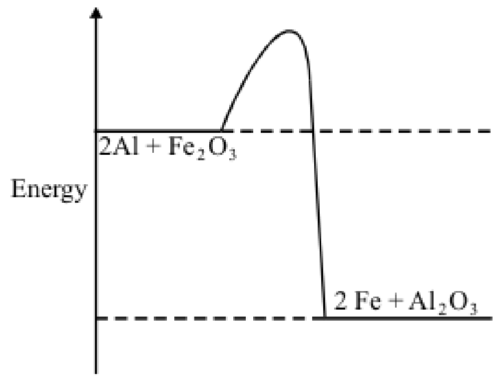
(3)
(Total 5 marks)

Q13. The reaction between aluminium and iron oxide is used to weld together railway lines.

$$2Al(s) + Fe_2O_3(s) \rightarrow 2Fe(l) + Al_2O_3(s)$$



A simple, qualitative energy level diagram for this reaction is shown.



Use the energy level diagram to:

(i) describe the idea of activation energy;

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.... **(1)**

(ii) explain why the reaction produces molten iron.

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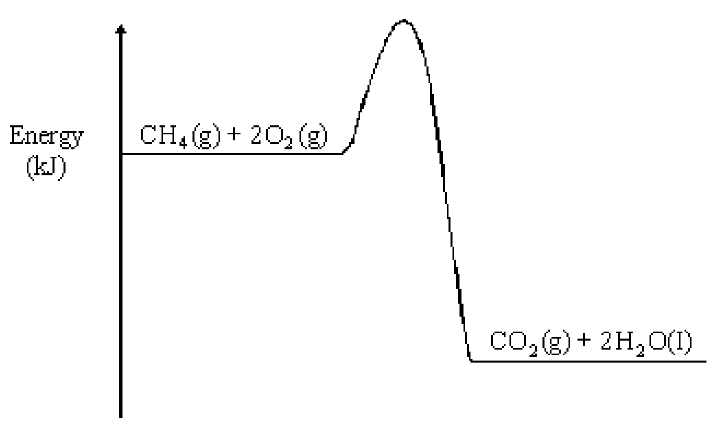
.... **(2)**

(Total 3 marks)

Q14. Many hydrocarbons are used as fuels. An energy level diagram is shown for the combustion of the hydrocarbon methane.



Describe and explain why the line rises and then falls to a lower level.

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(Total 4 marks)

Q15. Some of the hydrogen and chlorine are reacted together to form hydrogen chloride.

$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

Bond	**Bond energy in kJ/mol**
Cl–Cl	242
H–Cl	431
H–H	436

(i) Use the bond energies to calculate the energy change for the formation of hydrogen chloride.

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Energy change = ... kJ/mol

(3)

(ii) Is this reaction exothermic or endothermic? Explain your answer.

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(2)

(iii) Explain why hydrogen chloride only acts as an acid when dissolved in water.

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(3)

(Total 8 marks)

Q16. The reaction of methane with steam is used in industry to make hydrogen.

(a) One of the reactions in this process is represented by this equation.

$$CH_4\,(g) \quad + \quad H_2O \quad \rightleftharpoons \quad CO\,(g) \quad + \quad 3H_2\,(g)$$

The forward reaction is endothermic.

State the conditions of temperature and pressure that would give the maximum yield of hydrogen.

Explain your answers.

(i) Temperature

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(2)

(ii) Pressure

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(2)

(iii) Which one of the following metals is most likely to be a catalyst for this process? Draw a ring around your answer.

aluminium **lead** **magnesium** **nickel** **sodium**

Give a reason for your choice.

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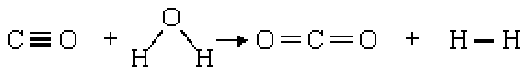
(1)

(b) A second stage in this process is represented by this equation.



(i) Use the bond energies given in the table to help you to calculate the nett energy transfer (energy change) for this reaction.

Bond	Bond energy in kJ/mol
$C \equiv O$	1077
$C = O$	805
H – H	436
O – H	464

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Nett energy transfer = ... kJ/mol

(3)

(ii) State whether this reaction is exothermic or endothermic. ....

Explain, by reference to your calculation, how you know.

