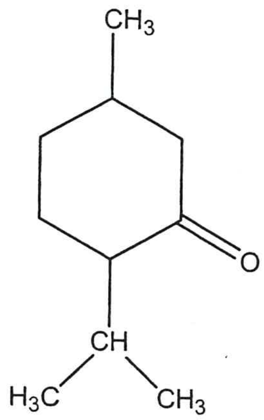
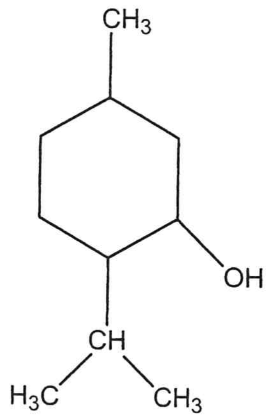
Chapter 11 | Organic Chemistry

1. **[3 marks]** *(2008:04)*

The structures and melting points are provided for two similarly-sized organic substances. Explain the difference in their melting points.



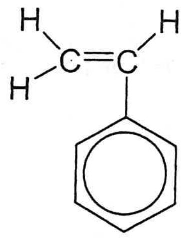
Menthone
-6°C



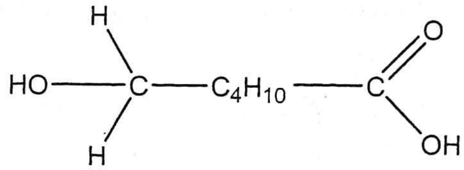
Menthol
35°C

2. **[4 marks]** *(2008:10)*

In the boxes below draw diagrams of an addition polymer and condensation polymer using the monomers provided. You may use one or both monomers in both polymers. (You must show a minimum of two repeating units.)



Monomer 1

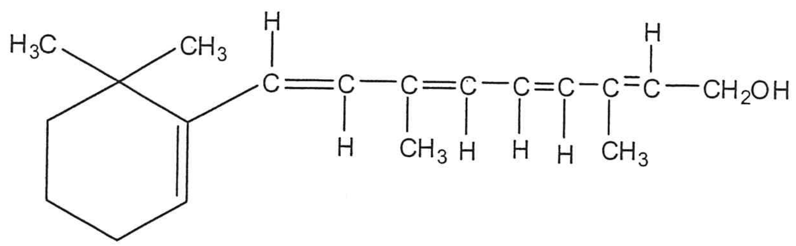


Monomer 2

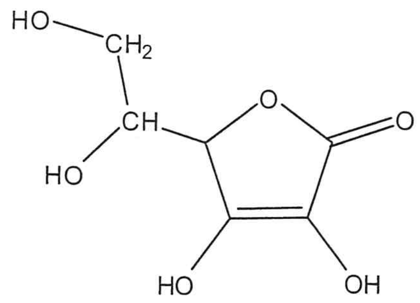
Addition polymer	
Condensation polymer	

3. **[3 marks]** *(2009:04)*

Examine the structures for vitamin A and vitamin C shown below.



Vitamin A



Vitamin C

Vitamin C is very soluble in water whilst vitamin A is sparingly soluble in water. (Vitamin A is fat soluble.)

Explain fully this difference in solubility.

4. **[3 marks]**

(2009:09)

Only one compound can be formed between the two elements sodium and chlorine, whereas many thousands of hydrocarbons can be formed between the two elements carbon and hydrogen. Explain why many thousands of hydrocarbons can exist.

5. **[6 marks]** *(2009:10)*

Draw the structure and give the IUPAC name of the organic compounds that match the following descriptions.

Show all atoms in the structure

(a) A primary amine containing 9 hydrogen atoms.

Structure	Name

(b) The product of the oxidation of 2-pentanol

Structure	Name

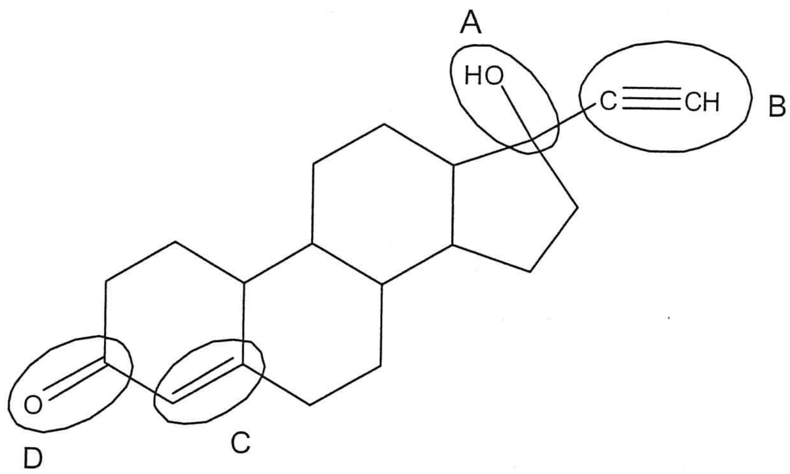
(c) A compound X has the molecular formula C_5H_8. When X is warmed with excess hydrogen in the presence of powdered nickel, it forms a compound with the molecular formula C_5H_{10}.

Give the structure and name of compound X.

Structure	Name

6. **[4 marks]** *(2009:11)*

The steroid norgestrel has the structure shown below. Name the class of compounds associated with each of the groups of atoms indicated.



A ______________________________

B ______________________________

C ______________________________

D ______________________________

7. **[8 marks]** *(2010:29)*

See Chapter 9 question *(2010:29)*.

8. **[6 marks]** *(2010:30)*

Consider the following reactions and complete the tables that follow.

(a) An excess of 2-butanol is oxidised by acidified $Na_2Cr_2O_7$. [3]

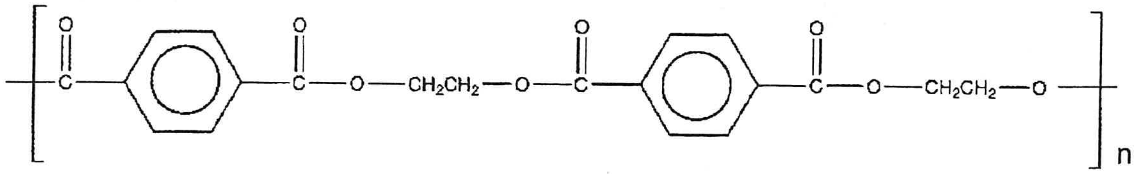
Observations	
Structural formula of organic product Show all atoms	
Name of organic product	

(b) Butanoic acid reacts with methanol in the presence of H_2SO_4. [3]

Observations	
Structural formula of organic product Show all atoms	
Name of organic product	

9. **[3 marks]** *(2010:31)*

Condensation polymers form from two monomers, each with functional groups at their terminal carbon atoms (that is, the monomers are difunctional). Examine the polyester structure below.



