An introduction to organic chemistry

(Past Year Topical Questions 2010-2015)

May/June 2010 (21)

5 Isomerism occurs in many organic compounds. The two main forms of isomerism are structural isomerism and stereoisomerism. Many organic compounds that occur naturally have molecules that can show stereoisomerism, that is *cis-trans* or optical isomerism.

(a) (i) Explain what is meant by *structural isomerism*.

.....

.....

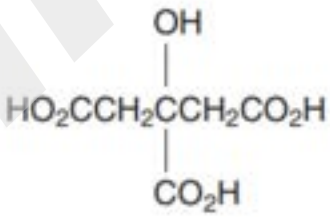
(ii) State **two** different features of molecules that can give rise to **stereoisomerism**.

.....

.....

[3]

Another acid present in unripe fruit is citric acid,



(c) Does citric acid show optical isomerism? Explain your answer.

.....

.....

..... [1]

A third polycarboxylic acid present in unripe fruit is a colourless crystalline solid, **W**, which has the following composition by mass: C, 35.8%; H, 4.5%; O, 59.7%.

(d) (i) Show by calculation that the empirical formula of **W** is $C_4H_6O_5$.

(ii) The M_r of **W** is 134. Use this value to determine the molecular formula of **W**.

[3]

A sample of **W** of mass 1.97 g was dissolved in water and the resulting solution titrated with 1.00 mol dm^{-3} NaOH. 29.4 cm^3 were required for complete neutralisation.

(e) (i) Use these data to deduce the number of carboxylic acid groups present in one molecule of **W**.

(ii) Suggest the displayed formula of **W**.

[5]

May/June 2010 (22)/Q4

(c) Compound **F**, is an ester with the molecular formula $C_4H_8O_2$.

F is one of four isomers, **S**, **T**, **U**, and **V**, that are all esters.

In the boxes below, the structural formula of **S** is given.

Draw the structural formulae of the other **three** isomers of **F** that are esters.

$HCO_2CH(CH_3)_2$ **S**	**T**	**U**	**V**

[3]

May/June 2010 (23)

4 Organic reactions involve substances which may be

atoms, *molecules*, *ions* or *free radicals*.

We also apply the terms

electrophilic, *nucleophilic*, *addition*, *elimination* and *substitution*

to organic reactions.

Consider the following reactions.

$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ reaction 1

$CH_3CH_2OH \rightarrow CH_2{=}CH_2 + H_2O$ reaction 2

$CH_3I + OH^- \rightarrow CH_3OH + I^-$ reaction 3

$CH_3COCH_3 + HCN \rightarrow CH_3C(OH)(CN)CH_3$ reaction 4

(b) By considering the four reactions above, suggest a formula for **each** of the following substances.
In **each** case, state which reaction you are considering.

(i) **one** substance that is an addition product

reaction..... addition product

(ii) **one** substance that is a leaving group

reaction..... leaving group

(iii) **one** substance that behaves as an electrophile

reaction..... electrophile

[3]

(c) What is meant by the term *nucleophile*?

.....

..... [1]

(d) Reactions 3 and 4 involve nucleophiles.

For **each** reaction, give the formula of the nucleophile.

reaction 3

reaction 4

[2]

Oct/Nov 2010 (21)/Q3

Pentane, C_5H_{12}, exhibits structural isomerism.

(c) **(i)** Draw the three structural isomers of pentane.

isomer **B**	isomer **C**	isomer **D**

(d) When CFCs are present in the upper atmosphere, homolytic fission takes place in the presence of ultraviolet light.

(i) What is meant by the term *homolytic fission*?

.....

.....

(ii) Suggest an equation for the homolytic fission of CCl_2F_2.

.....[2]

(e) The most common replacements for CFCs as aerosol propellants are hydrocarbons such as propane and butane.

Suggest **one** disadvantage of these compounds as aerosol propellants.

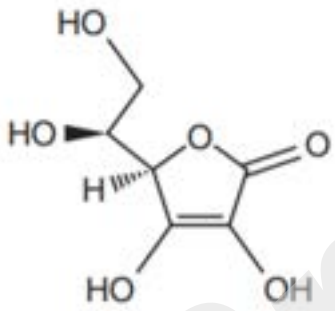
.....[1]

May/June 2011 (22)/Q5

Animal fats and vegetable oils can become rancid because of oxidation. The rancid fat or oil has an unpleasant smell and taste.

