A LEVEL

Exemplar Candidate Work

CHEMISTRY A

H432
For first teaching in 2015

H432/02 Summer 2018
examination series

Version 1

www.ocr.org.uk/chemistry
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Introduction

These exemplar answers have been chosen from the summer 2018 examination series.

OCR is open to a wide variety of approaches and all answers are considered on their merits. These exemplars, therefore, should not be seen as the only way to answer questions but do illustrate how the mark scheme has been applied.

Please always refer to the specification https://www.ocr.org.uk/Images/171720-specification-accredited-a-level-gce-chemistry-a-h432.pdf for full details of the assessment for this qualification. These exemplar answers should also be read in conjunction with the sample assessment materials and the June 2018 Examiners’ report or Report to Centres available from Interchange https://interchange.ocr.org.uk/Home.mvc/Index

The question paper, mark scheme and any resource booklet(s) will be available on the OCR website from summer 2019. Until then, they are available on OCR Interchange (school exams officers will have a login for this and are able to set up teachers with specific logins – see the following link for further information http://www.ocr.org.uk/administration/support-and-tools/interchange/managing-user-accounts/).

It is important to note that approaches to question setting and marking will remain consistent. At the same time OCR reviews all its qualifications annually and may make small adjustments to improve the performance of its assessments. We will let you know of any substantive changes.
Question 1

1 Which compound is used as a standard for NMR chemical shift measurements?

A $\text{Si(CH}_3\text{)}_4$
B $\text{CDCl}_3$
C $\text{D}_2\text{O}$
D $\text{CCl}_4$

Your answer

Exemplar 1

Examiner commentary

This underlining of 'standard for NMR' and the annotation of 'TMS' alongside $\text{Si(CH}_3\text{)}_4$ show the candidate's thought process and helps in identifying 'A' as the correct option.

This is recall of specification content, but many candidates selected $\text{D}_2\text{O}$ instead. This could have been misunderstanding of the word 'standard' or not knowing what TMS was. This should have been an easy mark.
Question 2

2 Which compound is a secondary amide?

A \[
\begin{align*}
\text{HO} & \quad \text{C} \quad \text{CH}_2 \quad \text{N} \\
\text{H} & \quad \text{CH}_3
\end{align*}
\]

B \[
\begin{align*}
\text{HO} & \quad \text{C} \quad \text{CH}_2 \quad \text{N} \\
\text{CH}_3 & \quad \text{CH}_3
\end{align*}
\]

C \[
\begin{align*}
\text{H}_3\text{C} & \quad \text{C} \quad \text{N} \\
\text{H} & \quad \text{CH}_3
\end{align*}
\]

D \[
\begin{align*}
\text{H}_3\text{C} & \quad \text{C} \quad \text{N} \\
\text{CH}_3 & \quad \text{CH}_3
\end{align*}
\]

Your answer [ ] [1]
Examiner commentary

This candidate has shown good exam technique by identifying each functional group, allowing the correct option ‘C’ to be selected. Most candidates were awarded this mark.
Question 3

3 Which compound does **not** react with nucleophiles?

A CH₃CH₂CHO
B CH₃CHCH₂
C CH₃CH₂COCH₃
D CH₃CH₂CH₂Cl

Your answer [ ]

Exemplar 1

A CH₃CH₂CHO
B CH₃CHCH₂
C CH₃CH₂COCH₃
D CH₃CH₂CH₂Cl

Your answer [B] 

Examiner commentary

This candidate has drawn out sections of each molecule to help identify the functional group. They are then able to see the alkene group, which is the only group that reacts with electrophiles rather than nucleophiles.
Question 4

4 Which structure represents an alicyclic compound?

A

B

C

D

Your answer [1]
Exemplar Candidate Work

Exemplar 1

A

B

C

D

Your answer: C

Examiner commentary

Candidates were expected to spot that A, B and D contained delocalised and Kekulé structures of aromatic compounds, leaving C as the correct option.

From the annotations, this candidate has eliminated two options, B and D. The correct choice between A and C could well have been a guess. B and D were often seen on scripts. This suggested some candidates misunderstood the meaning of alicyclic (a carbon ring containing single or double bonds that is not aromatic).
Question 5

5 Which molecule is not planar?

A C₂H₄
B C₂H₆
C H₂CO
D HCN

Exemplar 1 1 mark

Examiner commentary

This candidate has drawn out structures of the three planar compounds (presumably C₂H₄ was more obvious as non-planar). The candidate has selected the correct B, having first opted for D.

Notice that the candidate has completely crossed out their initial wrong answer and has written the changed letter afresh. This is good practice. Many candidates attempt to change the letter in the box into another letter. Unfortunately, often all that can then be seen is a mixture of two letters, and a mark cannot then be awarded if the intended letter is not clear.
Question 6

6 What is the number of peaks in the $^1$H NMR spectrum of HOOCCH$_2$CHOHCH$_2$COOH?

A 3
B 4
C 5
D 6

Your answer

Exemplar 1 1 mark

A 3
B 4
C 5
D 6

Your answer

Examiner commentary

This candidate has used a diagram to identify the different hydrogen environments. This approach is commended, making it much easier to predict the number of peaks.
Question 7

7 Ethanol can be prepared by different reactions.

Which reaction has the lowest atom economy?

A \( \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2 \)

B \( \text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} \)

C \( \text{C}_2\text{H}_5\text{Br} + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{HBr} \)

D \( \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{CH}_3\text{COOH} \)

Your answer [ ]

Exemplar 1

1 mark

\[
\begin{align*}
\text{A} & \quad \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2 \quad 181 \quad 50.8 \\
\text{B} & \quad \text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} \quad 126 \quad 30.2 \\
\text{C} & \quad \text{C}_2\text{H}_5\text{Br} + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{HBr} \quad 106 \quad 41.4 \\
\text{D} & \quad \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{CH}_3\text{COOH} \\
\end{align*}
\]

Examiner commentary

From the annotations, this candidate discounted option B as being addition with 100% atom economy. The candidate understands that the molecular masses of products need to be calculated. The actual atom economies have then been calculated on the right leading to C as the correct choice. The incorrect ‘181’ has made little difference in this case.