(a) Circle **all** the ester linkages (functional groups that link the monomers) represented in the above structure. [1]

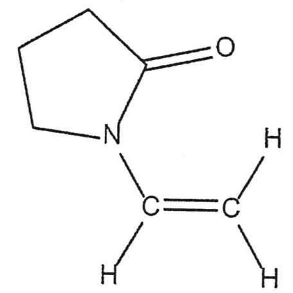
(b) Identify the two monomer compounds (A and B) used in the production of this polymer and draw their molecular structures. [2]

Monomer A

Monomer B

10. **[2 marks]** *(2011:31)*

Polyvinylpyrrolidone is a polymer with a wide range of applications including as a binder in tablets and hair styling agents. It is made from the monomer shown below.



(a) Draw three units in the polymer formed from this monomer. [1]

(b) What type of polymerisation reaction occurs to form the polymer from the above monomer? [1]

11. **[13 marks]** *(2011:32)*

(a) Draw the structure for, and write the name of, any five straight chain isomers for the compounds with the molecular formula C_5H_{10}. Show all atoms in the structures. [10]

Name: ______________________________

Name: ______________________________

Name: ______________________________

CONTINUED NEXT PAGE

Name: ______________________________

Name: ______________________________

(b) An organic compound is known to be an ester. Its molar mass is 74 g mol^{-1}.

(i) Draw the structural formula for the compound. Show all atoms in the structure. [1]

(ii) Write the name for the compound you have drawn. [1]

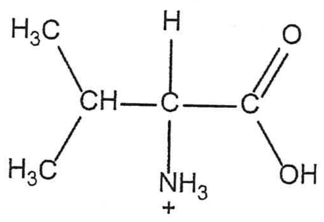
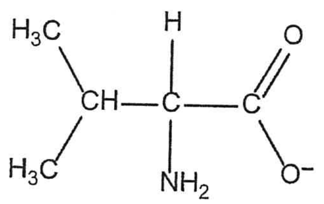
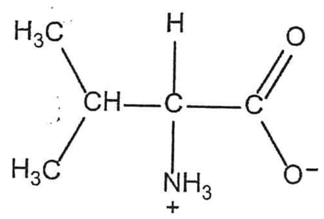
....

(iii) What is the IUPAC name for a carboxylic acid that has the same molecular formula as the ester above? [1]

....

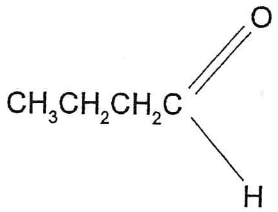
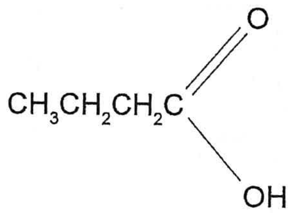
12. **[3 marks]** *(2011:33)*

Below are the structures for the amino acid valine under different pH conditions. In the spaces provided, give the approximate pH range (acidic, basic or neutral) under which each valine structure would exist.

Valine structure	pH range
	
	
	

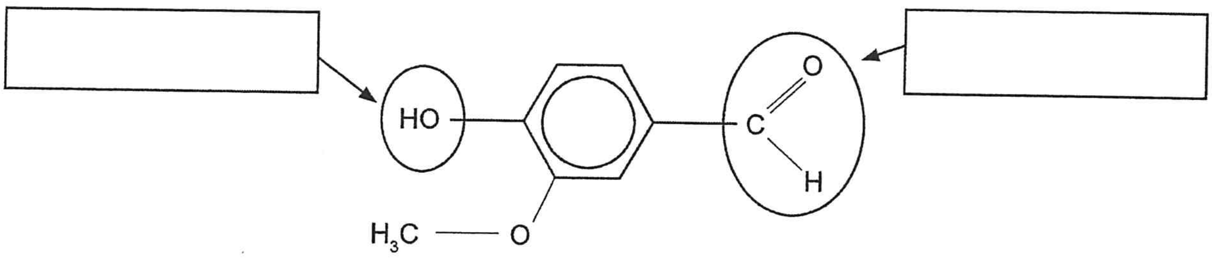
13. **[4 marks]** *(2012:27)*

Examine the data in the table below. Use your knowledge of intermolecular forces to explain the differences in boiling points of the three compounds listed in the table.

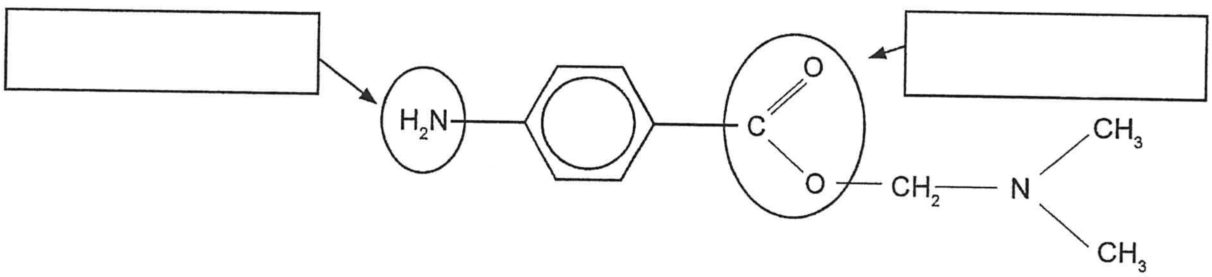
Compound	Structure	Molar mass ($g\ mol^{-1}$)	Boiling point (°C)
Butan-1-ol	$CH_3CH_2CH_2CH_2OH$	74.24	118
Butanal		72.22	75
Butanoic acid		88.22	163

14. **[4 marks]** *(2012:31)*

Examine the two compounds below. Compound 1 is the naturally occurring flavouring agent vanillin. Compound 2 is the local anaesthetic procaine. Name the functional groups circled in these two compounds.