Antioxidants are used to prevent the spoilage of many foodstuffs by oxidation.

One antioxidant that is widely used is vitamin C, ascorbic acid.



ascorbic acid

(f) **(i)** How many chiral carbon atoms are present in one molecule of ascorbic acid? If none, write 'none'.

.....

(ii) The ascorbic acid molecule contains three functional groups.

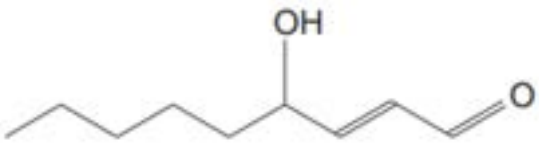
Two of these are alcohol (primary and secondary) and alkene.

What is the name of the third functional group?

..... [2]

May/June 2011 (23)

4 The compound *trans*-4-hydroxy-2-nonenal (HNE) is thought to lead to infections of the lung when cigarettes are smoked.



$CH_3(CH_2)_4CH(OH)CH{=}CHCHO$

***trans*-4-hydroxy-2-nonenal**

(a) What is the empirical formula of *trans*-4-hydroxy-2-nonenal?

.....

[1]

(b) **(i)** HNE contains an alkene group. Name as fully as you can **two** other functional groups which are present in the HNE molecule.

.....

.....

5 Fermentation of sugars by bacteria or moulds produces many different organic compounds.

One compound present in fermented molasses is 2-ethyl-3-methylbutanoic acid which gives a distinctive aroma to rum.

$(CH_3)_2CHCH(C_2H_5)CO_2H$

2-ethyl-3-methylbutanoic acid

(a) **(i)** What is the molecular formula of 2-ethyl-3-methylbutanoic acid?

(ii) How many chiral carbon atoms are present in a molecule of 2-ethyl-3-methylbutanoic acid? If none write 'none'.

.....

[2]

An isomer of 2-ethyl-3-methylbutanoic acid which is an ethyl ester is a very strong smelling compound which is found in some wines.

(d) This ethyl ester contains a branched hydrocarbon chain and is chiral.

Draw the displayed formula of this ethyl ester.

Identify the chiral carbon atom with an asterisk (*).

[3]

Oct/Nov 2011 (21)

5 Astronomers using modern telescopes of various types have found many molecules in the dust clouds in space. Many of these molecules are those of organic compounds and astronomers constantly look for evidence that amino acids such as aminoethanoic acid, $H_2NCH_2CO_2H$, are present.

One molecule that has been found in the dust clouds is hydroxyethanal, $HOCH_2CHO$.

(a) Hydroxyethanal contains two functional groups.

(i) Name, **as fully as you can**, each of the functional groups present in hydroxyethanal.

1 .....

2 .....

(ii) For **each** functional group, identify a reagent that will react with this group and **not** react with the other functional group present.
In each case, describe what would be observed when this reaction is carried out.

functional group 1 reagent .....

observation.....

functional group 2 reagent .....

observation..... [7]

Oct/Nov 2011 (23)/Q2

(b) Analysis of another organic compound, **B**, gave the following composition by mass: C, 64.86%; H, 13.50%, O, 21.64%.

(i) Use these values to calculate the empirical formula of **B**.

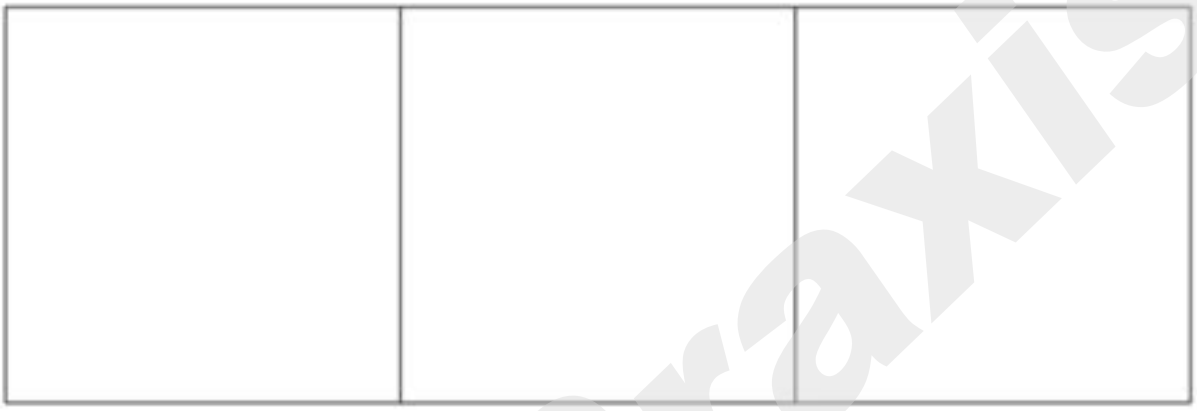
(ii) The empirical and molecular formulae of **B** are the same.