The most successful responses used this methodical approach. Overall, many candidates seemed to guess, with the incorrect A, B and D being seen often.
Question 8

8 The breakdown of ozone is catalysed by NO radicals.

Which equation is a propagation step in the mechanism for this process?

A  \( \text{NO} + \text{O}_2 \rightarrow \text{N} + \text{O}_3 \)
B  \( \text{NO} + \text{O}_2 \rightarrow \text{NO}_2 + \text{O} \)
C  \( \text{N} + \text{O}_3 \rightarrow \text{NO} + \text{O}_2 \)
D  \( \text{NO}_2 + \text{O} \rightarrow \text{NO} + \text{O}_2 \)

Your answer  

Exemplar 1

A  \( \text{NO} + \text{O}_2 \rightarrow \text{N} + \text{O}_3 \)
B  \( \text{NO} + \text{O}_2 \rightarrow \text{NO}_2 + \text{O} \)
C  \( \text{N} + \text{O}_3 \rightarrow \text{NO} + \text{O}_2 \)
D  \( \text{NO}_2 + \text{O} \rightarrow \text{NO} + \text{O}_2 \)

Your answer  

Examiner commentary

The candidate has initially rejected option C as the only equation with no nitrogen oxide on the left-hand side.

The correct response of D has been accompanied by written equations which the candidate has presumably memorised and used to determine the answer. This question was answered poorly, suggesting that many candidates had not learnt this part of the specification.
Question 9

9 Which compound could have produced the IR spectrum below?

![IR spectrum graph]

A CH₃CH₂OH  
B CH₃CHOHCN  
C CH₃COOH  
D CH₃CONH₂

Your answer [ ]
Exemplar 1

1 mark

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Examiner commentary

The annotation of the functional groups responsible for the key peaks on the IR spectrum makes this question easy with option B being the only one containing a C≡N bond.
Question 10

10 Benzene reacts with an organic reagent in the presence of a halogen carrier to form phenylethanone.

\[ \text{Benzene} \quad \xrightarrow{\text{halogen carrier}} \quad \text{phenylethanone} \]

Which organic reagent is required?

A. \( \text{CH}_3\text{CH}_2\text{OH} \)
B. \( \text{CH}_3\text{CHO} \)
C. \( \text{CH}_3\text{COCl} \)
D. \( \text{CH}_3\text{COOH} \)

Your answer

[1]

Exemplar 1

1 mark

\[ \text{Benzene} \quad \xrightarrow{\text{Arylation}} \quad \text{phenylethanone} \]

Which organic reagent is required?

A. \( \text{CH}_3\text{CH}_2\text{OH} \)
B. \( \text{CH}_3\text{CHO} \)
C. \( \text{CH}_3\text{COCl} \)
D. \( \text{CH}_3\text{COOH} \)

Your answer

[1]
Examiner commentary

The candidate's annotation of 'acylation' above the reaction shows that the candidate has recognised the type of reaction and has used this knowledge to select the correct response.
Question 11

11 How many straight-chain structural isomers of $C_7H_{15}Cl$ contain a chiral carbon atom?

A 1
B 2
C 3
D 4

Your answer [ ]

Exemplar 1 1 mark

A 1
B 2
C 3
D 4

Examiner commentary

This candidate has selected the correct response after first drawing out the straight carbon chain and annotating the positions where chiral carbons would be found. It was common to see structures drawn, sometimes for all the possible isomers.

Candidates did find this question difficult. Candidates were much more likely to get the correct answer if there was some attempt to draw out the carbon chain.
Question 12

12 The mass spectrum of \((\text{CH}_3)_2\text{CHCH}_2\text{OH}\) is shown below.

Which ion is responsible for the peak with the greatest relative intensity?

A \(\text{CHCH}_2\text{OH}^+\)
B \(\text{CH}_3\text{CH}_2\text{CH}^+\)
C \((\text{CH}_3)_2\text{CH}^+\)
D \(\text{CH}_3\text{CO}^+\)

Your answer [ ] [1]
12 The mass spectrum of \((\text{CH}_3)_2\text{CHCH}_2\text{OH}\) is shown below.

Which ion is responsible for the peak with the greatest relative intensity?

A \(\text{CHCH}_2\text{OH}^+\) 4f

B \(\text{CH}_3\text{CH}_2\text{CH}^+\) 42

C \((\text{CH}_3)_2\text{CH}^+\) 45

D \(\text{CH}_3\text{CO}^+\) 43

Your answer [D]

Examiner commentary

From the annotation on the IR spectrum, the candidate has first correctly identified 43 as the \(m/z\) value with the greatest relative intensity. The candidate has then calculated the \(m/z\) values of each fragment ion and has then chosen the incorrect option D. This is the result of a careless error with calculating the \(m/z\) value for option C, which is also 43. The candidate hasn’t considered that D is not possible from parent compound, \((\text{CH}_3)_2\text{CHCH}_2\text{OH}\).
Question 13

Which statement(s) support(s) the delocalised model for the structure of benzene?

1. All carbon–carbon bonds have the same length.
2. The enthalpy change of hydrogenation of benzene is less exothermic than expected.
3. Bromine reacts with benzene less readily than with cyclohexene.

A. 1, 2 and 3
B. Only 1 and 2
C. Only 2 and 3
D. Only 1

Your answer [ ]

Exemplar 1

1. All carbon–carbon bonds have the same length. ✓
2. The enthalpy change of hydrogenation of benzene is less exothermic than expected. ✓
3. Bromine reacts with benzene less readily than with cyclohexene.

A. 1, 2 and 3
B. Only 1 and 2
C. Only 2 and 3
D. Only 1

Your answer [ ]

Examiner commentary

The bonding in benzene is well known by candidates at A Level and most candidates correctly selected A as their response.

