Please check the examination details below before entering your candidate information

| Candidate surname | Other names |
|---|---|
| | |

**Pearson Edexcel Level 3 GCE**

Centre Number | | | | | |

Candidate Number | | | | |

# Tuesday 4 June 2019

Afternoon (Time: 1 hour 45 minutes) | Paper Reference **9CH0/01**

# Chemistry

## Advanced

## Paper 1: Advanced Inorganic and Physical Chemistry

**Candidates must have:** **Data Booklet**
**Scientific calculator**
**Ruler**

Total Marks

## Instructions

- Use **black** ink or **black** ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

## Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- For the question marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically showing the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

## Advice

- Read each question carefully before you start to answer it.
- Show all your working in calculations and include units where appropriate.
- Check your answers if you have time at the end.

*Turn over* ▶









Pearson

**Answer ALL questions.**

**Some questions must be answered with a cross in a box ☒.**
**If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.**

**1** This question is about atoms, molecules and ions.

(a) The numbers of subatomic particles in an $^{18}O$ atom are

**(1)**

☒ **A** 8 protons, 10 neutrons and 8 electrons

☒ **B** 9 protons, 9 neutrons and 9 electrons

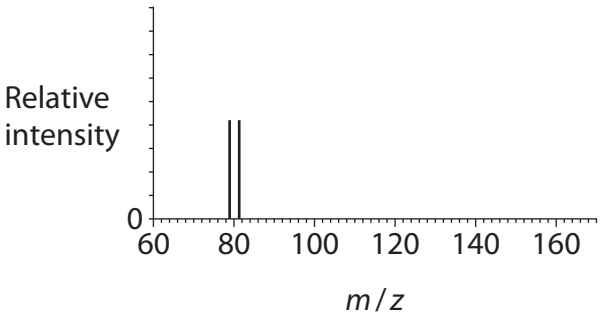
☒ **C** 10 protons, 8 neutrons and 10 electrons

☒ **D** 18 protons, 18 neutrons and 18 electrons

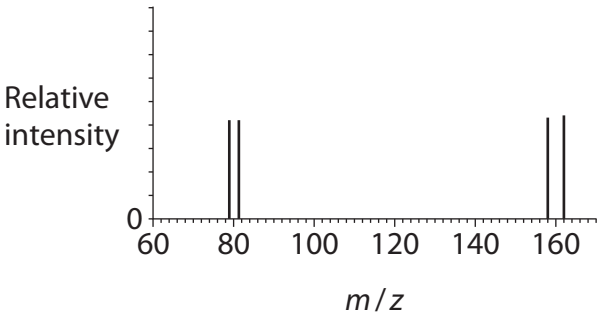
(b) The mass spectrum of a sample of bromine **molecules** with approximately equal proportions of the $^{79}Br$ and $^{81}Br$ isotopes is

**(1)**

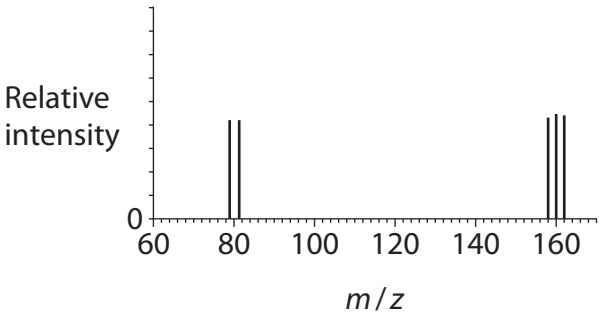
☒ **A**



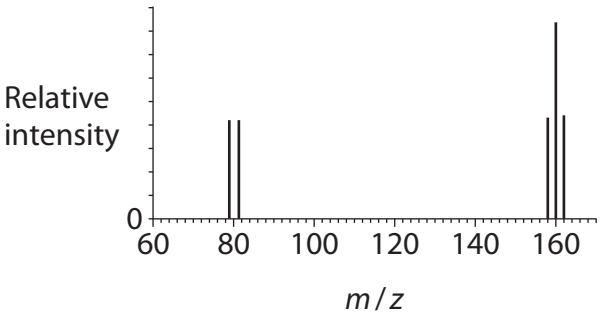

☒ **B**




☒ **C**




☒ **D**



(c) The total number of electrons in **all** the occupied **p** orbitals in a chloride ion, $Cl^-$, is

**(1)**

☒ **A** 5

☒ **B** 6

☒ **C** 12

☒ **D** 18

(d) Which of these isoelectronic ions has the largest ionic radius?