Compound 1: Vanillin



Compound 2: Procaine

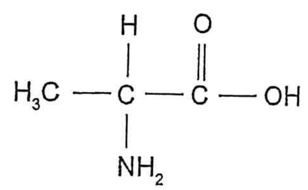
15. **[8 marks]**

(2013:34)

(a) The chemical formula of the α-amino acid glycine is $C_2H_5NO_2$. Draw the structure of glycine, showing all atoms.

(1 mark)

(b) The structure for the α-amino acid alanine is given below.



Give the structure for alanine under acidic, neutral and basic conditions by completing the table below.

(3 marks)

pH	**Structure of alanine**
acidic	
neutral	
basic	

CONTINUED NEXT PAGE

(c) When crystallised from a neutral solution, alanine exists as a white crystalline solid. The solid has a melting point of 258°C. This contrasts with a melting point of –47°C for 2-methylpropanoic acid (molar mass 87 g mol^{-1}), a molecule of similar size to alanine. With reference to the appropriate structure in (b), explain why alanine has such a high melting point. (4 marks)

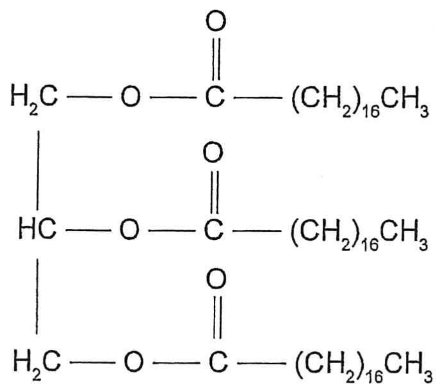
16. **[6 marks]** *(2013:36)*

Draw the structure in the box provided and name the organic product(s) for each of the following reactions. Include **all** H atoms in your structures.

(a) $CH_3CH_2CHCHCH_3 + Br_2$ (2 marks)

Name: ____________________

(b) Triglyceride of stearic acid esters heated with sodium hydroxide (4 marks)



+ NaOH

Name: ____________________

Name: ____________________

Chapter

12 Empirical and Molecular Formulae

1. **[12 marks]** *(2008:05)*

An old drum of pesticide has been found on a farm. The label has fallen off and for safe disposal its contents need to be analysed.

Elemental analysis shows the presence of carbon, hydrogen, phosphorus and oxygen. A 5.21 g sample of the pesticide produces 6.32 g of carbon dioxide and 3.23 g of water when combusted completely in excess oxygen.

A second, 3.15 g, sample of the pesticide is treated with excess nitric acid to convert all of the phosphorus to phosphate ions. The resulting solution is treated with excess calcium nitrate solution to produce 3.37 g of calcium phosphate.

(a) Determine the empirical formula of the pesticide.

(b) Mass spectral analysis shows the molar mass of the pesticide to be 290.18 g mol^{-1}. What is the pesticide's molecular formula?

2. **[11 marks]** *(2009:03)*

A polyester polymer was analysed to determine its empirical formula. Combustion of a 9.76 g sample of the polyester in excess oxygen produced 17.9 g of carbon dioxide and 4.88 g of water.

(a) Calculate the empirical formula of the polyester.

The polymer was then hydrolysed using sulfuric acid to split it into the diol and dicarboxylic acid monomers used in its preparation. The flow diagram below illustrates this.

$$\boxed{\text{polyester}} \xrightarrow{H_2SO_4} \boxed{\text{diol}} + \boxed{\text{dicarboxylic acid}}$$

2.20 g of the dicarboxylic acid monomer was isolated and dissolved in 250.0 mL of distilled water. 50.0 mL of the diacid solution required 15.3 mL of 0.487 mol L^{-1} sodium hydroxide solution for complete neutralisation.

(b) Calculate the molar mass of the dicarboxylic acid monomer.

(c) Draw a possible structure of the dicarboxylic acid that is consistent with your answer to part (b).

3. **[13 marks]** *(2010:40)*

The manufacturer of the soft drink referred to in question 39 also produces a diet version of the drink, containing artificial sweetener. The quality assurance procedures of the soft drink manufacturer require that incoming batches of the artificial sweetener be analysed to ensure compliance with standards. A combustion analysis of a 1.021 g sample of sweetener produced 1.715 g CO_2, 0.2521 g H_2O, 0.2558 g NO_2 and 0.3568 g SO_2. The sweetener contains the elements C, H, O, N and S. Determine its empirical formula.

(2011:36)

4. **[10 marks]**

Sevoflurane is a gaseous compound (at room temperature) used for inducing and maintaining general anaesthesia. It contains carbon, hydrogen, oxygen and fluorine.

Analysis of a 1.6328 g sample of sevoflurane yielded, on combustion, 866.0 mL of carbon dioxide at 50°C and 101.3 kPa and 0.220 g of water. The fluorine was released as hydrogen fluoride and absorbed by alkaline solution, revealing 5.71×10^{-2} mole of hydrogen fluoride. Determine the empirical formula of sevoflurane.

5. **[18 marks]**

(2012:39)

Qualitative analysis of an organic compound showed that it contained only carbon, hydrogen and oxygen. A quantitative study of the same compound was performed, in which a 0.5096 g sample was burnt in excess oxygen to produce 0.4160 g of water and 700.7 mL of carbon dioxide, collected at 100.0°C and 102.8 kPa.

(a) Determine the empirical formula of the compound. [10]

(b) A second 0.4832 g sample of the compound was heated to 261°C. The vaporised sample was found to exert a pressure of 241 kPa in a 100.0 mL container. Use this information to determine the molecular formula of the compound. [4]

(c) When the original compound was reacted with acidified ethanol it produced a fruity smelling liquid. Infer the structure of the original compound, and draw its structure in the box below. Name the original compound. [2]

Name:

(d) Describe briefly and give observations for an additional chemical test to confirm the identity of the functional group in the original compound. [2]

6. **[7 marks]** *(2013:35)*

A white solid is analysed and found to have the empirical formula CHO and a molar mass of 116 g mol^{-1}.