From the annotations, this candidate is sure that statements 1 and 2 are correct. From the crossings out, there is some uncertainty around statement 3 but eventually the candidate has chosen correctly.
Question 14

A solid organic compound can be purified by recrystallisation.

Which statement(s) about recrystallisation is/are true?

1. The organic compound is more soluble in hot solvent.

2. The hot solution is cooled before the purified organic compound is collected.

3. The melting point of the purified organic compound is lower than the impure compound.

A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer

[1]

Exemplar 1

1. The organic compound is more soluble in hot solvent.

2. The hot solution is cooled before the purified organic compound is collected. ✗ ✓

3. The melting point of the purified organic compound is lower than the impure compound.

A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer  B ✓

[1]

Examiner commentary

From the annotations, the candidate has rejected statement 3 but is unsure whether statement 2 is correct. This candidate then selected correctly.

Many candidates chose A, showing that the melting point difference of pure and unpure samples is not well known.
Question 15

15 Which of the following could react with the compound below to form a carbon–carbon bond?

\[
\text{\begin{center}
\begin{tikzpicture}
\tikz[baseline = 0, scale = 0.5]{
\node (a1) at (-2,0) [shape = circle, fill = white, draw = black] {
\text{\Huge C}
};
\node (a2) at (0,0) [shape = circle, fill = white, draw = black] {
\text{\Huge C}
};
\node (a3) at (2,0) [shape = circle, fill = white, draw = black] {
\text{\Huge C}
};
\node (a4) at (-2,-2) [shape = circle, fill = white, draw = black] {
\text{\Huge C}
};
\node (a5) at (0,-2) [shape = circle, fill = white, draw = black] {
\text{\Huge C}
};
\node (a6) at (2,-2) [shape = circle, fill = white, draw = black] {
\text{\Huge C}
};
\node (b1) at (-2,-4) [shape = circle, fill = white, draw = black] {
\text{\Huge OH}
};
\node (b2) at (0,-4) [shape = circle, fill = white, draw = black] {
\text{\Huge OH}
};
\node (b3) at (2,-4) [shape = circle, fill = white, draw = black] {
\text{\Huge OH}
};
\node (c1) at (-4,-2) [shape = circle, fill = white, draw = black] {
\text{\Huge Br}
};
\node (c2) at (2,-4) [shape = circle, fill = white, draw = black] {
\text{\Huge Br}
};
\node (d1) at (-2,2) [shape = circle, fill = white, draw = black] {
\text{\Huge H}
};
\node (d2) at (-4,0) [shape = circle, fill = white, draw = black] {
\text{\Huge H}
};
\node (d3) at (2,2) [shape = circle, fill = white, draw = black] {
\text{\Huge H}
};
\end{tikzpicture}
\end{center}
}\]

1 CH\textsubscript{3}Cl and AlCl\textsubscript{3}
2 KCN in ethanol
3 CH\textsubscript{3}OH and H\textsubscript{2}SO\textsubscript{4}

A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer

Exemplar 1

1 mark

[1]
Examiner commentary

With different possible reactions of three functional groups, candidates found this question difficult.

This candidate has chosen the correct response after first drawing out sections of the product structures to identify the functional groups formed. This is good practice, making it much easier to select the correct answer.
Question 16(a)(i)

16 This question is about reactions of organic compounds containing carbon, hydrogen and oxygen.

(a) A chemist investigates two reactions of alcohol A, shown below.

Examiner commentary
This candidate has made a common error of numbering the carbon chain from the wrong end. The functional group (alcohol) takes precedent over the alkyl side chain, giving the name as 3-methylbutan-2-ol.
Question 16(a)(ii)

(ii) What is the structural formula of alcohol A?

.................................................................................................................................................................................................................................................. [1]

Exemplar 1 0 marks

.................................................................................................................................................................................................................................................. [1]

Examiner commentary

This response shows a mistake easily avoided, as the second carbon atom from the left would be bonded to 5 atoms.

Candidates are advised to check that all atoms in a formula have the correct number of bonds.
Question 16(a)(iii)

(iii) The chemist heats alcohol A with an acid catalyst to form a mixture containing two alkenes.

Draw the structures of the two alkenes formed in this reaction.

Exemplar 1 1 mark

Examiner commentary

The candidate has drawn the two alkenes with the correct numbers of carbon atoms and carbon skeletons, but the right-hand structure has been spoilt by the (CH$_3$)$_2$CH$-$ side chain rather than (CH$_3$)$_2$CH$. This is a similar error to the example shown for 16(a)(ii) but from a different candidate.

As the structure of alcohol A had been shown as a skeletal formula in the question, it would have been more logical to have drawn the alkenes skeletally. Most candidates did copy the skeletal structure for alcohol A, with a double bond on either side of where the −OH group had been. This approach is easier, clearer and offers a much better chance of success.
Question 16(a)(iv)

(iv) The chemist heats alcohol A with sodium chloride and sulfuric acid.

Construct a balanced equation for this reaction.  
Show structures for the organic compounds in your equation.

Exemplar 1

The chemist heats alcohol A with sodium chloride and sulfuric acid.

\[ \text{NaCl} + \text{H}_2\text{SO}_4 \rightarrow \]

[OCH]

\[ \text{NaCl} \quad \text{H}_2\text{SO}_4 \]

[OCH]

\[ \text{Cl} \quad + \text{NaOH} \]

Examiner commentary

The candidate has drawn the correct structure of the haloalkane formed and scores the first mark. However, the response does not recognise that the reaction occurs under acidic conditions and omits the sulfuric acid from the equation (although it is shown above the arrow). In acidic conditions, a salt of NaOH would be formed.

Most candidates did score the mark for identifying the haloalkane but made the same mistake as in this example.
Question 16(b)

(b) Compound B, shown below, is refluxed with excess acidified potassium dichromate(VI) to form a single organic product.