B is found to be chiral.

Draw displayed formulae of the two optical isomers of this compound, indicating with an asterisk (*) the chiral carbon atom.

(iii) There are three other structural isomers of **B** which are not chiral but which contain the same functional group as **B**.

In the boxes below, draw the structural formulae of these isomers.



[7]

Oct/Nov 2011 (23)

4 The structural formulae of six different compounds, **P – U**, are given below.

$CH_3CH=CHCH_2CH_3$	$CH_3CH_2COCH_2CH_3$	$CH_2=CHCH_2CH_2CH_3$
P	**Q**	**R**
$CH_3CH_2CH_2CH_2CH_2OH$	$HOCH_2CH_2CH(OH)CH_3$	$CH_3CH_2CH_2OCH_2CH_3$
S	**T**	**U**

(a) (i) What is the empirical formula of compound **T**?

.....

(ii) Draw the skeletal formula of compound **S**.

[2]

(b) (i) Compounds **S** and **U** are isomers.

What type of isomerism do they show?

.....

(ii) Two of the six formulae **P – U** can **each** be drawn in two forms which are known as stereoisomers.

Which two compounds have formulae that can be drawn in two forms?

What type of stereoisomerism does each show?

Identify each compound by its letter.

compound	type of stereoisomerism

[3]

May/June 2012 (22)/Q3

Malic acid has the structural formula $HO_2CCH_2CH(OH)CO_2H$.

(d) (i) Malic acid is chiral.
Draw fully displayed formulae of the two optical isomers of malic acid.
Indicate with an asterisk (*) the chiral carbon atom.

$HO_2CCH{=}CHCO_2H$

C

(ii) Compound **C** also shows stereoisomerism.
Draw the skeletal formulae of **each** of the stereoisomers of **C**. Label **each** isomer.

[6]

(e) The food additive E330 is another organic compound which occurs naturally in fruit. E330 has the following composition by mass: C, 37.5%; H, 4.17%; O, 58.3%.
Calculate the empirical formula of E330.

[3]

May/June 2012 (23)

3 With the prospect that fossil fuels will become increasingly scarce in the future, many compounds are being considered for use in internal combustion engines. One of these is DME or dimethyl ether, CH_3OCH_3. DME is a gas which can be synthesised from methanol. Methanol can be obtained from biomass, such as plant waste from agriculture.

(c) DME and ethanol are isomers with the molecular formula C_2H_6O.

(i) Draw the displayed formula of DME and of ethanol.

DME	ethanol

(ii) What type of isomerism do DME and ethanol show?

.....

[2]

Oct/Nov 2012 (21)

5 Compound **X** has the molecular formula $C_4H_8O_2$.

(a) (i) Treatment of **X** with sodium metal produces a colourless flammable gas.
What does this result tell you about the functional groups that could be present in **X**?

.....

.....

(ii) There is no reaction when **X** is treated with sodium hydrogencarbonate, $NaHCO_3$.
What does this result tell you about the functional groups that could be present in **X**?

.....

.....

(iii) When **X** is shaken with aqueous bromine the orange colour disappears.
What does this result tell you about the functional groups that could be present in **X**?

.....

.....

[3]

(b) The molecule of **X** has the following features.

- The carbon chain is unbranched and the molecule is not cyclic.
- No oxygen atom is attached to any carbon atom which is involved in π bonding.
- No carbon atom has more than one oxygen atom joined to it.

There are five possible isomers of **X** which fit these data. Four of these isomers exist as two pairs of stereoisomers.

(i) Draw displayed formulae of **each** of these two pairs.

pair 1		
pair 2		

(ii) These four isomers of **X** show two types of stereoisomerism.

State which type of isomerism each pair shows.

pair 1 .....

pair 2 .....