(a) Determine the molecular formula of the compound. Justify your answer. (2 marks)

(b) Two tests were conducted on the white solid, as shown in the table below. Complete the table by drawing a possible functional group that is consistent with the finding of each of the tests. (2 marks)

Test	Observation	Possible functional group
Water solubility	788 g L^{-1}	
Add to bromine water	Bromine water decolourises rapidly	

(c) A further 2.32 g sample of the white solid was analysed and shown to release 0.0400 mol of H^+ ions. Use this information and your answers to (a) and (b) to determine the structural formula of the white solid, and draw it in the box below. Show **all** atoms in your structure.

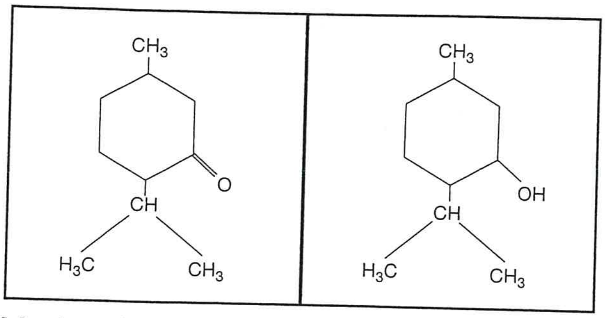
(3 marks)

The net result of all these is that the oxidising agents will not be available to oxidise the species that we require them to (such as Fe^{2+}) as they oxidise chloride ions instead. Therefore, HCℓ is unsuitable to acidify these oxidising agents. H_2SO_4 is the one that is generally used.

Chapter 11: Organic Chemistry

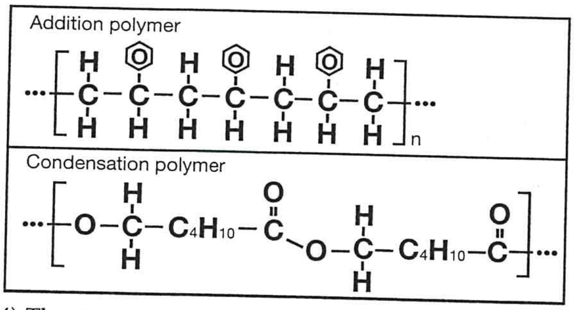
1.(2008:04)

Menthone (–6°C) Menthol (35°C)



Menthone has a melting point of –6°C and has the molecular formula $C_6H_3(CH_3)_3CHO$ with a molar mass of 149. Menthol has a higher melting point of 35°C and has the molecular formula $C_6H_3(CH_3)_3OH$ with a molar mass of 137. Both have a similar structure.
Menthone has dipole-dipole interaction forces between its molecules in addition to the weak dispersion forces. Menthol, on the other hand, has hydrogen bonding between molecules which is ten times stronger than dipole-dipole forces between molecules, all other factors such as size of molecules, shape and molar mass being nearly equal. It therefore requires more energy to break the bonds between menthol molecules and hence it has a higher melting point.

2.(2008:10)

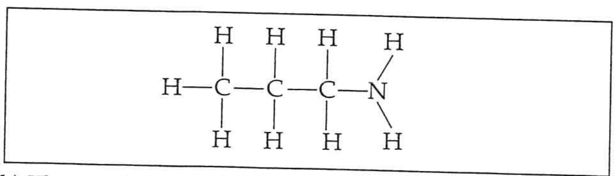


3.(2009:04) The structure for vitamin C indicates multiple OH links which can provide a greater bonding capacity with water, which is held together with hydrogen bonds also. Vitamin A, on the other hand, has a long carbon chain with a non-polar end and a single OH link at the other end to act as a polar end. This makes it less soluble in water compared to vitamin C. The non-polar vitamin A molecules are predominantly held together by dispersion forces and has a lower solubility in water.

4.(2009:09) Carbon has the capacity to form strong covalent bonds with each other and with hydrogen atoms. This, together with the fact that carbon has a valency of 4, enables carbon chains to branch. Long chain, branched chain and closed chain compounds are possible due to the C-C, C-H (and also C-N and C-O) bonding, double and triple bonding. Carbon can also form isomeric compounds. This is why many thousands of hydrocarbons can exist.

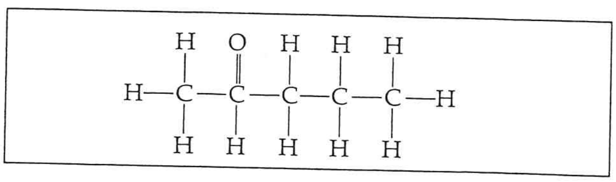
5.(2009:10) a) A primary amine containing 9 hydrogen atoms

Name: 1-aminopropane or 1-propanamine

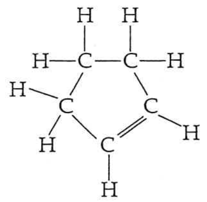
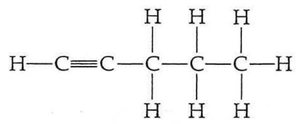


b) The product of oxidation of 2-pentanol

Name: 2-pentanone or pentan-2-one



c) A compound X has the molecular formula C_5H_8. When X is warmed with excess hydrogen in the presence of powdered nickel, it forms a compound with the molecular formula C_5H_{10}. Give the structure and the name of the compound X.

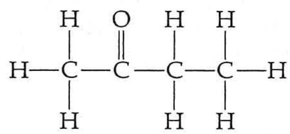
	
Cyclopentene	Pentyne

6.(2009:11)

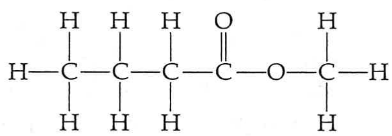
A: Alcohol
B: Alkyne
C: Alkene
D: Ketone

7.(2010:29) Please see Chapter 9, Question (2010:29).

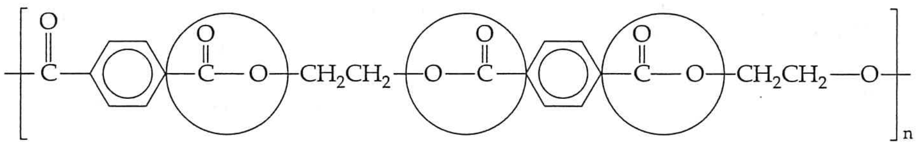
8.(2010:30) a) An excess of 2-butanol is oxidised by acidified $Na_2Cr_2O_7$.