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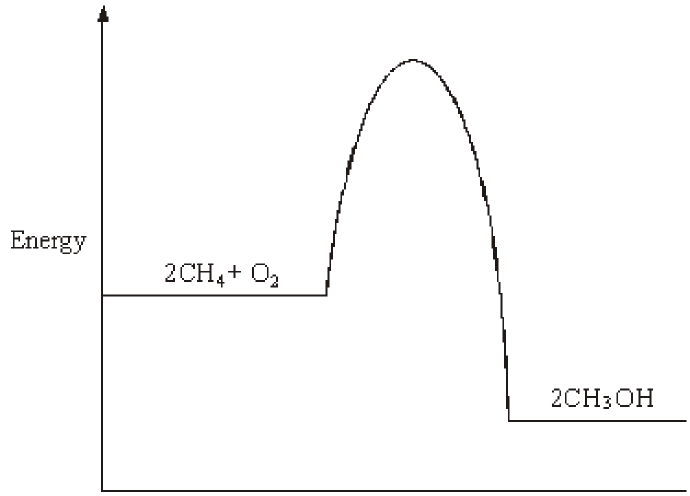
(2)
(Total 10 marks)

Q17. Methanol (CH_3OH) can be made by reacting methane (CH_4) and oxygen (O_2) in the presence of a platinum catalyst. The reaction is exothermic.

An equation that represents the reaction is:

$$2CH_4 + O_2 \rightarrow 2CH_3OH$$

(a) The energy level diagram for this reaction is given below.



(i) Use the diagram to explain how you know that this reaction is exothermic.

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(1)

(ii) Explain, in terms of the energy level diagram, how the platinum catalyst increases the rate of this reaction.

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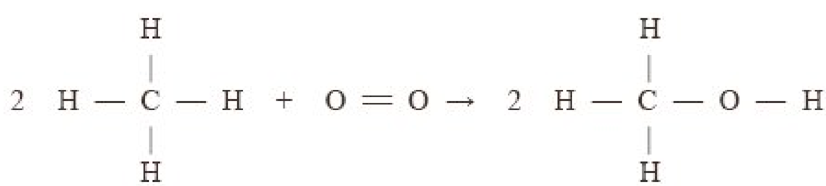
(1)

(b) The equation can also be written showing the structural formulae of the reactants and the product.



(i) Use the bond energies given in the table to help you to calculate the energy change for this reaction.

Bond	Bond energy in kJ
C — H	435
O = O	498
C — O	805
O — H	464

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Energy change = ... kJ

(3)

(ii) In terms of the bond energies, explain why this reaction is exothermic.

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(1)
(Total 6 marks)

Q18.

An airship caught fire when it was coming in to land in 1937. The airship was filled with hydrogen. A spark or flame ignited the hydrogen. The hydrogen reacted with oxygen in the air to produce water.

(a) The equation for the reaction can be represented using structural formulae for the chemicals.

$$2\ H-H + O=O \rightarrow 2\ H-O-H$$

Use the bond energies given in the table to help you to calculate the energy change for this reaction.

Bond	Bond energy in kJ per mole
H – H	436
O = O	498
O – H	464

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Energy change = ... kJ

(3)

(b) Explain, in terms of making and breaking bonds, why this reaction is exothermic.

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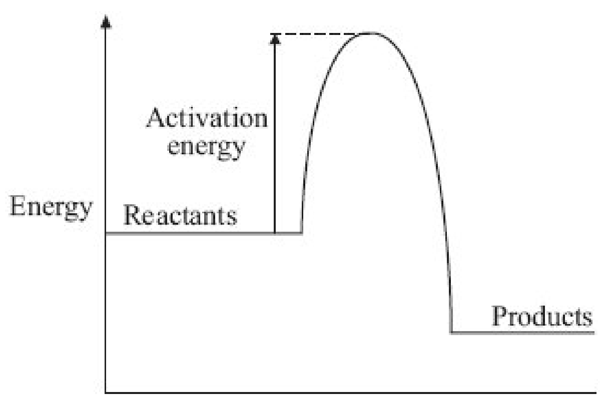
(1)

(c) Use the energy level diagram for this reaction to help you to answer these questions.



(i) The hydrogen did **not** burn until ignited by a spark or flame.

Explain why.

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(1)

(ii) Platinum, a transition metal, causes hydrogen to ignite **without** using a spark or flame.

Explain why.

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(2)

(Total 7 marks)

Q19. Hydrogen could be the fuel used in all cars. One advantage is that when hydrogen reacts with oxygen only water is produced.