**(1)**

☒ **A** $N^{3-}$

☒ **B** $O^{2-}$

☒ **C** $Na^+$

☒ **D** $Al^{3+}$

**(Total for Question 1 = 4 marks)**

**2** This question is about some redox reactions of chlorine, bromine and iodine.

(a) An **excess** of aqueous potassium bromide was added to chlorine water and the solution turned orange.

(i) Write an equation for this reaction. State symbols are not required.

**(1)**

(ii) Silver nitrate solution was added to the mixture in (a) and excess dilute ammonia solution was then added to the precipitate formed. Only some of the precipitate dissolved.

Deduce why only **some** of the precipitate dissolved.

**(3)**

(iii) Aqueous potassium bromide was added to aqueous iodine, instead of chlorine water. There was no reaction.

Give a reason why no reaction occurred.

**(1)**

(b) Chlorine undergoes disproportionation when it reacts with **hot** aqueous sodium hydroxide solution.

(i) Complete the ionic equation for this reaction.
State symbols are not required.

**(1)**

..... $Cl_2$ + ..... $OH^-$ → ..... $Cl^-$ + ..... $ClO_3^-$ + ..... $H_2O$

(ii) Explain, in terms of oxidation numbers, why this is a disproportionation reaction.

**(2)**

**(Total for Question 2 = 8 marks)**

**3** The standard molar enthalpy change of neutralisation is the enthalpy change when an acid and an alkali react under standard conditions to form one mole of water.

(a) An experiment was carried out to determine the enthalpy change of neutralisation for the reaction between propanoic acid and sodium hydroxide.

The equation for this reaction is

$$CH_3CH_2COOH(aq) + NaOH(aq) \rightarrow CH_3CH_2COO^-Na^+(aq) + H_2O(l)$$

50.0 $cm^3$ of sodium hydroxide solution, of concentration 1.00 mol $dm^{-3}$, was placed in a polystyrene cup. The initial temperature was measured.

(i) Which piece of equipment has the **smallest** measurement uncertainty for the measurement of 50.0 $cm^3$ of sodium hydroxide solution?

**(1)**

| | | Equipment | Measurement uncertainty for **each** reading |
|---|---|---|---|
| ☒ | **A** | burette | ±0.05 $cm^3$ |
| ☒ | **B** | 50 $cm^3$ measuring cylinder | ±1 $cm^3$ |
| ☒ | **C** | 25 $cm^3$ pipette | ±0.06 $cm^3$ |
| ☒ | **D** | 50 $cm^3$ pipette | ±0.08 $cm^3$ |

(ii) 50.0 $cm^3$ of propanoic acid solution, of concentration 1.00 mol $dm^{-3}$, was added and thoroughly mixed with the sodium hydroxide solution in the polystyrene cup.

The maximum temperature rise was 6.5 °C.

Calculate the enthalpy change of neutralisation for propanoic acid, in kJ $mol^{-1}$, giving your answer to the **nearest whole number**.