Observations	The orange colour fades and the solution turns blue
Structural formula of organic product (**show all atoms**)	$CH_3COCH_2CH_3$ 
Name of organic product	butanone

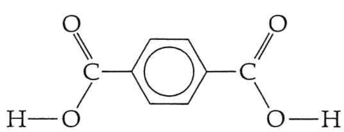
b) Butanoic acid reacts with methanol in the presence of H_2SO_4

Observation	A fruity or sweet smell is produced
Structural formula of organic product (**show all atoms**)	$CH_3CH_2CH_2COOCH_3$ 
Name of organic product	methylbutanoate

9.(2010:31) a) All ester linkages are shown by a circle.



b) Two monomers:
Monomer A (1,4-dicarboxyl benzene)



1,4-dicarboxylbenzene

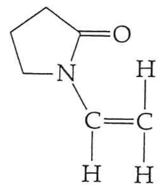
Monomer B (ethan-1,2-diol)

HO—CH_2CH_2—OH

ethane-1,2-diol

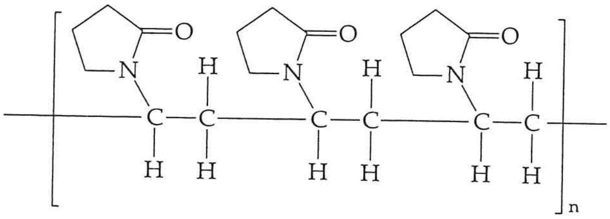
10.(2011:31) a) Three units in the polymer formed by the monomer, 'Polyvinylpyrrolidone'.
The monomer:

Monomer



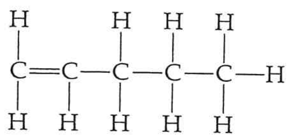
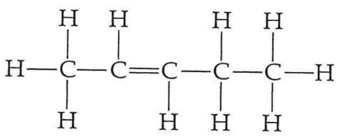
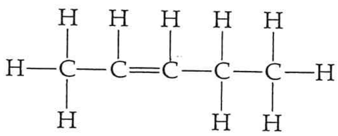
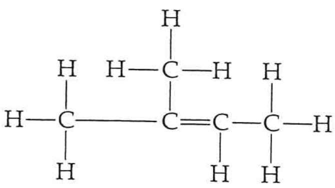
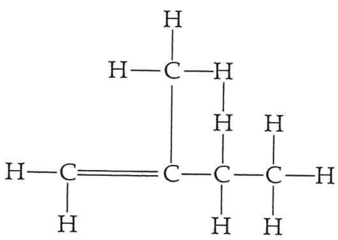
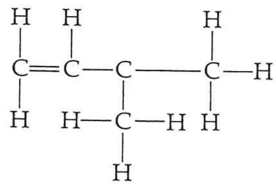
The polymer:

A polymer chain of 3 monomer units

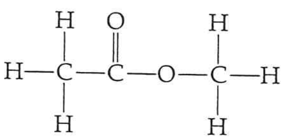
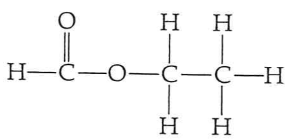


b) The type of polymerisation reaction that occurs to form this polymer is **addition** polymerisation.

11.(2011:32) a) Five straight chain isomers and their names, with the molecular formula, 'C_5H_{10}'

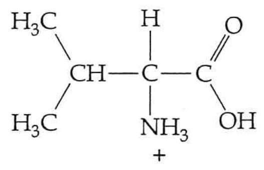
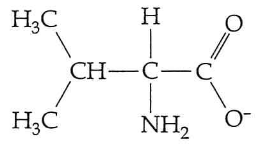
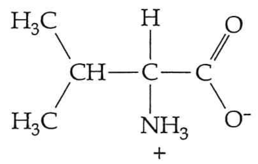
1-pentene or, pent-1-ene 	*Trans*-2-pentene or, *trans*-pent-2-ene 	*Cis*-2-pentene, or *cis*-pent-2-ene 
2-methyl-2-butene or, 2-methyl-but-2-ene 	2-methyl-1-butene or, 2-methyl-but-1-ene 	3-methyl-1-butene or, 3-methyl-but-1-ene 

b) i) and ii) Structural formula for an organic compound which is an ester with a molar mass of 74 g mol^{-1}

Methyl ethanoate 	Ethyl methanoate 

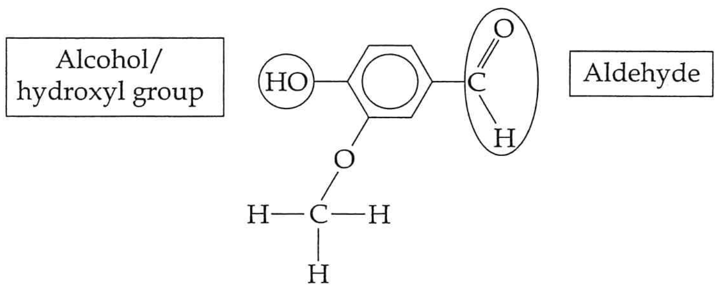
iii) The IUPAC name for a carboxylic acid that has the same molecular formula as the ester above: **Propanoic acid**

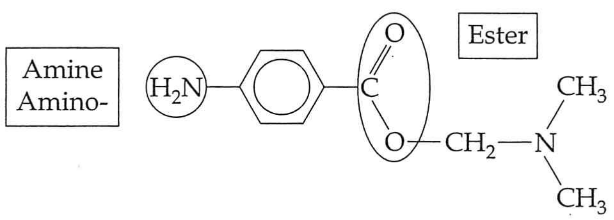
12.(2011:33) The approximate pH ranges of the amino acid 'valine' under different pH conditions.

Valine structure	pH range
	Acidic: (pH<7)
	Basic (pH>7)
	Neutral (ph=7)

13.(2012:27) Butanoic acid ($CH_3CH_2CH_2COOH$) has the highest boiling point. This is due to hydrogen bonding between molecules, dipole-dipole interaction forces as well as strong dispersion forces.
Butan-1-ol ($CH_3CH_2CH_2CH_2OH$) has a lower boiling point than butanoic acid because it has hydrogen bonding and dispersion forces only.
Butanal ($CH_3CH_2CH_2CHO$) has the lowest boiling point of the three. There are no hydrogen bonding sites in the molecule. It has dipole-dipole forces and dispersion forces only.
As the molar masses are not very much different, they do not significantly contribute to any difference in the boiling points among the three compounds.