Complete the equation for this reaction.

\[
\begin{align*}
\text{H}_3\text{C} & - \text{C} - \text{C} - \text{OH} + \ldots \ldots \ldots \text{[O]} & \rightarrow \\
\text{compound B}
\end{align*}
\]

Exemplar 1 2 marks

Examiner commentary

This candidate has circled the hydrogens lost in compound B during the reaction. This helps with drawing the correct structure of the organic product. The second mark is for the balanced equation.

Many candidates correctly identified the organic product. Only the higher ability candidates could complete the equation, with omission of water being the most common error.
(c) The flowchart below shows some reactions of compound C.

In the boxes, draw the organic products of these reactions.

Excess CH₃OH/H₂SO₄

HOOC\(\rightleftharpoons\)COOH

compound C

Steam

\(\text{H}_₃\text{PO}_₄\)

polymerisation

repeat unit of polymer

[3]
Examiner commentary

This candidate shows the correct responses for two of the three structures. Interestingly, the candidate has drawn a correct skeletal formula outside the box for the top compound but has missed off hydrogens in their attempt to draw it as a displayed formula. As with Question 16a(iii), skeletal formulae offer an easier, clearer and better chance of drawing correct organic structures, especially if a skeletal formula has been provided for the parent compound (compound C here).
Question 17(a)

17 The general formula of an $\alpha$-amino acid is $\text{RCH(NH}_2\text{)COOH}$.  

(a) The $\alpha$-amino acid cysteine ($\text{R} = \text{CH}_2\text{SH}$) shows optical isomerism.  

Draw 3-D diagrams to show the optical isomers of cysteine.

Exemplar 1 1 mark

Examiner commentary

The candidate has shown that they know the structure of an amino acid for the first mark.

Despite trying to draw 3D structures, the candidate has not been awarded the second mark because the connectivity to the COOH and NH$_2$ groups is incorrect in one of the structures. In this case the mark scheme ignored poor connectivity to the –CH$_2$SH bond.

When drawing out any organic structure candidates should always connect bonds to the correct atoms.


**Question 17(b)**

(b) The α-amino acid lysine \( R = (CH_2)_4NH_2 \) reacts with an excess of dilute hydrochloric acid to form a salt.

Draw the structure of the salt formed in this reaction.

[2]

**Exemplar 1**

1 mark

Examiner commentary

This candidate has shown the structure with alkylammonium ions on both nitrogen atoms. However, the question asks for the structure of the salt, with two chloride ions also required for the second mark.

Candidates are advised to check that they have answered all aspects of the question being asked.
Question 17(c)

(c) α-Amino acids can react to form proteins.

A short section of a protein chain is shown below.

A student hydrolysies the protein with hot NaOH(aq).

Draw the structures of the organic products formed from this section of the protein.

[3]

Exemplar 1

1 mark
Examiner commentary

The candidate has correctly hydrolysed the protein section into two amino acids and has shown the sodium salt of the COOH groups. Both organic products show the NH₂ groups protonated as NH₃⁺, but this is alkaline hydrolysis and there would be no protonation of NH₂ groups. The error was only penalised once. The candidate also did not hydrolyse the CONH₂ group in the second product. Candidates found this part difficult and this 1 mark response was typical.
Question 18(a)(i)

This question is about aromatic compounds.

(a) Phenol undergoes nitration more readily than benzene.

(i) A student carries out the nitration of phenol with dilute nitric acid to produce 2-nitrophenol and 4-nitrophenol.

A small amount of 3-nitrophenol is also produced.

\[
\begin{align*}
\text{2-nitrophenol} & \quad \text{OH} \quad \text{NO}_2 \\
\text{3-nitrophenol} & \quad \text{OH} \quad \text{NO}_2 \\
\text{4-nitrophenol} & \quad \text{OH} \\
\end{align*}
\]

The student thought that \(^{13}\text{C}\) NMR spectroscopy could be used to distinguish between these three nitrophenols.

Explain whether the student is correct.

.................................................................................................................................................. [3]
Examiner commentary

This is an excellent, very clear response. The candidate has added numbers to the structures to show the different carbon environments. The written response then summarises the different carbon environments well and shows that only 4-nitrophenol can be distinguished.
Question 18(a)(ii)
(ii) Explain why phenol is nitrated more readily than benzene.

..............................................................................................................................................................................
.............................................................................................................................................................................. [3]

Exemplar 1 2 marks

Phenol has a OH group attached to it. The OH group push electrons into the delocalised structure of the aromatic ring. Because phenol now has a higher electron density, it can induce a dipole in nonpolar molecules and also is more susceptible to electrophilic attack from the NO₂ electrophile. [3]

Examiner commentary
This response has been let down by the use of imprecise language. The candidate knows that the OH group feeds electrons into the ring but has omitted the source of the electrons: the lone pair on the O atom of the OH group. Later in the response, the candidate has used NO₂ rather than NO₂⁺ but the mark was still awarded because of the reference to electrophilic attack.
Question 18(b)

(b) Methylbenzene reacts with sulfur trioxide, SO₃, to form D, shown below.

The electrophile in this reaction is SO₃.

Complete the mechanism for the formation of D. Show curly arrows and the structure of the intermediate.
Examiner commentary

This response has been let down by 'sloppy' use of a curly arrow. Curly arrows show movement of an electron pair and need to originate from a bond, a lone pair or a negative charge. In the intermediate, the curly arrow starts from the H atom instead of the H–C bond.
**Question 19(a)**

19 This question is about the hydrolysis of haloalkanes.

(a) The rate of hydrolysis of a haloalkane depends on the halogen present.

State and explain how the halogen in the haloalkane affects the rate of hydrolysis.

………………………………………………………………………………………………………………………………………………………………………………… [2]

---

**Exemplar 1**

Examiner commentary

This candidate has linked the strength of a covalent bond with the rate of hydrolysis but has not linked their explanation to the breaking of a \( \text{C-Hal} \) bond. Consequently, the candidate has scored only the first available mark.
**Question 19(b)**

(b) Chlorocyclohexane is hydrolysed with aqueous sodium hydroxide.

Outline the mechanism for this reaction.

Show curly arrows, relevant dipoles and the products.