The chemical equation for this reaction is:

$$2\,H_2 \quad + \quad O_2 \longrightarrow 2H_2O$$

This equation can be written showing the structural formulae.

$$2\ \mathrm{H{-}H} \quad + \quad \mathrm{O{=}O} \longrightarrow 2\ \mathrm{H{-}O{-}H}$$

(a) Use the bond energies in the table to calculate the energy change for this reaction.

Bond	**Bond energy in kJ**
H – H	436
O = O	498
O – H	464

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Energy change = ... kJ

(3)

(b) Suggest why the bond energy of O = O is higher than the bond energies of both H – H and O – H.

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(1)

(c) In terms of bond energies, explain why hydrogen can be used as a fuel

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(2)
(Total 6 marks)

Q20. When a known mass of a hydrocarbon was completely burned in oxygen, 17.6 g of carbon dioxide and 7.2 g of water were the only products.

Relative formula masses (M_r): CO_2 = 44; H_2O = 18.

Use this information to calculate the number of moles of carbon dioxide and of water produced in this reaction. Use your answers to calculate the empirical formula of this hydrocarbon.

You must show your working to gain full marks.

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The empirical formula of this hydrocarbon is ....

(3)
(Total 3 marks)

Q21. During a thunderstorm lightning strikes the Eiffel Tower.

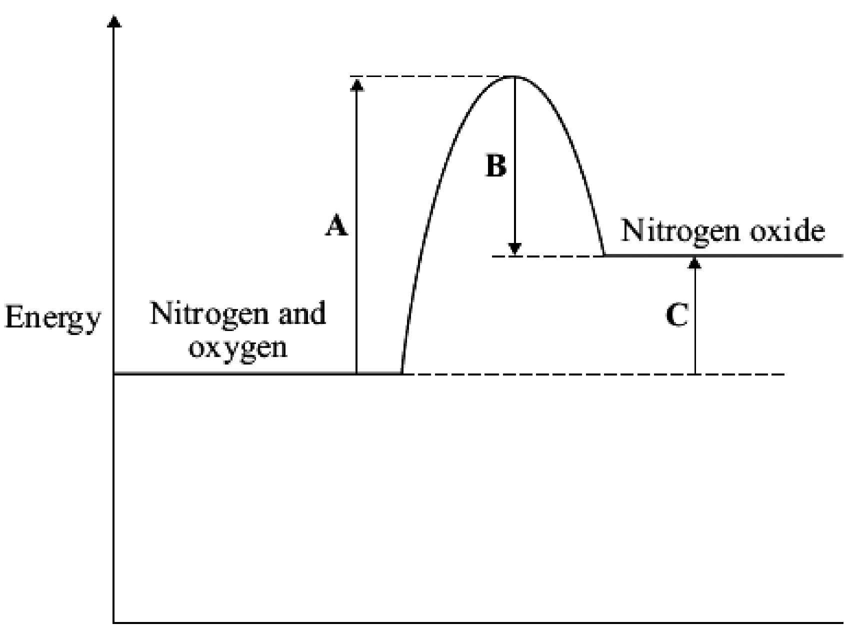
By M. G. Loppé [Public domain], via Wikimedia Commons

In lightning the temperature can reach 30 000 °C. This causes nitrogen and oxygen in the air to react, producing nitrogen oxide. This reaction has a high *activation energy* and is *endothermic*.

An equation that represents this endothermic reaction is:

$$N_2 \quad + \quad O_2 \quad \rightarrow \quad 2NO$$

The energy level diagram for this reaction is given below.



(a) The energy level diagram shows that this reaction is *endothermic*.

Explain how.

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(1)

(b) What is meant by the term *activation energy*?

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(1)

(c) The equation showing the structural formulae of the reactants and products is

$$N \equiv N \quad + \quad O = O \quad \rightarrow \quad 2\ N = O$$

Bond	**Bond energy in kJ**
N ≡ N	945
O = O	498
N = O	630

(i) Use the bond energies in the table to calculate the energy change for this reaction.

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Energy change = ... kJ

(3)

(ii) In terms of bond energies, explain why this reaction is endothermic.

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(1)
(Total 6 marks)

Q22. Hydrogen peroxide decomposes to give water and oxygen.

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

The reaction is *exothermic*.

(a) Explain, in terms of bond breaking and bond making, why the decomposition of hydrogen peroxide is *exothermic*.

