



**Fuels & Thermochemistry**  
**Chemistry Past Exam Questions**  
**Higher Level**

## Section B - Question 6

6. (a) Define the *octane number* of a fuel. (5)

(b) Compound A is obtained from the fractional distillation of crude oil and is converted to compound B by isomerisation.

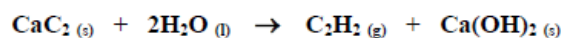
(i) Give the systematic (IUPAC) names for A and B.

(ii) Explain the term *isomerisation*.

Draw the structural formula of another isomer of A and B.

(iii) Predict whether A or B has the higher octane number. Justify your answer. (21)

(c) Ethyne is produced from calcium carbide and water according to the following balanced equation:

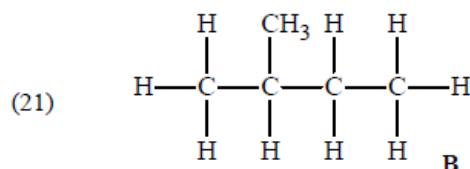
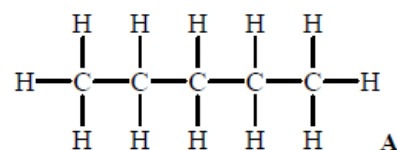


Calculate the heat change for this reaction given that the heats of formation of calcium carbide, water, ethyne and calcium hydroxide are  $-59.8$ ,  $-285.8$ ,  $227.4$  and  $-985.2$   $\text{kJ mol}^{-1}$  respectively. (15)

(d) Describe the structure of benzene in terms of

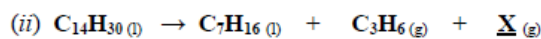
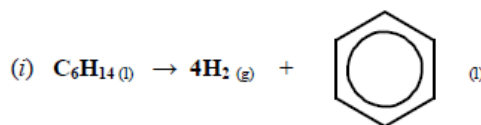
(i) the bonding between the carbon atoms and the hydrogen atoms,

(ii) the bonding between the carbon atoms. (9)



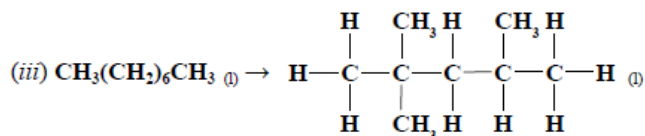
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6. (a) Several processes are used in oil refining to convert less useful hydrocarbons into more useful ones. For each conversion, (i) to (iii), name the process involved. (8)



- (b) Name a hydrocarbon that X could be and draw its structural formula.

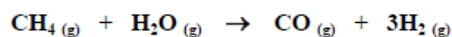
Name the product of process (iii) and state its octane number. (12)



- (c) Explain why the substance MTBE (methyl *tert*-butyl ether) is sometimes added to motor fuel. Name the substance previously added to motor fuel for the same purpose and state why its use was discontinued. (9)
- (d) Define *heat of combustion*. Name the laboratory apparatus used to measure the heats of combustion of fuels and foodstuffs. (9)
- (e) Calculate the heat of formation of the hydrocarbon ( $\text{C}_8\text{H}_{18}$ ) produced in process (iii), given that its heat of combustion value has been measured to be  $-5502 \text{ kJ mol}^{-1}$  and that the heats of formation of carbon dioxide and water are  $-394$  and  $-286 \text{ kJ mol}^{-1}$ , respectively. (12)



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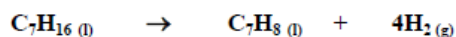
6. Over 20% of the crude oil refined at Whitegate in Cork Harbour in 2010 was imported from Libya. Libyan crude oil is particularly valued because of its rich light gasoline and naphtha content. Social unrest in the Middle East early in 2011 has again highlighted Ireland's heavy dependence on oil as an energy source. Unstable supplies, the high cost of importing quality crude oil, and environmental issues focus attention on alternative energy sources including fuels, other than fossil fuels, e.g. hydrogen, and diesel derived from vegetable oil.
- (a) What is the nature of the chemicals that make up the bulk of crude oil? (5)
- (b) Unprocessed crude oil, obtained by drilling on land or at sea, is not generally useful. Describe with the aid of a labelled diagram how crude oil is separated into useful substances in an oil refinery. Give the major use for the light gasoline and naphtha fractions of crude oil. (15)
- (c) What is *catalytic cracking*? Why is it carried out in oil refining? (9)
- (d) Hydrogen gas can be obtained industrially by the reaction between natural gas and water in the form of steam (steam reforming).
- (i) Describe another method by which large quantities of hydrogen can be obtained from water.
- (ii) State **one** disadvantage of using hydrogen as a fuel. (9)
- (e) Steam reforming takes place according to the following balanced equation:



Calculate the heat of this steam reforming reaction given that the heats of formation of methane, steam and carbon monoxide are  $-74.6$ ,  $-242$  and  $-111 \text{ kJ mol}^{-1}$  respectively. (12)