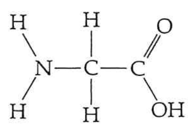
14.(2012:31)





15.(2013:34) a) Chemical formula of glycine is $C_2H_5NO_2$, also written as a condensed structure, NH_2CH_2COOH.
Its structural formula is given below:

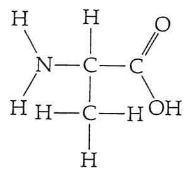
Chemical formula of Glycine, NH_2CH_2COOH



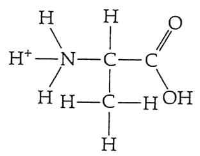
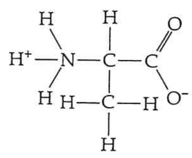
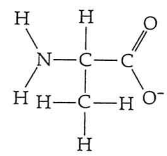
or, H_2NCH_2COOH

b) The structural formula for α – amino acid, alanine is given below.

Structural formula of Alanine, H_2NCHCH_3COOH

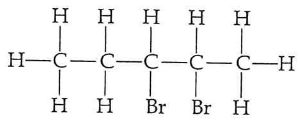


The structure for alanine in acidic, neutral and basic conditions.

Acidic species	Neutral species	Basic species
	 Zwitterion	

16.(2013:36) Organic products for the following reactions:

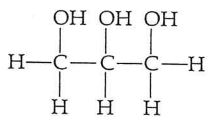
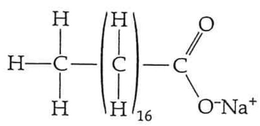
a) $CH_3CH_2CHCHCH_3 + Br_2 \rightarrow CH_3CH_2CHBrCHBrCH_3$ (2,3-dibromopentane)



or, $CH_3CH_2CHBrCHBrCH_3$

Name: 2,3-Dibromopentane

b) The products

 Name: 1,2,3-Propantriol or, Glycerol	 Name: Sodium Stearate

Chapter 12: Empirical & Molecular Formulae

NOTE: The following guidelines have been used in setting out the calculations in this section.

1. *Intermediate answers are not rounded off too early in order to improve accuracy.*

2. *In multiple stage problems, unrounded quantitative answers are carried over to the next stage of the problem, though a rounded answer is provided for each stage of the problem.*

3. *Standard scientific notations and up to four significant figures are used in most of the quantitative sections as appropriate.*

4. *The approaches used in solving problems are those commonly used by most students. It is recognised, however, that there are several other valid methods which are also acceptable.*

1.(2008:05) This is a straightforward empirical and molecular formula calculation. (Note: You need to be careful when determining the mass of phosphorus in the sample as this involves a different mass of the compound. However, if you are using the percentage method, this problem would not arise.)
The compound contains C, H, P and O.

a) m (the first sample) = 5.21 g
m (CO_2) produced = 6.32 g
n (CO_2) produced = (6.32 ÷ 44.01) = 0.1436 mol
n (C) = *0.1436 mol*
m (C) = n × M = 0.1436 × 12.01 = *1.7247 g* (Therefore % C = 33.10%)
m (H_2O) produced = 3.23 g
n (H_2O) produced = (3.23 ÷ 18.06) = 0.1793 mol
n (H) produced = 2 × 0.1793 mol = *0.3586 mol*
m (H) produced = n × M = 0.3584 × 1.008 = *0.3614 g* (Therefore % H = 6.94%)
m (the second sample) = 3.15 g
m ($Ca_3(PO_4)_2$) produced = 3.37 g
Therefore 5.21 g sample will produce = [(5.21 × 3.37) ÷ 3.15] = 5.5739 g
n ($Ca_3(PO_4)_2$) produced by the original mass of the sample = (m ÷ M)
= (5.5739 ÷ 310.18) = 0.01797 mol
n (P) produced = 2 × 0.01797 = 0.03594 mol
m (P) produced = n × M = 0.03594 × 30.97 = 1.113 g (Therefore % P = 21.36%)
Therefore m (O) = 5.21 – (1.7247 + 0.3614 + 1.113) = *2.0109 g*
n (O) = (m ÷ M) = (2.0109 ÷ 16.00) = *0.1257 mol*

	C	H	P	O
% composition	33.1	6.94	21.36	38.61
(This is not used in the following calculation)				
Mass ratio	1.7247	0.3614	1.113	2.0109
Mole ratio	0.1436	0.3586	0.03594	0.1257
Dividing by the smallest mol ratio of 0.03594				
Simple ratio	3.996	9.978	1	3.497
Multiplying by 2, and rounding	8	20	2	7

The **empirical formula** is $\mathbf{C_8H_{20}P_2O_7}$

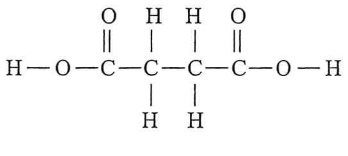
b) The molecular mass is = 290.18 g mol^{-1}, and the empirical mass is ≈ 290. Thus, the molecular formula is the same as the empirical formula within the limitations of the experimental errors.
Therefore the **molecular formula** of the compound is $\mathbf{C_8H_{20}P_2O_7}$

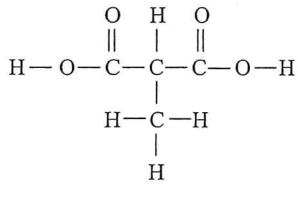
2.(2009:03) This is a straightforward empirical and molecular formula calculation.
a) Calculating the empirical formula:
mass of the sample = 9.76 g; mass of carbon dioxide = 17.9 g; mass of water = 4.88 g.
m (C) = [17.9 × (12.01 ÷ 44.01)] = 4.88 g.
m (H) = [4.88 × (2.016 ÷ 18.016)] = 0.546 g.
Therefore m (O) = [9.76 – (4.88 + 0.546)] = 4.33 g.