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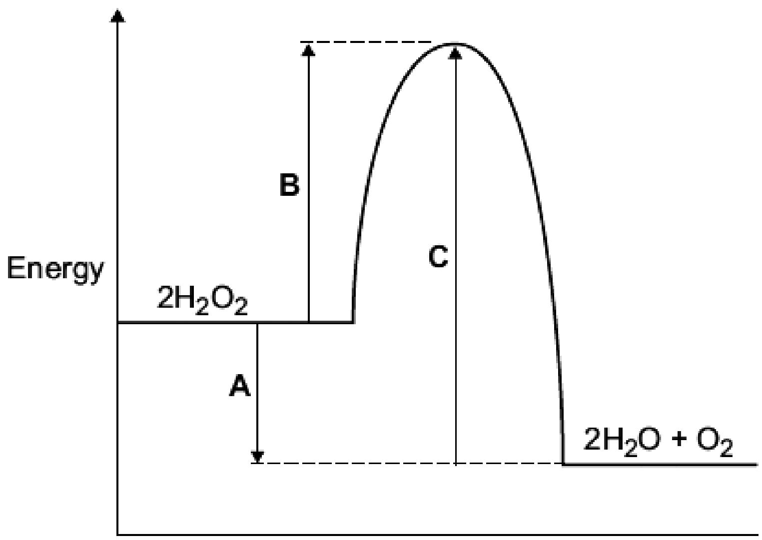
(1)

(b) The energy level diagram for this reaction is shown below.



The energy changes, **A**, **B** and **C**, are shown on the diagram.

Use the diagram to help you answer these questions.

(i) How do you know that this reaction is *exothermic*?

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(1)

(ii) The decomposition of hydrogen peroxide is slow.
What does this suggest about energy change **B**?

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(1)

(iii) Hydrogen peroxide decomposes quickly when a small amount of manganese(IV) oxide is added.

Explain why.

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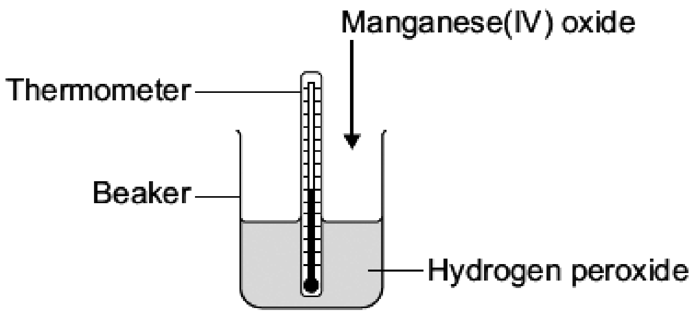
(2)

(c) A student did an experiment to find the amount of energy produced when hydrogen peroxide solution is decomposed using manganese(IV) oxide.

The apparatus the student used is shown in the diagram.



The student first measured the temperature of the hydrogen peroxide. Then the student added the manganese(IV) oxide and recorded the highest temperature.

The temperature rise was smaller than expected.

Suggest why.

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(2)
(Total 7 marks)

Q23. Hydrogen peroxide is often used to bleach or lighten hair.

Hydrogen peroxide slowly decomposes to produce water and oxygen.

(a) The equation for the reaction can be represented using structural formulae.

$$2\ H-O-O-H \longrightarrow 2\ H-O-H \quad + \quad O=O$$

Use the bond energies in the table to help you to calculate the energy change for this reaction.

Bond	**Bond energy in kJ per mole**
H – O	464
O – O	146
O = O	498

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Energy change = ... kJ

(3)

(b) Explain, in terms of bond making and bond breaking, why the reaction is exothermic.

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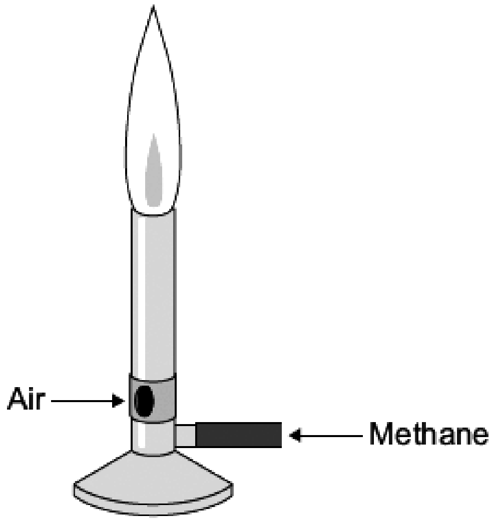
(1)
(Total 4 marks)

Q24. A Bunsen burner releases heat energy by burning methane in air.