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6. (a) Give the systematic (IUPAC) names for the three hydrocarbon compounds X, Y and Z. (8)  $\text{CH}_3(\text{CH}_2)_5\text{CH}_3$  X
- (b) Compounds X and Z are obtained from the same fraction in the oil refining process. Name the fraction in which X and Z occur. What two properties of the compounds are responsible for them being found in the same fraction? (9)  Y
- (c) What is meant by *auto-ignition* in petrol engines? Compound Y has an octane number of 83 and therefore has the same octane rating as an 83:17 mixture of two reference hydrocarbons. Name the reference hydrocarbon that is the major component of the 83:17 reference mixture. (6)  Z
- (d) Define *heat of combustion*. Outline how the heat of combustion of X could be measured using a bomb calorimeter. (15)
- (e) In order to increase its octane rating, compound X is converted to compound Z in oil refineries by the following reforming (dehydrocyclisation) process:

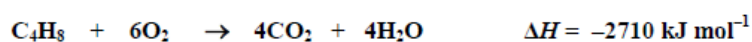


Calculate the heat change for this reaction given that the heats of formation of  $\text{C}_7\text{H}_{16(l)}$ , and  $\text{C}_7\text{H}_8(l)$  are  $-224.2$  and  $12.4 \text{ kJ mol}^{-1}$ , respectively.

State one important industrial use for the hydrogen produced in this reaction. (12)

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6. (a) Define (i) hydrocarbons, (ii) structural isomers. (8)
- (b) Give a use for the kerosene fraction obtained when crude oil is fractionated.  
Explain why some of the kerosene produced in oil refining is subjected to catalytic cracking. (9)
- (c) Straight chain molecules of  $C_{13}H_{28}$  occur in the kerosene fraction. Upon cracking a molecule of  $C_{13}H_{28}$ , a  $C_2H_4$  molecule, a  $C_4H_8$  molecule and an unbranched alkane molecule are obtained. Identify this unbranched alkane molecule and state its octane number.  
Draw structures for three of the isomers of  $C_4H_8$ . (15)
- (d) Name two other processes carried out in oil refineries to modify hydrocarbon structures. (6)
- (e) The combustion of one of the  $C_4H_8$  isomers is described by the following balanced equation.



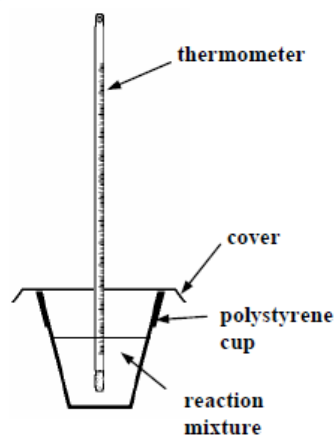
The standard heats of formation of water and carbon dioxide are  $-286$  and  $-394 \text{ kJ mol}^{-1}$ , respectively.  
Calculate the heat of formation of this  $C_4H_8$  isomer. (12)

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6. (a) The hydrocarbon molecules in petrol typically contain carbon chains with between five and ten carbon atoms. The most widely used petrol in Ireland has an octane number of 95.
- (i) What is meant by the *octane number* of a fuel? (5)
  - (ii) The two hydrocarbons used as references when establishing the octane number of a fuel are heptane and 2,2,4-trimethylpentane. Draw the structure of each of these molecules. (6)
  - (iii) Crude oil is separated into a number of fractions in oil refining. Name the **two** fractions which contain molecules with the carbon chain lengths needed for petrol. (6)
  - (iv) Dehydrocyclisation is one of the processes used to increase the octane numbers of hydrocarbons. What **two** changes to the hydrocarbon molecules occur during this process? (6)
  - (v) Ethanol is an example of an oxygenate. Give another example of an oxygenate. Give **two** reasons why oxygenates are added to petrol. (9)
- (b) Write a balanced chemical equation for the combustion of ethanol,  $C_2H_5OH$ .  
Given that the heats of formation of ethanol, carbon dioxide and water are  $-278$ ,  $-394$  and  $-286 \text{ kJ mol}^{-1}$ , respectively, calculate the heat of combustion of ethanol. (18)

## Section A - Question 3

3. In an experiment to measure the heat of reaction for the reaction between sodium hydroxide with hydrochloric acid, a student added 50 cm<sup>3</sup> of 1.0 M HCl solution to the same volume of 1.0 M NaOH solution in a polystyrene foam cup.