[Assume density of the mixture = 1.00 g $cm^{-3}$, specific heat capacity of the mixture = 4.18 J $g^{-1}$ °$C^{-1}$]

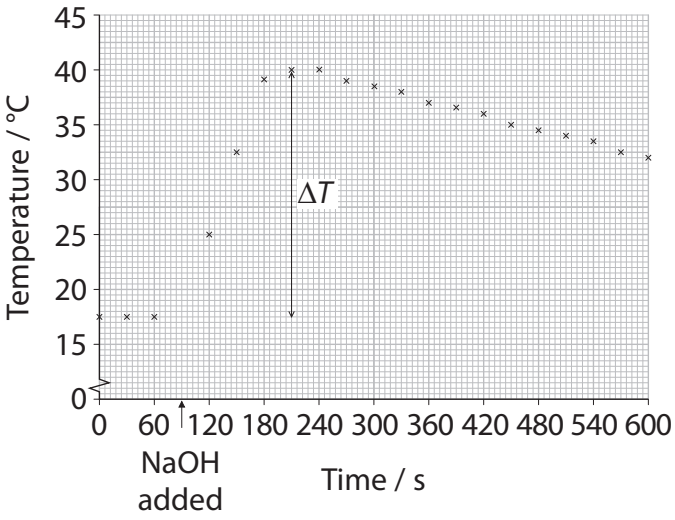
**(3)**

(b) Another experiment was carried out with a solution of ethanoic acid and sodium hydroxide solution of the same concentration.

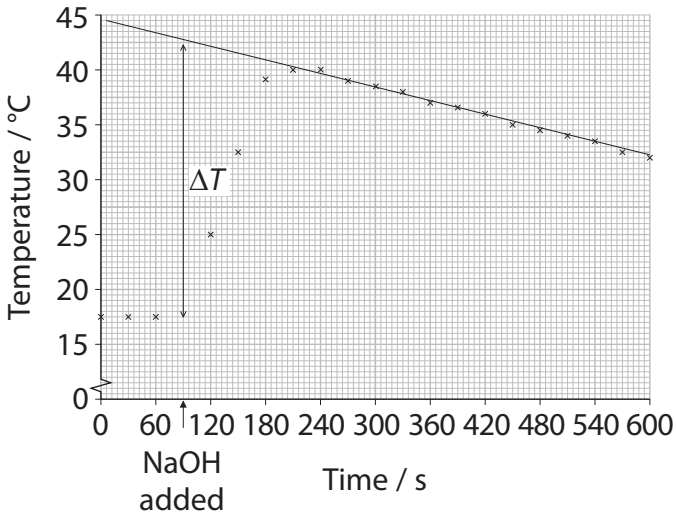
(i) Which graph shows the correct way that the maximum temperature rise should be determined?