	C	H	O
Mass ratio (g)	4.88	0.546	4.38
Mole ratio	4.88 ÷ 12.01	0.546 ÷ 1.008	4.33 ÷ 16.00
	0.406	0.542	0.271
Simple ratio	0.406 ÷ 0.271	0.542 ÷ 0.271	0.271 ÷ 0.271
Simple ratio	1.5	2.00	1.00
Empirical ratio	3	4	2

Therefore the empirical formula is $\mathbf{C_3H_4O_2}$

b) Calculating the molar mass of the dicarboxylic acid monomer:
n (NaOH) = c × v = 0.487 × 0.0153 = 7.451 × 10^{-3} mol
n (acid) in 0.050 L =($\frac{1}{2}$ × 7.451 × 10^{-3} mol) = 3.725 × 10^{-3} mol
n (acid) in 0.250 L = [3.725 × 10^{-3} × (0.250 ÷ 0.050)] = 1.863 × 10^{-2} mol
Therefore the molar mass of the acid = (m ÷ n) = (2.20 ÷ 1.863 × 10^{-2}) = **118.1 g mol^{-1}**
c) A possible structure for the dicarboxylic acid:
The monomer has four oxygen atoms as it has two 'COOH' groups in it. Taking away the mass of the four oxygen atoms from the molar mass of 118, the residual mass is (118 – 64) 54 which is shared by 4 carbon atoms and 6 hydrogen atoms. This gives a molecular formula of $C_4H_6O_4$.
The following are two possible structures:





3.(2010:40) This is a straight forward calculation requiring you to determine the empirical formula of an artificial sweetener contained in a diet version of a soft drink, from the usual set of data.

m (sample sweetener) = 1.021 g; m (CO_2) = 1.715 g, m (H_2O) = 0.2521 g; m (NO_2) = 0.2558 g; m (SO_2) = 0.3568 g

m (C) = [1.715 × (12.01 ÷ 44.01)] = 0.4680 g
Therefore, n (C) = (0.4680 ÷ 12.01) = *0.03897*

m (H) = [0.2521 × (2.016 ÷ 18.016)] = 0.02821 g
Therefore, n (H) = (0.02821 ÷ 1.008) = *0.02799*

m (N) = [0.2558 × (14.01 ÷ 46.01)] = 0.07789 g
Therefore, n (N) = (0.07789 ÷ 14.01) = *0.00556*

m (S) = [(0.3568 × (32.06 ÷ 64.06)] = 0.17857 g
Therefore, n (S) = (0.17857 ÷ 32.06) = *0.00557*

Therefore, m (O) = [1.021 – (0.4680 + 0.02821 + 0.07789 + 0.17857)] = 0.2683 g
n (O) = (0.2683 ÷ 16.0) = *0.01677*

	C	H	N	S	O
Mole ratio	0.03897	0.02799	0.00556	0.00557	0.01677
Dividing each by the smallest mole of 0.00556					
Simple ratio	6.959	4.998	1.000	1.002	3.016
	7	5	1	1	3

Therefore, the empirical formula is $\mathbf{C_7H_5NSO_3}$

4.(2011:36) This is an empirical-molecular formula calculation in which gas volume calculation steps are involved. The compound contains carbon, hydrogen, oxygen and fluorine.

m (sample) = 1.6328 g.
The volume of CO_2 produced at 50°C and 101.3 kPa = 0.866 L.
Since, PV = nRT, n = (PV ÷ RT),
n = [(101.3 × 0.866) ÷ (8.315 × 323)] = 0.03266 mol
Therefore, n (C) = **0.03266 mol** and, m (C) = n × M = 0.03266 × 12.01 = **0.3923 g**

m (H_2O) = 0.220 g; n (H_2O) = (0.220 ÷ 18.016) = 0.0122 mol
Therefore, n (H) = 2 × 0.0122 = **0.02442 mol** and, m (H) = 0.02442 × 1.008 = **0.02462 g**

n (HF) = 0.0571 mol
Therefore, n (F) = **0.0571 mol** and, m (F) = 0.0571 × 19.00 = **1.0849 g**

m (O) = [1.638 –(0.3923 + 0.02462 + 1.0849)] = **0.131 g**
Therefore, n (O) = (0.131 ÷ 16.0) = **0.008188 mol**

	C	H	O	F
Mass ratio	0.3923	0.02462	0.131	1.0849
Mole ratio	0.03266	0.0244	0.008188	0.0571
Simple ratio	÷ 0.008188	÷ 0.008188	÷ 0.008188	÷ 0.008188
	3.989	2.98	1	6.97
Whole No. ratio	4	3	1	7

Empirical Formula = $\mathbf{C_4H_3OF_7}$

Alternative Method using the percentage composition

% C = [(0.0923 ÷ 1.6328) × 100] = 24.03%; Mol ratio = (24.03 ÷ 12.01) = 2.00
% H = [(0.02462 ÷ 1.632) × 100] = 1.51%; Mol ratio = (1.51 ÷ 1.008) = 1.50
% O = [(0.131 ÷ 1.632) × 100] = 8.03%; Mol ratio = (8.03 ÷ 16.00) = 0.50
% F = [(1.0849 ÷ 1.632) × 100] = 66.48%; Mol ratio = (66.48 ÷ 19.00) = 3.5

Fractional mole ratio of the elements in the compound: C = 2.00, H = 1.50; O = 0.50 and F = 3.5
Multiplying this ratio throughout by 2, in order to get whole numbers,
we get the empirical formula: $\mathbf{C_4H_3OF_7}$

5.(2012:39) This is a straight forward empirical-molecular formula calculation requiring a structural formula and a chemical test to confirm the identity of the compound.

a) The compound contains carbon, hydrogen and oxygen only.
m (sample) = 0.5096 g
n (H_2O) = 0.4160 g
n (H_2O) = 0.4160 ÷ 18.016 = 0.0231 mol
n (H) = 2 × 0.0231 = 0.0462 mol
m (H) = n × M = 0.0462 × 1.008 = 0.04655 g

V (CO_2 – 100°C & 102.8 kPa) = 0.7007 L
Using the equation, PV = nRT
n = (PV ÷ RT) = [(102.8 × 0.7007) ÷ (8.314 × 373.15)] = 0.02322 mol of CO_2
Therefore, n (C) = n (CO_2) = 0.02322 mol
Therefore, m (C) = n × M = 0.02322 × 12.01 = 0.2789 g