[6]

Oct/Nov 2012 (23)

5 The molecular formula C_4H_8O can represent a number of compounds which have different functional groups and which show different types of isomerism.
Compounds **H**, **J** and **K** each have the molecular formula C_4H_8O.
In **each** of the molecules of **H**, **J** and **K**,

- the carbon chain is unbranched and the molecule is not cyclic,
- no oxygen atom is attached to any carbon atom which is involved in π bonding.

When compound **H** is reacted with sodium metal, a colourless flammable gas is produced.

Both **J** and **K** give an orange-red precipitate when reacted with 2,4-dinitrophenylhydrazine reagent but only **K** reacts with Fehling's solution.

(a) (i) Suggest possible structural formulae for **H**, **J** and **K**.
Three structural formulae are possible for **H** but only one for **J** and one for **K**.

H	J	K

In addition to being structural isomers of each other, some of the possible structures for **H**, **J** or **K** show *cis-trans* isomerism or are chiral.

(ii) Draw the displayed formulae of those isomers which show *cis-trans* isomerism.

(iii) Draw the displayed formulae of those isomers which are chiral, indicating in each case the chiral carbon atom with an asterisk (*).

[8]

May/June 2013 (21)

4 Organic chemistry is the chemistry of carbon compounds. The types of organic reactions that you have studied are listed below.

addition	elimination	hydrolysis
oxidation	reduction	substitution

Addition and substitution reactions are further described as follows.

electrophilic	nucleophilic	free radical

Complete the table below.
Fill in the central column by using **only** the types of reaction given in the lists above.
Use **both** lists when appropriate.
In the right hand column give the formula(e) of the reagent(s) you would use to carry out the reaction given.

organic reaction	type of reaction	reagent(s)
$CH_3CH_2CH_2CH_2Br \rightarrow$ $CH_3CH_2CH_2CH_2NH_2$		
$CH_3CH_2CH_2CH_2OH \rightarrow$ $BrCH_2CH_2CH_2CH_2OH$		
$CH_3COCH_3 \rightarrow$ $CH_3C(OH)(CN)CH_3$		
$CH_3CH(OH)CH_2CH_3 \rightarrow$ $CH_3CH{=}CHCH_3$		

5 Crotonaldehyde, $CH_3CH=CHCHO$, occurs in soybean oils.

(b) Crotonaldehyde exists in more than one stereoisomeric form.
Draw the **displayed formulae** of the **stereoisomers** of crotonaldehyde.
Label **each** isomer.

[3]

(c) Draw the **skeletal formula** of crotonaldehyde.

[1]

Oct/Nov 2013 (23)

4 Compound **Q** is a viscous liquid which is very soluble in water.
The M_r of **Q** is 90.0.

Three possible structures for **Q** are shown below.

R	S	T
$HOCH_2CH_2CO_2H$	$HOCH_2CO_2CH_3$	$HCO_2CH_2CH_2OH$

(a) (i) What type of isomerism do **R**, **S** and **T** show?

.....

(ii) What oxygen-containing functional groups are present in R, **S** and **T**?
Give their **full names**.

R ..... and .....

S ..... and .....

T ..... and .....

(iii) Which functional group(s) in **(ii)** will react with sodium carbonate?

.....

(iv) Which functional group(s) in **(ii)** will react with sodium metal?

.....

[6]

(b) When 0.002 mol of **Q** is reacted with an excess of solid sodium carbonate, Na_2CO_3, 24 cm^3 of carbon dioxide, measured at room temperature and pressure, is produced.

(i) Calculate the amount, in moles, of carbon dioxide produced in this reaction.

(ii) Hence calculate the amount, in moles, of carbon dioxide produced by 1 mol of **Q**.

[2]

When 0.002 mol of **Q** is reacted with an excess of metallic sodium, 48 cm^3 of hydrogen, measured at room temperature and pressure, is produced.

(c) **(i)** Calculate the amount, in moles, of hydrogen molecules produced in this reaction.

(ii) Hence calculate the amount, in moles, of hydrogen molecules produced by 1 mol of **Q**.

[2]

(d) Use your answers to **(b)** and **(c)** to deduce which structure, **R**, **S** or **T**, corresponds to the structure of **Q** and write balanced equations for the reactions that occurred.

identity of **Q** is .....

equation for reaction with sodium carbonate

.....

equation for reaction with sodium metal

..... [5]

May/June 2014 (23)/Q4

(c) **(i)** Give the structures of the four structural isomers of C_4H_9Br and identify each as primary, secondary or tertiary.

....

....

