Victorian Certificate of Education

CHEMISTRY 2026 Unit 4

SAC 3 AOS 1 Outcome 1

Reading time: 5 minutes

Writing time: 70 minutes

Directions to students

Student's Name: _____

Teacher: _____

Structure of booklet

Section	Question to be answered	Total marks
Short answer	6	58
	Total	58

Materials

Students are permitted to bring into the examination room: pencils, highlighters, erasers, sharpeners, rulers, and an approved scientific calculator.

Students are NOT permitted to bring into the examination room:
- white out liquid/tape, phones or electronic devices, including smart watches.

Students are provided with the following:
- Question and answer book of 10 pages and the VCAA Data booklet.
- Media reference article

The task

- Please ensure that you write your name and teacher's name on this booklet. This paper consists of short answer questions.

- There are a total of 60 marks available.

- Be sure to include states with all chemical equations.

- All numerical answers need to be quoted to the correct number of significant figures.

- All working out must be shown in the space provided.

1. Consider the structural formula of DMC shown in fig 2 above. (13 marks)
   a. Does DMC contain a typical ester functional group? Justify your answer.
      1-----mark => No
      1-----mark => Typical esters have the general structure R–COO–R', where a single carbonyl carbon (C=O) is bonded to one carbon atom and one oxygen atom. This oxygen is then covalently bonded to another carbon atom. In contrast, DMC (dimethyl carbonate, $O=C(OCH_3)_2$) has a carbonyl carbon bonded to two oxygen atoms, each connected to a methyl group.
   b. What other functional group is clearly present in the DMC structural formula?

      _____*Carbonyl (C=O) or ether (C-O-C)*___*Either were accepted.*

   c. Consider reaction "B" in fig 2 above.
      i. Write the word equation for the reaction.

Ethylene carbonate + methanol → Dimethyl carbonate + ethane-1,2-diol

Or

Ethylene carbonate + methanol → DMC + ethane-1,2 -diol

      ii. Write the balanced chemical equation, for the word equation given in part i. above. States not required

$$C_3H_4O_3 + 2CH_3OH \rightarrow C_3H_6O_3 + C_2H_6O_2$$

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d. With reference to Fig. 3, the synthesis of dimethyl carbonate (DMC) can proceed via two reactions, the phosgene reaction and the direct synthesis from CO_2 reaction.

i. Calculate the **atom economy** for both the phosgene and the CO_2 reactions, showing your working clearly in the space below. 2 marks

Phosgene	CO_2
55.3%	83.4%

ii. Select any three green chemistry principles. For each principle, compare how the phosgene reaction and the direct CO_2 synthesis reaction of dimethyl carbonate align with or violate that principle. Use specific examples from each synthesis reaction to support your explanation.

1-----mark for each of the following and for any valid Green Chemistry Principle.

1. *Prevention of waste*
   - *Phosgene reaction produces hydrogen chloride (HCl) as a hazardous byproduct, requiring careful disposal and generating chemical waste.*
   - *Direct CO_2 synthesis produces water (H_2O) as a byproduct, which is harmless and does not require special treatment. This aligns better with waste prevention principles by minimizing harmful waste.*
2. *Use of Safer Chemicals and Solvents*
   - *Phosgene reaction uses phosgene ($COCl_2$), a highly toxic and dangerous reagent, posing significant safety and environmental risks. This violates the principle of safer chemicals.*
   - *Direct CO_2 synthesis uses carbon dioxide (CO_2), a less toxic, abundant, and renewable resource, making the process much safer for workers and the environment.*
3. *Energy Efficiency*
   - *Phosgene reaction can proceed under relatively mild conditions and is well-established industrially, but handling toxic reagents can complicate energy use in safety protocols. However students needed to realise in the body of the media article the phosgene did not require a catalyst therefore assuming that energy needed is higher.*
   - *Direct CO_2 synthesis requires catalysts to proceed efficiently where the catalyst aims to lower energy requirements, aligning better with energy efficiency principles.*

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2. A student wrote the following statement about the direct synthesis of dimethyl carbonate (DMC) from carbon dioxide.
"***Use of a catalyst improves yield and eliminates the reliance on high temperature and pressures which makes the production more economically viable***"

Using your knowledge of the CO_2 synthesis reaction and the role of catalysts answer the following. (6 marks)

a) Identify and explain the correct aspects of the student's statement.