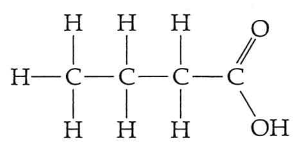
Therefore, m (O) = [0.5096 g – (0.04655 g + 0.2789 g)] = 0.1842 g
Therefore, n (O) = (m ÷ M) = (0.1842 ÷ 16) = 0.01151 mol

	C	H	O
Mass ratio	0.2789 g	0.04655 g	0.1842 g
Mole ratio	0.2789 ÷ 12.01	0.04655 ÷ 1.008	0.01842 ÷ 16
	0.02322	0.04618	0.01151
Dividing by the smallest mole of 0.01151,			
Simple ratio	0.02322 ÷ 0.01151	0.04618 ÷ 0.01151	0.01151 ÷ 0.01151
	2.017	4.012	1
Rounded mole ratio	2	4	1
Empirical Formula:	$\mathbf{C_2H_4O}$	(Empirical Mass = 44.052 g)	

b) Determining the molecular mass.
m (second sample) = 0.4832 g
This sample at 261°C, has a pressure of 241 kPa in a 100.0 mL container.
Using the relationship, PV = nRT, and, n = PV ÷ RT,
n = [(241 × 0.100) ÷ (8.314 × 534.15)] = 5.4268×10^{-3} mol
Since, 5.4268×10^{-3} mol has a mass of 0.4832 g
One mole has a mass = [(1 × 0.4832) ÷ (5.4268×10^{-3})] = 89.04 g mol^{-1}.
The ratio of molecular mass ÷ empirical mass = (89.04 ÷ 44.052) = Nearly 2.
Therefore, the **molecular formula** = 2 × $C_2H_4O_2$ = $\mathbf{C_4H_8O_4}$

c) Since a fruity smell is characteristic of an ester and the ester is the product of an alcohol and a carboxylic acid, this compound is most likely to be butanoic acid with the following Lewis structure.

Structure of butanoic acid



d) Additional chemical tests for butanoic acid:
i) Reaction with metallic carbonates such as $CaCO_3$ would produce a colourless, odourless gas and the test tube (if the reaction is carried out in a test tube) will get warm.
$CaCO_3(s) + CH_3CH_2CH_2COOH(\ell) \rightarrow Ca(CH_3CH_2CH_2COO)_2(aq) + CO_2(g) + H_2O(\ell)$
Other minor tests for consideration:
ii) Litmus test: acids turn litmus red. This confirms that the compound is an acid.
A large amount of heat is produced when butanoic acid is mixed with water.

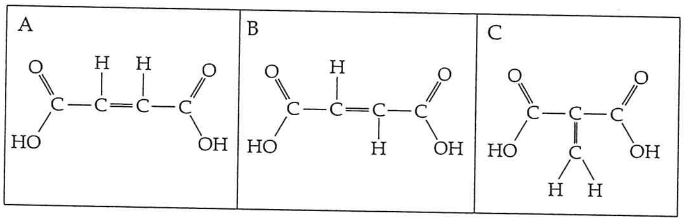
6.(2013:35) a) Empirical formula = CHO
Empirical mass = 12.01 + 1.008 + 16.00 = 29.018
Molecular mass = 116 g mol^{-1}
Molecular mass to empirical mass ratio = 116 ÷ 29.018 = 3.9975 ≈ 4
Molecular formula = Empirical formula × 4 = CHO × 4 = $\mathbf{C_4H_4O_4}$

b)

Test	Observation	Possible functional group
Water solubility	788 g L^{-1}	R—COOH = arboxylic acid or, R—OH = alcohol
Add to bromine water	Bromine water decolourises rapidly	Can be a double bond or a triple bond.

c) m (sample of the white solid) = 2.32 g
n (H^+) ions in the above sample = 0.0400 mol
n (in 2.32 g sample) = (2.32 ÷ 116) = 0.0200 mol
Therefore, the ratio of the moles of the compound to the moles of hydrogen = 0.0200 ÷ 0.0400
= 1:2

Therefore, the substance is a diprotic acid
Three possible structures are shown below:



Chapter 13: Volumetric Analysis, Acids & Bases, Redox

1.(2008:02)

This is a problem in which stoichiometric ratios are used to calculate the excess chlorine used in a bleaching process, and the volume of NaOH of a certain concentration needed to completely react with all the H^+ and HSO_4^- ions produced in that process.

a) The first step is to calculate the mass of the excess chlorine as this is removed, using sodium thiosulfate ($Na_2S_2O_3$). The reaction is

$S_2O_3^{2-}(aq) + 4\ Cl_2(aq) + 5\ H_2O(l) \rightarrow 2\ HSO_4^-(aq) + 8\ Cl^-(aq) + 8\ H^+(aq)$

n ($S_2O_3^{2-}$) used = c × V = 5.45 mol L^{-1} × 14.2 L = 77.39 mol
Using the reacting mol ratio,
n ($C\ell_2$) removed by $S_2O_3^{2-}$ = 77.39 × 4 = 309.56 mol
m ($C\ell_2$) removed = n × M = 309.56 × 70.90 = 21948 g = **2.195 × 10^4 g**

b) Concentration of $C\ell_2$ in 265 L in parts per million (ppm)
Since 265 L = 265 kg,
concentration of $C\ell_2$ in milligrams per kilograms = [(2.195 × 10^4 × 10^3) ÷ 265]
= **8.282 × 10^4 ppm**

c) Volume of NaOH required:
From the same equation,

$S_2O_3^{2-}(aq) + 4\ Cl_2(aq) + 5\ H_2O(l) \rightarrow 2\ HSO_4^-(aq) + 8\ Cl^- + 8\ H^+(aq)$

n (H^+) ions to be reacted with = 10 × n ($S_2O_3^{2-}$) = 10 × 77.39 = 773.9 mol
(Note: The total number of moles of H^+ ions includes the 2 H^+ from 2 HSO_4^-.)
Since, $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$,
n (OH^-) = n (NaOH) = 773.9 mol
V (NaOH) = (n ÷ c) = (773.9 mol ÷ 6.88 L) = 112.5 L
Volume of NaOH needed = **112.5 L**