[4]

(ii) Name the isomer of C_4H_9Br that contains a chiral centre and draw the three-dimensional structures of the two optical isomers.

name .....

structures

[3]

Oct/Nov 2014 (21)

3 **P**, **Q** and **R** are structural isomers with the molecular formula C_4H_8.

All three compounds readily decolourise bromine in the dark.

P and **Q** do not exhibit stereoisomerism but R exists as a pair of geometrical (cis-trans) isomers.

All three compounds react with hot concentrated, acidified potassium manganate(VII) to produce a variety of products as shown in the table.

compound	products
P	CO_2 and **S** (C_3H_6O)
Q	CO_2 and $CH_3CH_2CO_2H$
R	CH_3CO_2H only

S reacts with 2,4-dinitrophenylhydrazine reagent, 2,4-DNPH, to form an orange crystalline product but does not react with Fehling's reagent.

(a) Give the structural formulae of **P**, **Q**, **R** and **S**.

P ..... **Q** .....

R ..... **S** .....

[4]

(b) (i) Explain what is meant by the term *stereoisomerism*.

.....

.....

..... [2]

(ii) Draw the **displayed** formulae of the geometrical isomers of **R** and name them both.

name ..... name ..... [2]

(c) State a reagent that could be used for the reduction of **S** and **name** the organic product of this reduction.

reagent ..... product ..... [2]

Oct/Nov 2014 (23)

3 **P**, **Q**, **R** and **S** are structural isomers with the molecular formula C_5H_{10}.

All four compounds readily decolourise bromine in the dark.

P, **R** and **S** do not exhibit stereoisomerism but **Q** exists as a pair of geometrical (cis-trans) isomers.

All four compounds react with hot concentrated, acidified potassium manganate(VII) to produce a variety of products as shown in the table.

compound	products
P	CO_2 and $CH_3CH_2CH_2CO_2H$
Q	CH_3CO_2H and $CH_3CH_2CO_2H$
R	CO_2 and **T** (C_4H_8O)
S	CH_3CO_2H and $(CH_3)_2CO$

T reacts with 2,4-dinitrophenylhydrazine reagent, 2,4-DNPH, to form an orange crystalline product but does not react with Fehling's reagent.

(a) Give the structural formulae of **P**, **Q**, **R**, **S** and **T**.

P ..... **Q** .....

R ..... **S** .....

T ..... [5]

(b) (i) Explain what is meant by the term *stereoisomerism*.

.....

.....

..... [2]

(ii) Draw the **displayed** formulae of the geometrical isomers of **Q** and name them both.

name ..... name ..... [2]

(c) Name the organic product of the reaction of **T** with sodium borohydride, $NaBH_4$.

..... [1]