Examiner commentary

The candidate has shown relatively clear curly arrows to achieve all three available marks. In the products, the candidate appears to have first included Na$^+$ as well as Cl$^-$ but this has not been rubbed out properly. As the charge on Cl$^-$ has been shown, Na$^+$ has been ignored. This would have been clearer if the original Na$^+$Cl$^-$ response had been crossed out and replaced with Cl$^-$. The curly arrow from the hydroxide ion has been shown from a lone pair on the O atom. The response could have been improved if the – charge had been placed above the O atom rather than the H atom.
Question 19(c)(i)

(c) A student hydrolys a haloalkane, E, using the following method.

- 0.0100 mol of haloalkane E is refluxed with excess NaOH(aq) to form a reaction mixture containing an organic product F.
- The reaction mixture is neutralised with dilute nitric acid.
- Excess AgNO₃(aq) is added to the reaction mixture. 1.88 g of a precipitate G forms.

Organic product, F, has a molar mass of 74.0 g mol⁻¹ and has a chiral carbon atom.

(i) Draw a labelled diagram to show how the student would carry out the hydrolysis of haloalkane E.

Exemplar 1

1 mark

Examiner commentary

The overall standard of diagrams could be improved; the quality of the diagram in this response was typical. The diagram is lacking in detail: the flask and the condenser are sealed and the inside of condenser is not shown. The candidate has just been awarded one mark, for recognising that a reflux set up has a vertical condenser above a flask. The direction of water flow has been shown but the apparatus has not been labelled, despite labelled being emphasised in the question.
Examiner commentary

This candidate has shown an exemplary diagram of a reflux set up, with correct labels. The superfluous diagrams for the subsequent reaction have been ignored but it would have been better had they not been included at all. Inclusion of material extra to that asked for risks contradicting correct answers and also wastes valuable exam time.

It is worth comparing the diagrams in the two examples – the first example was still better than many seen on scripts.
Question 19(c)(ii)

(ii) Analyse the information to identify E, F and G.

Show your working.

Exemplar 1

[3] 1 mark

Examiner commentary

This candidate has deduced that G is AgBr with clear working to back up their answer. The question asks for working.

The candidate has then identified the correct molecular formulae of F and E but has not factored in that F has a chiral carbon atom and must be C_4H_9CH(CH_3)OH. C_4H_9OH is ambiguous and its structure needs to be shown, with the structure of C_4H_9Br matching this. The best candidates drew out clear structures.
Question 20(a)

Cinnamaldehyde and methylcinnamaldehyde are naturally occurring organic compounds.

(a) Methylcinnamaldehyde is an E stereoisomer.

Explain this statement in terms of the Cahn-Ingold-Prelog (CIP) rules.

Exemplar 1

(a) Methylcinnamaldehyde is an E stereoisomer.

Examiner commentary

Cahn-Ingold-Prelog (CIP) rules were introduced to the reformed A level specification in 2015. This question clearly requires some explanation for the E assignment in natural methylcinnamaldehyde.

CIP rules are based on atomic numbers and not atomic or molecular masses.

This response is one of the many that attempted to explain the CIP rules in terms of Mr. This candidate has been credited for identifying the C₆H₅ and CHO priority groups but has not stated that these are positioned on opposite sides of the C=C bond. The best answers included a diagram labelling the C₆H₅ and CHO priority groups.
Question 20(b)(i)

(b) A student plans to carry out some chemical tests on both cinnamaldehyde and methylcinnamaldehyde.

![Cinnamaldehyde and Methylcinnamaldehyde structures]

cinnamaldehyde  methylcinnamaldehyde

(i) Suggest a suitable chemical test to confirm that both compounds contain an unsaturated carbon chain.

Your answer should include the reagent and observations.

................................................................................................................................................. [1]

Exemplar 1

(i) Suggest a suitable chemical test to confirm that both compounds contain an unsaturated carbon chain.

Your answer should include the reagent and observations.

Bromine water (Br₂).................................................................................................................

Colour change?...Brown...to colourless........................................................................... [1]

Examiner commentary

This concise response clearly identifies the reagent and the observed change.
Question 20(b)(ii)

(ii) Describe a chemical test to confirm that both compounds contain an aldehyde functional group.

Your answer should include the reagent and observations.


Exemplar 1

Examiner commentary

This candidate has identified Brady's reagent (2,4-DNP) and its observation, but without considering that Brady's reagent gives an orange/yellow precipitate with both aldehydes and ketones. Most candidates responded with Tollens' reagent and its silver mirror. This question proved to be easy for the majority of candidates, with few making the mistake shown here.
Question 20(b)(iii)

(iii) Describe a chemical test to confirm that cinnamaldehyde and methylcinnamaldehyde contain a carbonyl group.

How could the products of this test be used to distinguish between the two compounds?

Your answer should **not** include spectroscopy.

---------------------------------------------------------------------------------------- [3]

Exemplar 1

1 mark

Add 2,4-DNP. If carbonyl groups are present an orange/yellow precipitate forms. To distinguish the precipitate should be filtered off and the melting points should be identified and then compared to a data table.

Examiner commentary

The candidate has identified 2,4-DNP as the correct reagent with the correct observation. Unfortunately, the candidate has then discussed comparing boiling points rather than melting points (despite filtering off a solid). Melting points, the correct response, was changed to boiling points but it is unclear why.

Candidates are advised to check the logic of their responses.
Question 20(c)

(c) The flowchart below shows some reactions starting with cinnamaldehyde.

Draw the structures of the missing organic compounds in the boxes and add the missing reagent(s) on the dotted line.
Examiner commentary

This was a difficult question, assessing knowledge and understanding of reactions of several functional groups in a novel context.

This candidate has wisely drawn skeletal formulae based on the structures shown. This is good practice as it rules out losing marks for missing or extra H atoms on C atoms in displayed formulae (see the earlier comments in questions 16a(iii) and 16c).