1-----mark => The use of a catalyst does reduce the requirement for high temperature and pressure in the direct synthesis of DMC from CO_2.
1-----mark => This is because catalysts offer an alternative reaction pathway with lower activation energy, making it easier and more efficient to proceed under milder conditions, which helps reduce operational costs and energy demands.
1-----mark => A catalyst can reduce the cost of production making it economically viable by reducing the compromise temperature and pressure that are needed for a high rate and high yield.

b) Identify and explain any inaccuracies or misconceptions in the statement.

1-----mark => Catalysts do not increase the theoretical maximum yield (equilibrium yield) of the reaction, they only help reach equilibrium faster.

1-----mark => The statement incorrectly implies catalysts directly "improve yield," but yield depends on reaction conditions and equilibrium, not just catalysts.

1-----mark => The statement incorrectly implies that catalyst will totally remove the need for high temperature and high pressures but this is not the case and a compromise temperature is used.

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3. Under certain conditions, reaction 3 has a % yield of 75%. Calculate the expected mass of DMC formed if 3.200 grams of methanol are placed in the reaction vessel." (3 marks)

1-----mark => Find the mol of 3.200 g of methanol
=> 3.2 /32.0 = 0.100
1-----mark => Find the theoretical mass of DMC
=> 0.0500 mol X 90.1 g/mol = 4.51
1-----mark Actual yield
=> actual yield = 3.4g (2 sig figs)

4. The following questions refer to fig. 2 shown above. (5 marks)
   a. Consider the molecule labelled "B" in fig. 2 above.
      i. Give the systematic name of the molecule.

_____*hexane-1,2,3,4,5,6-hexaol*_____1 mark

      ii. Semi-structural formula of B
      $HOCH_2(CHOH)_4CH_2OH$

   b. Give the degree of unsaturation of ethylene carbonate, shown in fig. 2 and explain how you derived this number.

1-----mark DOU = 2
1 for the ring structure and 1 for the C=O

Also for the purposes of VCAA 2026 Chemistry Study Design

1-----mark DOU = 0 (as only C=C are considered)

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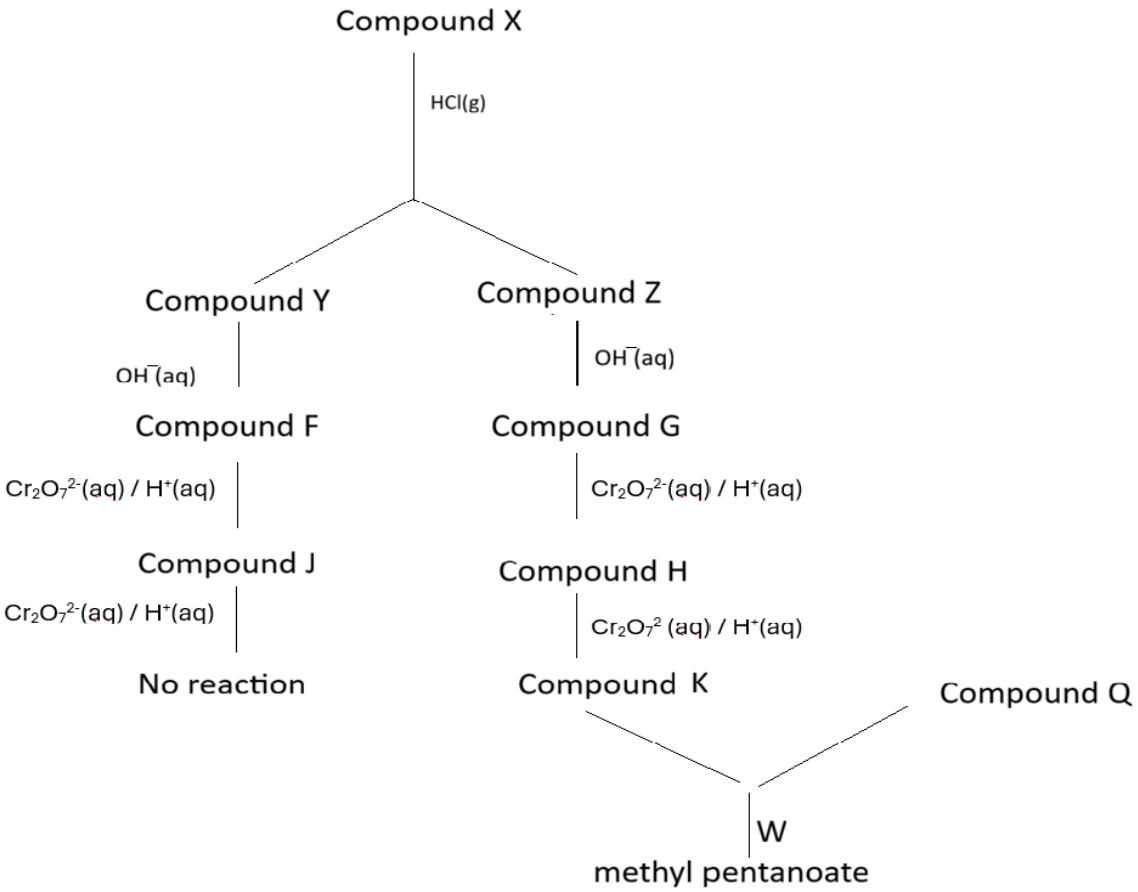
5. Many pharmaceuticals are produced from esterification reactions. Below is a reaction pathway to form methyl pentanoate. (17 marks)