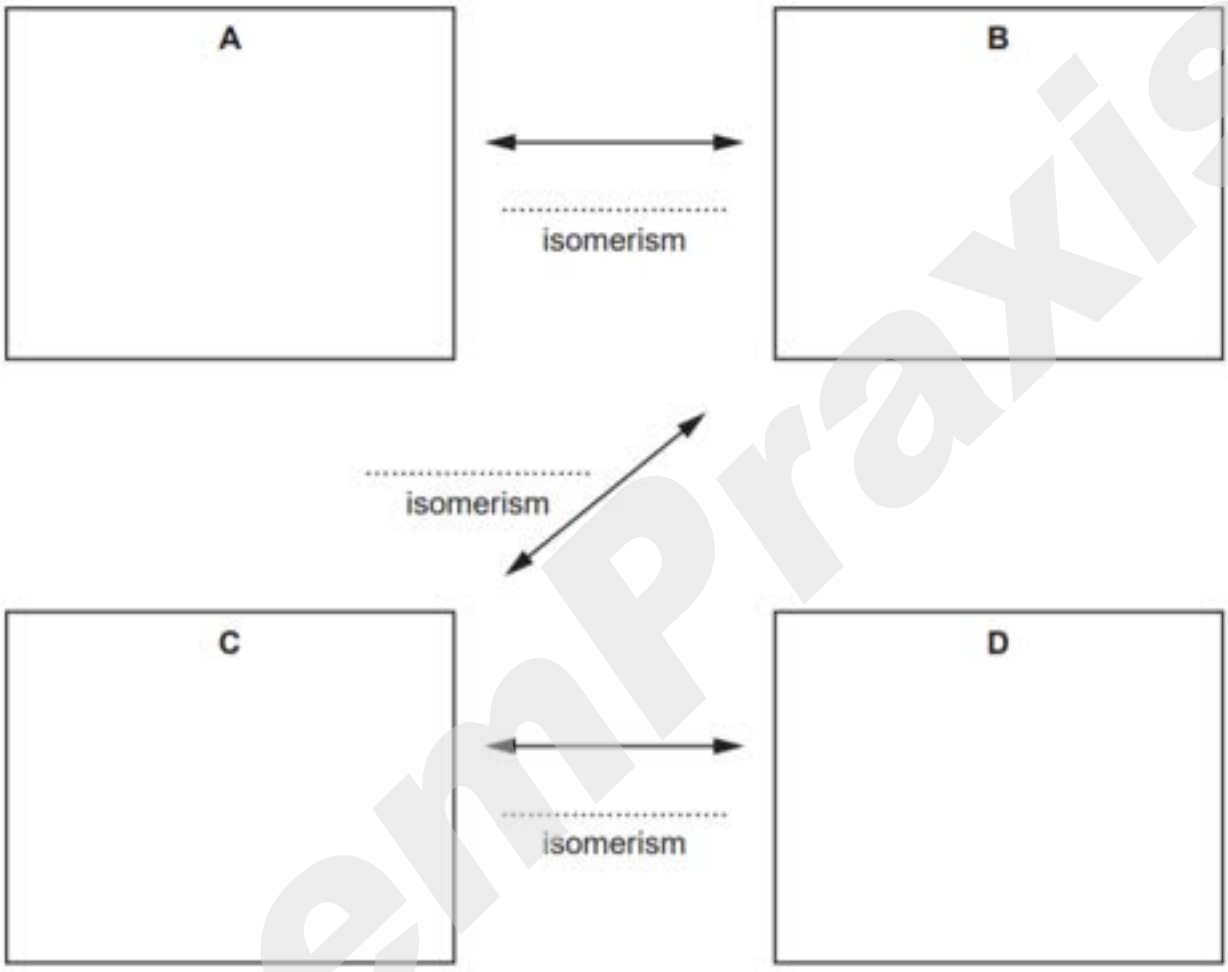
May/June 2015 (21)

4 There are four alcohols, **A**, **B**, **C** and **D**, which are structural isomers with the molecular formula $C_4H_{10}O$.

Alcohol **A** does not react with acidified potassium dichromate(VI) solution but **B**, **C** and **D** do.

All four alcohols react with hot, concentrated sulfuric acid to form products with the molecular formula C_4H_8. **A**, **C** and **D** each give a single product in this reaction. **B** gives a mixture of two structural isomers, one of which shows stereoisomerism.

(a) Give the **skeletal** formula for each of the four alcohols and complete the diagram with the names of the types of structural isomerism shown by each linked pair of compounds.



[7]

(b) (i) Give the names of the two structural isomers produced by the reaction of **B** with hot, concentrated sulfuric acid

.... [2]

(ii) State which of these two isomers shows stereoisomerism. Explain why this molecule is capable of showing stereoisomerism.

.....

.....

.....

..... [2]

(iii) Draw **displayed** formulae to show the two stereoisomers.

stereoisomer 1

stereoisomer 2

[2]

May/June 2015 (22)

4 There are seven structural isomers with the molecular formula $C_5H_{10}O$ that are carbonyl compounds. Four of these are aldehydes.

These four aldehydes, **A**, **B**, **C** and **D**, have the following properties.

- Aldehyde **A** has a straight chain while **B**, **C** and **D** are branched.
- Aldehyde **B** is the only one of the four isomers with a chiral centre and it exists as a pair of optical isomers.
- Aldehyde **C** has two methyl groups in its structure but **D** has three.

(a) (i) Give the structure of each of the four isomers.

A

B

C

D

[4]

(ii) Draw the three-dimensional structures of the two optical isomers of **B**.

[2]

Oct/Nov 2015 (21)

3 Heptane, C_7H_{16}, is an undesirable component of petrol as it burns explosively causing 'knocking' in an engine.

(a) There are nine structural isomers with the formula C_7H_{16}, only two of which contain chiral centres.

(i) Explain the meanings of the terms *structural isomers* and *chiral*.

structural isomers .....

.....

.....

chiral .....

.....

.....

[2]

(ii) Give the structures and names of the two structural isomers of C_7H_{16} which contain a chiral centre.

[4]