For the error in the top structure, the candidate has recognised that the CN group is reduced but has missed out the CH₂ group before the NH₂ group. This is careless but proved to be a common omission. The error in the bottom right structure suggests that the candidate had not learnt the hydrolysis of the CN group (or had not recognised the type of reaction from the H⁺(aq) reagent).
Question 20(d)

(d)* Methylcinnamaldehyde reacts with iodine monochloride, ICl, by electrophilic addition. The reaction produces a mixture containing two different organic products.

\[
\text{methylcinnamaldehyde}
\]

The electronegativity values of chlorine and iodine are given in the table below.

<table>
<thead>
<tr>
<th></th>
<th>Pauling electronegativity value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
<td>3.0</td>
</tr>
<tr>
<td>I</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Outline the mechanism, using the ‘curly arrow’ model, for the formation of one of the organic products and explain which of the two possible organic products is more likely to be formed.

In your mechanism, you can show the phenyl group as C₆H₅. [6]
### Exemplar 1

#### Level 3, 6 marks

<table>
<thead>
<tr>
<th></th>
<th>Pauling electronegativity value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
<td>3.0</td>
</tr>
<tr>
<td>I</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Outline the mechanism, using the 'curly arrow' model, for the formation of one of the organic products and explain which of the two possible organic products is more likely to be formed.

In your mechanism, you can show the phenyl group as \( \text{C}_6\text{H}_5 \).

\[
\begin{align*}
\text{H} & \quad \text{CH}_3 \\
\text{C} & \quad \text{C} \\
\text{H}_3\text{C} & \quad \text{C} \\
\text{H}_5\text{C} & \quad \text{C} \\
\end{align*}
\]

It is an electrophilic addition reaction. Cl is more electronegative than \( \text{H}_2 \text{O} \) because chlorine therefore attracts the electron pair more strongly, forming an induced dipole \( \text{I} \quad \overset{\text{O}}{\text{C}} \). The product \( \text{H}_5\text{C} - \text{C} - \text{C} - \text{CH}_3 \) would be the major product as it forms an intermediate which is a tertiary carbocation, which is more stable than

---

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Examiner commentary

This is an excellent Level 3 response, easily securing all marks in this Level of Response question.

The candidate has addressed all aspects of the question, showing clear arrows, charges, dipoles and relevant lone pairs in the mechanism and linking the major and minor products with clearly drawn carbocations. This is backed up by a coherent explanation.
Exemplar Candidate Work

Exemplar 2

Level 2, 3 marks

The electronegativity values of chlorine and iodine are given in the table below.

<table>
<thead>
<tr>
<th></th>
<th>Pauling electronegativity value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
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</tr>
<tr>
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<td>2.5</td>
</tr>
</tbody>
</table>

Outline the mechanism, using the ‘curly arrow’ model, for the formation of one of the organic products and explain which of the two possible organic products is more likely to be formed.

In your mechanism, you can show the phenyl group as \( \text{C}_6\text{H}_5 \).

[6]

The examiner commentary

This is a Level 2 response. Although the candidate has drawn a clear mechanism and has identified the major product, a line of reasoning is missing and the communication strand of the criteria has not been addressed. The candidate has mentioned a carbocation intermediate, but this should have been labelled in the mechanism. The question also clearly refers to two possible organic products, but the candidate has only referred to one.
Examiner commentary

This candidate has attempted a basic outline of the mechanism but the mechanism has errors in the direction of a curly arrow for the first stage, the intermediate and the product. The candidate realises that major and minor products are linked with stability but carbocation is not mentioned. The ‘other product’ as then just identified as a ‘different compound’.

The communication strand has been addressed as there is an attempt at a logical structure with a line of reasoning.

This response appears to be the response of a poorly prepared candidate.
Question 21(a)

21 This question is about aromatic carboxylic acids and their derivatives.

(a) The flowchart below shows some reactions of compound H.

In the boxes, draw the organic products of these reactions.
Examiner commentary

This candidate, like many, has identified the correct product at the bottom for the reaction with Br₂. The candidate has then drawn the same product in the two boxes at the top for the acid–base reaction with Na₂CO₃ and NaOH. This is unlikely but may suggest that they knew that one would be correct and they were hedging their bets. Overall, many candidates were confused between these two reactions and the carboxylate ion was seen far more often than the phenoxide ion.
Question 21(b)

(b) Compound H is used in the synthesis of polymer I, as shown in the flowchart below.

Complete the flowchart by drawing the structure of the acyl chloride and two repeat units of polymer I, and stating the formula of the reagent(s) required for the first stage on the dotted line.
Examiner commentary

This is a good, clear response, showing that the candidate has learnt the reaction for formation of an acyl chloride from a carboxylic acid. However, the response is spoilt by a careless mistake in drawing the section of the polymer, with O on either side of repeat units. Only the mark for the ester group could be awarded for the structure shown.
Question 21(c)(i)

(c) A cosmetic product containing four esters, J, K, L and M, is analysed by gas chromatography and mass spectrometry. The results are shown below.

Gas chromatogram

The numbers by the peaks are the relative molar proportions of the compounds in the mixture.

Mass spectrometry

<table>
<thead>
<tr>
<th>ester</th>
<th>m/z of molecular ion peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>152</td>
</tr>
<tr>
<td>K</td>
<td>166</td>
</tr>
<tr>
<td>L</td>
<td>180</td>
</tr>
<tr>
<td>M</td>
<td>180</td>
</tr>
</tbody>
</table>

(i) The concentration of ester K in the cosmetic product is 9.13 \times 10^{-2} \text{g dm}^{-3}.

Using the results, calculate the concentration, in mol dm^{-3}, of ester M in the cosmetic product.

Give your answer to two significant figures.

concentration of ester M = \ldots \ldots \text{mol dm}^{-3} [2]
Exemplar Candidate Work

Exemplar 1

1 mark

The numbers by the peaks are the relative molar proportions of the compounds in the mixture.