(a) Methane (CH_4) reacts with oxygen from the air to produce carbon dioxide and water.

(i) Use the equation and the bond energies to calculate a value for the energy change in this reaction.

$$CH_4 \;(\text{H–C(H)(H)–H}) + 2[O=O] \longrightarrow O=C=O + 2[H\!-\!O\!-\!H]$$

Bond	Bond energy in kJ per mole
C — H	414
O = O	498
C = O	803
O–H	464

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Energy change = ... kJ per mole

(3)

(ii) This reaction releases heat energy.

Explain why, in terms of bond energies.

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(2)

(b) If the gas tap to the Bunsen burner is turned on, the methane does not start burning until it is lit with a match.

Why is heat from the match needed to start the methane burning?

....

....

(1)
(Total 6 marks)

Q25. Vinegar can be added to food. Vinegar is an aqueous solution of ethanoic acid.

Ethanoic acid is a *weak* acid.

(a) Which ion is present in aqueous solutions of all acids?

....

(1)

(b) What is the difference between the pH of a *weak* acid compared to the pH of a strong acid of the same concentration?

Give a reason for your answer.

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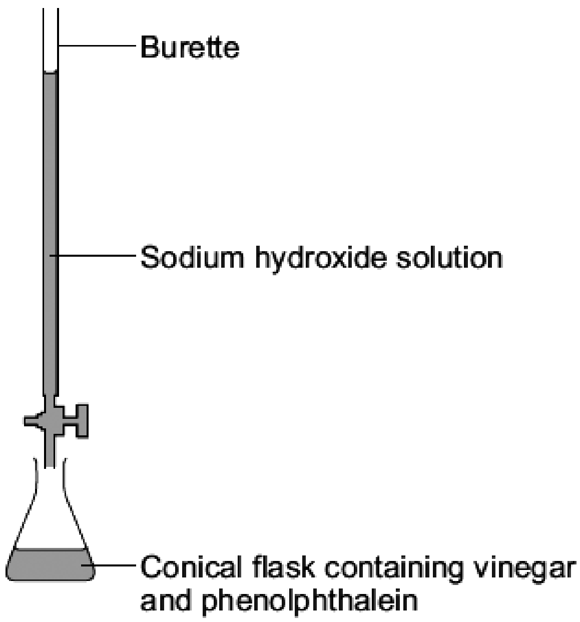
....

....

(2)

(c) The diagram shows the apparatus used to find the concentration of ethanoic acid in vinegar.



(i) Why should phenolphthalein indicator be used for this titration instead of methyl orange?

....

....

(1)

(ii) 25.00 cm^3 of vinegar was neutralised by 30.50 cm^3 of a solution of sodium hydroxide with a concentration of 0.50 moles per cubic decimetre.

The equation for this reaction is:

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$$

Calculate the concentration of ethanoic acid in this vinegar.

....

....

....

....

Concentration of ethanoic acid in this vinegar = ... moles per cubic decimetre

(2)

(d) The concentration of ethanoic acid in a different bottle of vinegar was 0.80 moles per cubic decimetre.

Calculate the mass in grams of ethanoic acid (CH_3COOH) in 250 cm^3 of this vinegar.

The relative formula mass (M_r) of ethanoic acid = 60.

....

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....

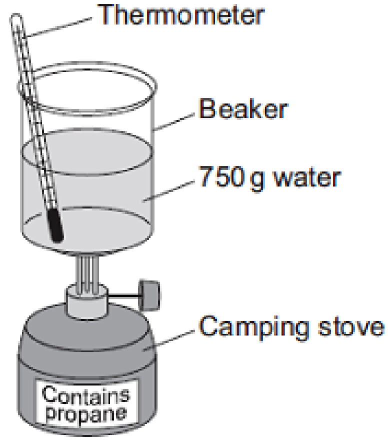
....

Mass of ethanoic acid = ... g

(2)

(Total 8 marks)

Q26. A camping stove uses propane gas.



(a) A student did an experiment to find the energy released when propane is burned.

The student:

- put 750 g water into a beaker
- measured the temperature of the water, which was 17 °C
- heated the water by burning propane
- measured the temperature of the water again, which was then 64 °C.

The student calculated the energy released using the equation

$$Q = m \times 4.2 \times \Delta T$$

Where:

Q = energy released (J)

m = mass of water (g)

ΔT = temperature change (°C)

(i) Use the student's results to calculate the energy released in joules (J).

....

....

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....

....

Energy released = ...