- (a) To achieve an appreciable temperature rise during the reaction, quite concentrated solutions of acid and base, carrying the label illustrated, were used. What word describes the chemical hazard illustrated in this label? State **one** precaution the student should take when using these solutions. (8)
- (b) The student had a choice of using either a graduated cylinder or a burette to measure out the solutions used in this experiment. Which piece of apparatus should have been used to achieve the more accurate result? (3)
- (c) If the hydrochloric acid and sodium hydroxide solutions had been stored at slightly different temperatures, explain how the initial temperature of the reaction mixture could have been obtained. (6)
- (d) List **three** precautions which should have been taken in order to obtain an accurate value for the highest temperature reached by the reaction mixture. (9)
- (e) What was the advantage of mixing the solutions in a polystyrene foam cup rather than in a glass beaker or in a metal calorimeter? (3)
- (f) Calculate the number of moles of acid neutralised in this experiment. Taking the total heat capacity of the reaction mixture used in this experiment as 420 J K<sup>-1</sup>, calculate the heat released in the experiment if a temperature rise of 6.7 °C was recorded. Hence calculate the heat of reaction for
- $$\text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O} \quad (18)$$
- (g) Name the piece of apparatus used in industry to accurately measure the heats of combustion of foods and fuels. (3)



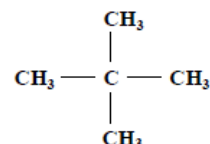
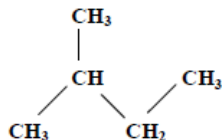
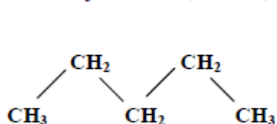


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6. Useful hydrocarbons are obtained by the fractional distillation of crude oil, which itself has little or no direct use. Hydrocarbons are excellent fuels.

(a) In which fraction of crude oil do pentane and its isomers occur? (5)

Give the systematic (IUPAC) name of each of the structural isomers of pentane shown below. (9)



Which of these isomers would you predict to have the lowest octane number?

Justify your choice in terms of the structural features of the molecules. (9)

Write a balanced equation for the combustion of pentane ( $\text{C}_5\text{H}_{12}$ ) in excess oxygen. (6)

(b) Naphtha and gas oil are two of the hydrocarbon fractions obtained from the fractional distillation of crude oil. How do the molecules of the naphtha fraction differ from the molecules of the gas oil fraction? (3)

Explain with the aid of a labelled diagram how naphtha (b.p. approximately  $100^\circ\text{C}$ ) is separated from gas oil (b.p. approximately  $300^\circ\text{C}$ ) in the fractional distillation of crude oil. (9)

Bitumen is a residue fraction obtained from crude oil. Give **one** use for bitumen. (3)

(c) What is catalytic cracking? What is its economic importance in oil refining? (6)

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6. (a) The table shows the octane numbers of four hydrocarbons.

Name	Formula	Octane No.
hexane	$C_6H_{14}$	25
cyclohexane	$C_6H_{12}$	83
benzene	$C_6H_6$	100
2,2,4-trimethylpentane	$C_8H_{18}$	100

(i) What is meant by the octane number of a fuel? (8)

(ii) Hexane has the lowest octane number of the four compounds listed. What structural feature of the molecule contributes to this? (3)

(iii) In the case of each of the other three compounds, identify the structural feature of its molecules which contributes to it having a high octane number. (9)

(iv) Name the process carried out in an oil refinery that converts hexane to compounds such as cyclohexane and benzene. Why is the use of benzene in petrol strictly controlled? (6)

(b) (i) Give two reasons why oxygenates such as MTBE are added to petrol.

(ii) Give two reasons why the addition of lead to petrol has been discontinued. (12)

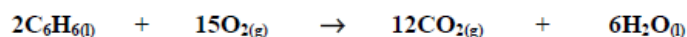
(c) The combustion of cyclohexane may be described by the following balanced equation:



Given that the heats of formation of cyclohexane, carbon dioxide and water are  $-156$ ,  $-394$  and  $-286 \text{ kJ mol}^{-1}$ , respectively, calculate the heat of combustion of cyclohexane. (12)

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6. (a) The octane number of a fuel is described as *a measure of the tendency of the fuel to cause knocking*, or as *a measure of the tendency of the fuel to resist auto-ignition*. This number is found by comparing the combustion of the fuel with the combustion of a mixture of two reference hydrocarbons using the same standard engine.
- (i) Name **both** of the reference hydrocarbons present in the mixture used when measuring octane number by this comparison method. (8)
  - (ii) State **two** structural features of a hydrocarbon molecule which contribute to it having a high octane number. (6)
  - (iii) Lead compounds were used in the past to increase the octane number of fuels. Why are lead compounds unsuitable as additives for petrol used in modern cars? (3)
  - (iv) Identify **one** additive *or* type of additive, other than a compound of lead, used to increase the octane number of fuels. (3)
- (b) There are **three** structural isomers of the hydrocarbon of formula  $C_5H_{12}$ . In the case of **each** of these isomers, draw the structure of the molecule and give its systematic IUPAC name. (18)
- (c) The combustion of liquid benzene is described by the following equation:



Given that the heats of formation of carbon dioxide gas, liquid water and liquid benzene are  $-394$ ,  $-286$  and  $49 \text{ kJ mol}^{-1}$  respectively, calculate the heat of combustion of liquid benzene. (12)