Mass spectrometry

<table>
<thead>
<tr>
<th>ester</th>
<th>m/z of molecular ion peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
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<td>166</td>
</tr>
<tr>
<td>L</td>
<td>180</td>
</tr>
<tr>
<td>M</td>
<td>180</td>
</tr>
</tbody>
</table>

(i) The concentration of ester K in the cosmetic product is $9.13 \times 10^{-2}$ g dm$^{-3}$.

Using the results, calculate the concentration, in mol dm$^{-3}$, of ester M in the cosmetic product.

Give your answer to two significant figures.

Conc of K in mol dm$^{-3}$ = $\frac{9.13 \times 10^{-2}}{166}$

Conc of M = $\frac{9.13 \times 10^{-2} \text{ g dm}^{-3} \times 5.9}{4.3}$

Concentration of ester M = $7.0 \times 10^{-4}$ mol dm$^{-3}$ [2]

Examiner commentary

This type of question has not been asked before and the unfamiliarity tested most candidates. Despite this, many attempted a calculation based on their understanding of the mole. Candidates fell down more by misinterpretation of the data than through problems with the mole calculations.

This response shows a common error where the candidate has used the molar mass of M (180) instead of K (166). The clear method shown ensures that one mark could be awarded using error carried forward.
Question 21(c)(ii)

(ii) A general structure for esters J, L and M is shown below.

\[
\begin{array}{c}
\text{HO} \\
\text{C} \\
\text{O} \\
\text{O} \\
\text{R}
\end{array}
\]

Where ‘R’ is an alkyl group.

Use the mass spectrometry results to deduce possible structures for esters J, L and M.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>L</td>
<td>M</td>
</tr>
</tbody>
</table>

[3]
Exemplar 1

(ii) A general structure for esters J, L, and M is shown below.

Where ‘R’ is an alkyl group.

Use the mass spectrometry results to deduce possible structures for esters J, L, and M.

![Mass spectra and structures]

Examiner commentary

The annotations show that the candidate has worked out the correct molar masses of the R groups and they have correct structures for J and L. The question does state that all R groups are alkyl groups but the candidate has shown the R group for M as an aldehyde (–CH₂CHO) rather than the branched CH(CH₃)₂. There is some logic, as –CH₂CHO and CH(CH₃)₂ both have a mass of 43, but essential information in the question has been ignored.
Question 22(a)

The relative molecular masses and boiling points of some fuels are shown in Table 22.1.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Relative molecular mass</th>
<th>Boiling point/°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>hexane</td>
<td>86</td>
<td>69</td>
</tr>
<tr>
<td>pentan-1-ol</td>
<td>88</td>
<td>138</td>
</tr>
<tr>
<td>heptane</td>
<td>100</td>
<td>98</td>
</tr>
</tbody>
</table>

Table 22.1

(a) Write an equation for the incomplete combustion of heptane.

Exemplar 1

\[ C_6H_{14} \]

(a) Write an equation for the incomplete combustion of heptane.

\[ C_6H_{14} + \frac{13}{2}O_2(\text{g}) \rightarrow 6CO(\text{g}) + 7H_2O(\text{l}) \]

Examiner commentary

This candidate is able to write an equation for the complete combustion of an alkane. Unfortunately, the candidate has written the equation for hexane instead of heptane and the response cannot be credited.

This is a careless error. Hexane and heptane do both feature in the table, but the candidate seems to have not read the question closely enough. Some candidates circled heptane in the table and in the question which helps to reinforce what is required.
Question 22(b)

(b) Explain the difference in the boiling points of the fuels in Table 22.1.

Exemplar 1

Pentan-1-ol has the highest boiling point because it can form hydrogen bonds so it requires a larger amount of energy to break the forces of interaction. Heptane has a higher boiling point than hexane because it has a larger contact area due to a longer chain length so has stronger London forces than hexane. It therefore requires more energy to break than hexane. Hexane has the weakest induced dipole-dipole interactions.

Examiner commentary

This candidate has produced a good comparison of the boiling points of hexane and heptane with a clear explanation in terms of points of contact, relative strengths of the London forces and energy. The candidate has stated that pentan-1-ol has hydrogen bonds but there is no direct statement that these are strong, nor a comparison with the strength of London forces. This is a good response, just lacking the necessary detail to be awarded the final mark.
Question 22(c)(i)

(c) Fuel additives are often used to improve the combustion of a fuel.

(i) Compound N is a fuel additive containing carbon, hydrogen and oxygen only.

Complete combustion of 1.71 g of compound N produces 2.97 g of CO₂ and 1.62 g of H₂O. The relative molecular mass of compound N is 76.0.

Calculate the molecular formula of N and suggest a possible structure for the compound.
Complete combustion of 1.71g of compound N produces 2.976g of CO₂ and 1.62g of H₂O. The relative molecular mass of compound N is 78.07.

Calculate the molecular formula of N and suggest a possible structure for the compound.

\[
\begin{align*}
\text{n of Compound } N &= \frac{1.71}{\frac{78.07}{1}} = 0.06225 \text{ moles.} \\
\text{n of CO}_2 &= \frac{2.976}{44} = 0.0675 \\
\text{n of H}_2\text{O} &= \frac{1.62}{18} = 0.09 \\
\end{align*}
\]

Compound N: H₂O

\begin{align*}
\text{Compound } N : \text{CO}_2 \\
\text{1 : 3.} \\
\end{align*}

\[
\begin{align*}
\text{C}_3\text{H}_8\text{OH} + 3\text{O}_2 &\rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O} \\
\text{Molec. : C}_3\text{H}_2\text{O}_9 \\
\end{align*}
\]

Examiner commentary

This candidate has shown a well-structured response, let down by the incorrect molecular formula. The candidate has drawn the correct structure but hasn’t checked that this agrees with their earlier molecular formula.
Question 22(c)(ii)

(ii) Solketal has been investigated as a potential fuel additive.

Solketal is synthesised from propane-1,2,3-triol and a carbonyl compound.

Construct a balanced equation for this synthesis.
Show structures for the organic compounds in your equation.