a. Identify the following . 10 marks

X _____*pent-1-ene*_____

Y _____ *2-chloropentane* _____

F _____*Pentan-2-ol*_____

J _____*Pent-2-one*_____

Z _____ *1-chloropentane* _____

H _____*pentanal*_____

K _____*pentanoic acid*_____

W _____*$H_2SO_4(l)$*_____

Q _____*methanol*_____

G _____ *Pentan-1-ol* _____

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b. What general class of reaction forms compound Y?

_____*addition* _____ 1 mark

c. What term would you use to best describe compounds Y and Z?

_____*Structural Isomers*_____ 1 mark

d. An alternative synthesis reaction is shown below using DMC ($(CH_3O)_2CO$).

$CH_3(CH_2)_3COOH + (CH_3O)_2CO \rightarrow CH_3(CH_2)_3COOCH_3 + CH_3OH + CO_2$

This reaction takes place in the presence of a metal catalyst and is regarded as being more green than the traditional method of producing esters which uses corrosive $H_2SO_4(l)$. During this alternative reaction methanol (CH_3OH, BP 65 °C) and CO_2 are produced.

i. Given that esters are unstable at high temperatures, explain why it is easier to purify the ester, methyl pentanoate, using this method than the traditional method that produces water as a byproduct.

1-----mark => Mentioning water as a high-boiling byproduct in the traditional method, requiring high-temperature distillation that risks ester decomposition

1-----mark =>Identifying methanol and CO_2 as byproducts in the DMC method, with methanol's lower boiling point (65°C) and CO_2 as a gas

1-----mark => Explaining that lower distillation temperature in the DMC method reduces ester decomposition, making purification easier

ii. With reference to fig. 3 (reaction 3 -direct synthesis of DMC), suggest why the production of CO_2 gas during the synthesis of methyl pentanoate is not considered an environmental hazard.

1-----mark => for suggesting that the original CO_2 to form DMC came from biomass or from carbon capture.
1-----mark => For correctly stating that there is no net increase of atmospheric CO_2 and that the equations shows 1 CO_2 in to form DMC and 1 CO_2 out when the ester, methyl pentanoate is formed.

6. DMC is used as a green chemical in the methylation of amino acids such as glycine. (12 marks)

a. With reference to acidity and reactivity, explain how methylation of the –COOH group in glycine using dimethyl carbonate (DMC) affects the chemical properties of the amino acid.

1-----mark => Once methylated, the –COOH group is transformed to an ester, which is not acidic as it cannot release H^+ ions. .

1-----mark => Reactivity: The –COOH group is reactive, capable of participating in hydrogen bonding, and formation of amide links between amino groups of neighbouring amino acids. Methylation reduces the polarity and hydrogen bonding ability of the –COOH group, which influences the overall chemical behavior of the amino acid.

b. Describe how methylation of the carboxyl group influences the solubility of the amino acid in water.