(3)

(ii) To find how much propane had been used the student weighed the camping stove before and after the experiment. The mass of the camping stove decreased by 6.0 g.

Using this information and your answer to part (a)(i), calculate the energy in kJ released when 1 mole of propane burns.

(If you have no answer for part (a)(i), assume the energy released during the experiment is 144 000 J. This is not the answer to part (a)(i).)

Relative formula mass (M_r) of propane = 44.

....

....

....

....

Energy released = ... kJ

(2)

(iii) Suggest **two** things the student could do to make his results more accurate.

....

....

....

....

(2)

(iv) The student's method does **not** give accurate results.

However, this method is suitable for comparing the energy released by different fuels.

Suggest why.

....

....

(1)

(b) The student used bond energies to calculate the energy released when propane is burned.

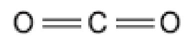
The equation for the combustion of propane is:

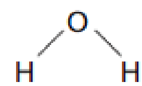
$$C_3H_8 \quad + \quad 5O_2 \quad \longrightarrow \quad 3CO_2 \quad + \quad 4H_2O$$

Some bond energies are given in the table

Bond	**Bond Energy in kJ per mole**
C=O	830
O—H	464

The displayed structures of the products are:

carbon dioxide 

water 

(i) Calculate the energy released by bond making when the products are formed.

....

....

....

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....

Energy released = ... kJ per mole

(3)

(ii) The energy used for bond breaking of the reactants in the equation is 6481 kJ per mole.

Calculate the overall energy change of this reaction.

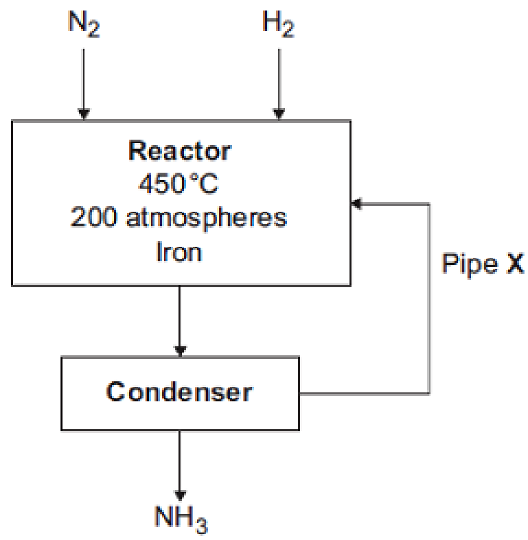
....

....

Overall energy change = ... kJ per mole

(1)
(Total 12 marks)

Q27. The flow diagram shows the Haber process. In the Haber process, ammonia (NH_3) is produced from nitrogen (N_2) and hydrogen (H_2).



(a) Which raw material is nitrogen obtained from?

....

(1)

(b) What is the purpose of Pipe **X**?

....

....

....

....

(2)

(c) Balance the chemical equation below for the production of ammonia.

N_2 + ...H_2 $\rightleftharpoons$ ....NH_3

(1)

(d) A temperature of 450°C is used in the reactor.
The reaction of nitrogen with hydrogen is reversible.
The forward reaction is exothermic.

Explain why a temperature of 450°C is the optimum temperature for the Haber process.

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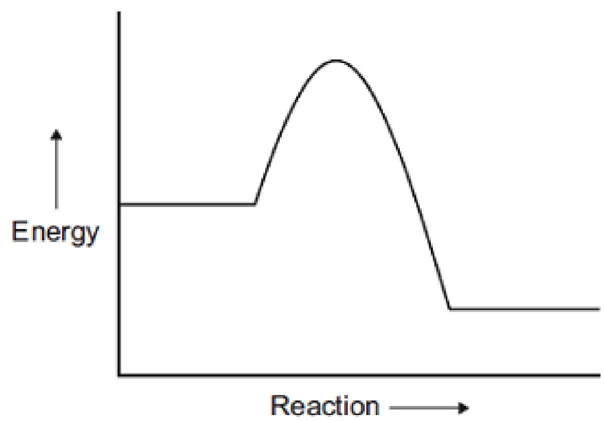
(2)

(e) An energy level diagram for the reaction between nitrogen and hydrogen is shown below.



(i) How does the energy level diagram show this reaction is exothermic?

....

....

(1)

(ii) In the Haber process iron is used as a catalyst.

Draw a line on the energy level diagram to show the effect of adding a catalyst.

(1)
(Total 8 marks)