Exemplar 1

Show structures for the organic compounds in your equation.

```
\text{OHCH}_2\text{CHOHCH}_2\text{OH} + (\text{CO}_2\text{H})_2\text{C(CH}_3\text{)}_2 \rightarrow \text{Solketal} + \text{H}_2\text{O}
```

[2] 

0 marks
Examiner commentary

This response is not without some logic. The working in the additional answer space shows that the candidate has tried to work out the fragments that would react to form solketal. The candidate has worked out the structure of propane-1,2,3-triol and has also identified that water is a side product. The formula of the second reactant is incorrect and the candidate has not made use of the information that it is a carbonyl compound. No marks could be awarded.
Question 22(d)

(d)* A scientist is researching compounds that might be suitable as fuel additives. One of the compounds gives the analytical results below.

Elemental analysis by mass:
C: 54.54%; H: 9.10%; O: 36.36%

Mass spectrum:
Molecular ion peak at m/z = 132.0

$^1$H NMR spectrum in D$_2$O

The numbers by the peaks are the relative peak areas.

When the spectrum is run without D$_2$O, there are two additional peaks with the same relative peak areas at 11.0 ppm and 3.6 ppm.

Use the information provided to suggest a structure for the compound.

Show all your reasoning. [6]
Examiner commentary

This is a Level 3 response and has been awarded all available marks. The response is clear, concise and is very well-organised. The working out of the empirical and molecular formulae is clear and the text that follows shows the logic in deciding the structural features from the NMR spectrum. This is extremely well explained. Finally, the candidate has combined all the evidence to produce a possible structure for the unknown compound.
Exemplar 2

Mass spectrum:
Molecular ion peak at \( m/z = 132.0 \)

\(^1\text{H} \text{NMR spectrum in D}_2\text{O}\)

The numbers by the peaks are the relative peak areas.

When the spectrum is run without D\(_2\)O, there are two additional peaks with the same relative peak areas at 11.0 ppm and 3.8 ppm.

\[
\text{empirical formula of compound:} \quad \frac{\text{C}}{\text{H}} = 11 : 0
\]

\[
\text{mass} : 9.1 : 36.36
\]

\[
\text{relative mass} : 9.1 : 2.2226
\]

\[
2 : 4 : 1 = \text{C}_2\text{H}_4\text{O}_4
\]

\[
\text{molecular formula} = \frac{127}{146}
\]

\[
\approx \text{C}_6\text{H}_2\text{O}_3
\]

Interpret relative peak area: Hydrogen atoms 1 : 1
and each additional peak area \( \approx 1 \).

Singlet at 1.2 ppm is \( \text{H} - \text{C} - \text{O} - \text{CH}_3 \)

Doublet at 1.9 ppm is \( \text{H} - \text{C} - \text{H}_3 \)

Quartet at 4.0 ppm is \( \text{H} - \text{C} - \text{H} \)

The two peaks which appear with D\(_2\)O are two \( -\text{OH} \) groups.

Therefore, structure:

\[
\text{H} - \text{C} - \text{O} - \text{C} - \text{CH}_3
\]

Additional answer space if required.
Examiner commentary

This is a Level 2 response and has been awarded four marks. The annotations on the spectrum show how the candidate has linked chemical shifts and splitting patterns to structure. The working out of the empirical and molecular formulae is clear and the text summarises the structural features annotated on the spectrum. Finally, the candidate has produced a possible structure that fits with the NMR splitting patterns. Unfortunately, the structure does not match the molecular formula and there is a C=O group missing.

This response shows good analytical skills in isolation but the candidate was unable to produce a structure that fitted with all of the evidence.
The numbers by the peaks are the relative peak areas.

When the spectrum is run without D₂O, there are two additional peaks with the same relative peak areas at 11.0 ppm and 3.6 ppm.

\[ C : \frac{5.4}{1.2} \quad H : \frac{9.10}{1} \quad O : \frac{30.36}{1.6} \]

\[ = \frac{4.545}{2.275} \quad = \frac{9.10}{2.275} \quad = \frac{2.3125}{2.275} \]

\[ C : 2 \quad H : 4 \quad O : 0 \]

Empirical formula: \( C₂H₄O \) = 44

\[ m/\ell = 182 \quad \text{mass of} \quad 3 \quad \text{of} \quad (C₂H₄O) \]

\[ C₆H₁₂O₂ \]

<table>
<thead>
<tr>
<th>Chemical Shift</th>
<th>Relative Peak Area</th>
<th>Splitting Pattern</th>
<th>Adjacent H's</th>
<th>Functional Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 ppm</td>
<td>2</td>
<td>doublet</td>
<td>1</td>
<td>CH₃−CH₂−CH₃</td>
</tr>
<tr>
<td>3.1 ppm</td>
<td>6 x 2 CH₃</td>
<td>singlet</td>
<td>0</td>
<td>H₃C−C−O</td>
</tr>
<tr>
<td>8.4 ppm</td>
<td>1</td>
<td>quartet</td>
<td>3</td>
<td>CH₂−CH₃</td>
</tr>
<tr>
<td>7.1 ppm</td>
<td>8</td>
<td>CH₂−CH₂−CH₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3 ppm</td>
<td>3</td>
<td>CH₃−CH₂−CH₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1 ppm</td>
<td>2</td>
<td>CH₂−CH₂−CH₃</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional answer space if required.

\[ C−CH₃ \]

\[ CH₃−C−C−O \]

\[ H₃C−C−C−O−C−CH₃ \]

\[ CH₂−CH₃ \]

\[ H \]
Examiner commentary

This is a Level 1 response and has been awarded two marks. The response is clear and aided by the use of a table to summarise the NMR data and the structures responsible for each peak.

The main problem is that the molecular formula is incorrect (C₆H₁₂O₂ instead of C₆H₁₂O₃). The candidate has also only accounted for one of the two peaks present when the NMR spectrum is run without D₂O.

When attempting to assemble the structural parts from the NMR spectrum, the candidate is one O atom short. The structure does not match the structural parts already identified in the table and is simply a structural isomer of the incorrect molecular formula, C₆H₁₂O₂.
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