1-----mark => The –COOH group is polar and can hydrogen bond with water, contributing to high water solubility.

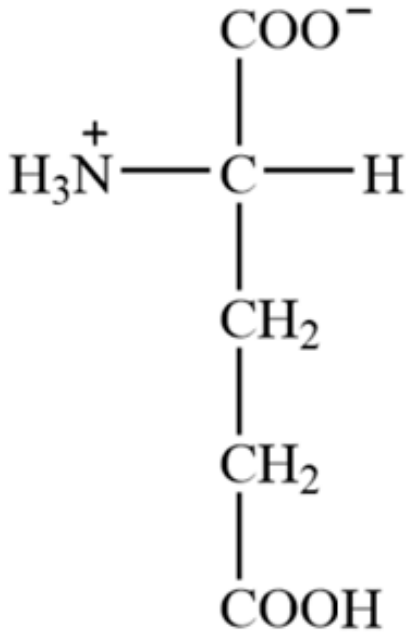
1-----mark => Upon methylation, the carboxyl group becomes an ester, which is less polar and less able to form hydrogen bonds with water molecules. This results in decreased solubility of the methylated amino acid in water compared to the unmethylated form.

c. How does the boiling temperature of a methylated amino acid ester compare with its pure unmethylated form? Justify your answer.

1-----mark => The unmethylated amino acid contains –COOH groups, which can form strong intermolecular hydrogen bonds, raising the boiling point due to stronger molecular interactions which take more energy to break down than the dipole-dipole interactions noticed in the methylated amino acid.

1-----mark => The methylated ester lacks the acidic proton and hydrogen bonding capability associated with the –COOH group, leading to weaker intermolecular forces. Consequently, the boiling temperature of the methylated amino acid ester is lower than that of the unmethylated amino acid because less energy is required to overcome these weaker interactions.

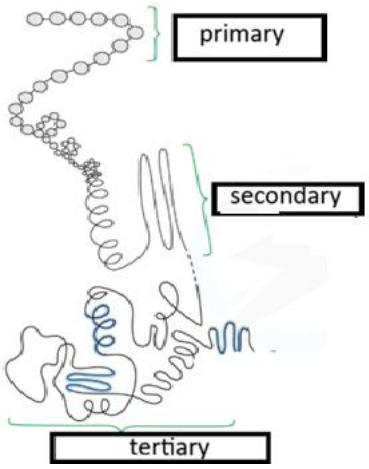
d. Draw the structural formula and clearly show the charges of the zwitterion form of glutamic acid in the box below. 2 marks



1-----mark => Correct structural formula
1-----mark => Only the amino and carboxyl groups coming off carbon 2 are correctly charged.

e. Consider three different structures of a protein, shown below.

i. Label each structure on the diagram below. 1 mark



ii. Explain how methylation of the carboxyl group of glycine impacts each of the three structures.

Primary

1-----mark => Methylation of the carboxyl group on the R group of glutamic acid does not change the sequence of amino acids in the protein (the primary structure remains the same).

1-----mark => The primary structure is formed from the reaction between the amino and carboxyl groups attached to carbon number 2 on neighbouring amino acids. This reaction forms peptide bonds

Secondary

1-----mark =>The secondary structure of a protein, such as α-helices and β-pleated sheets, is formed by hydrogen bonding between the amide (–NH) and carbonyl (C=O) groups of the protein backbone.

1-----mark => These amide links come from the reaction between the alpha amino and alpha carboxyl groups of amino acids. Methylation of the carboxyl group on the R group does not directly affect these backbone hydrogen bonds and therefore does not impact the secondary structure.

Tertiary

1-----mark => The tertiary structure of a protein is the overall 3D shape formed by interactions between amino acid side chains (R groups), including ionic bonds, hydrogen bonds, hydrophobic interactions, and disulfide bonds.

1-----mark => Methylation of the carboxyl group on the R group of glutamic acid removes the negative charge, preventing ionic interactions with positively charged side chains. This change can alter the folding and stability of the protein by disrupting key side chain interactions important for maintaining the tertiary structure.

End of assessment