**(1)**

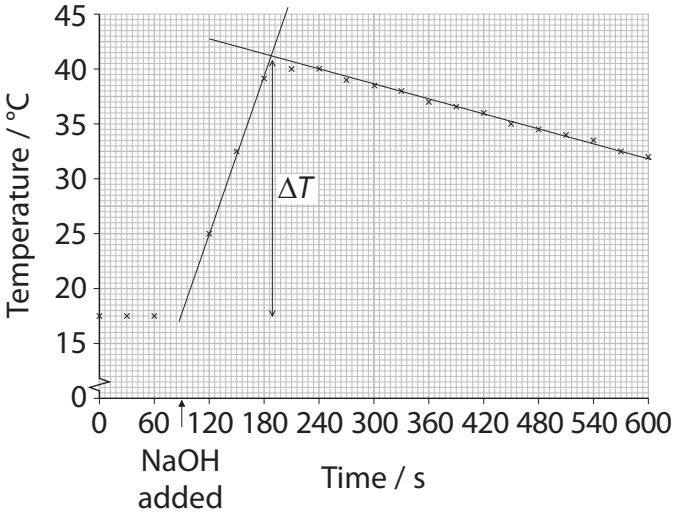
☒ **A**



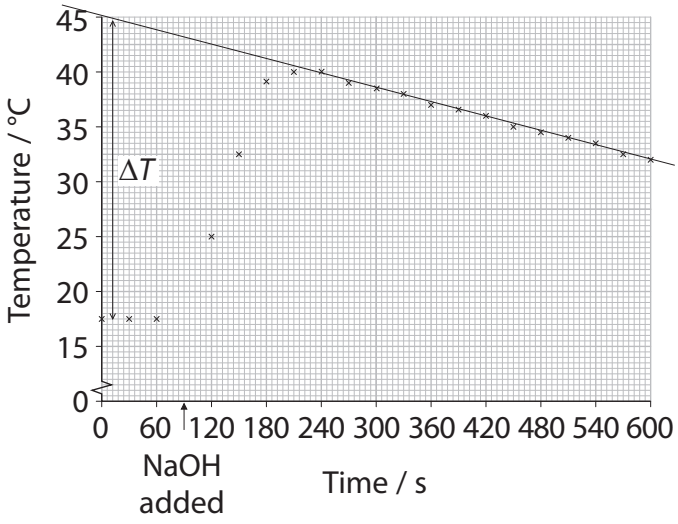

☒ **B**




☒ **C**




☒ **D**



(ii) Explain why the data book value for the standard enthalpy change of neutralisation of ethanoic acid with sodium hydroxide is $-55.2\,kJ\,mol^{-1}$ but the value for hydrochloric acid is $-57.1\,kJ\,mol^{-1}$.

**(2)**

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**(Total for Question 3 = 7 marks)**

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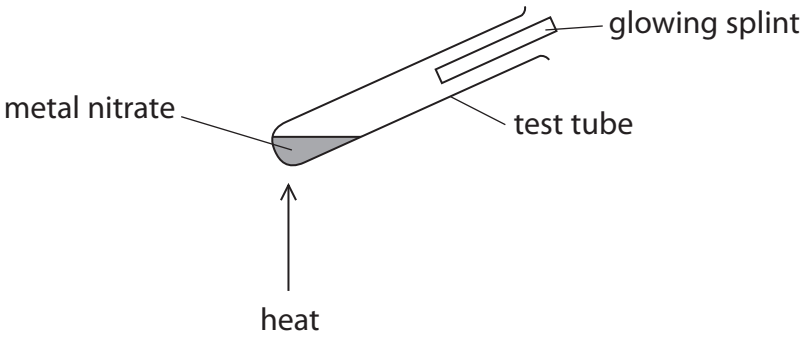
**4** Thermal decomposition is the breaking down of a substance by heat.

(a) An experiment was carried out to investigate the thermal decomposition of a metal nitrate using the apparatus shown.




(i) The glowing splint is used as a test for one of the gases given off in this experiment.

Identify this gas and the positive result of the test.

**(1)**

.....

.....

(ii) Give the name and appearance of the other gas given off in this experiment when a Group 2 nitrate is heated.

**(1)**

.....

.....

(iii) Write the equation for the decomposition if the Group 1 compound, sodium nitrate, was used in this experiment.
State symbols are not required.

**(1)**

(iv) Describe the apparatus that would be used to compare the decomposition of metal carbonates. Include how the rate of decomposition would be compared.

**(2)**

(b) Explain why magnesium carbonate decomposes much more readily on heating than barium carbonate.

**(3)**

**(Total for Question 4 = 8 marks)**

**5** This is a question about catalysis.

(a) The reaction between iodide ions and peroxodisulfate ions is catalysed by iron(II) ions.

$$2I^- + S_2O_8^{2-} \xrightarrow{Fe^{2+}} I_2 + 2SO_4^{2-}$$

(i) Give a reason why the reaction between iodide ions and peroxodisulfate ions has a high activation energy and is therefore very slow without a catalyst.

**(1)**

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(ii) Explain, with the aid of two equations, how the iron(II) ions catalyse this reaction. State symbols are not required.

**(3)**

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(b) The oxidation of sulfate(IV) ions to sulfate(VI) ions is catalysed by cobalt(II) ions in **acidic** solution. The role of cobalt(II) ions is similar to that of iron(II) ions in (a).

$$SO_3^{2-} + \tfrac{1}{2}O_2 \xrightarrow{Co^{2+}} SO_4^{2-}$$

Deduce two ionic equations to show how cobalt(II) ions catalyse the reaction in **acidic** solution. State symbols are not required.

**(2)**

(c) The rate of oxidation of ethanedioate ions by manganate(VII) ions starts slowly and then rapidly increases.

$$2MnO_4^- + 16H^+ + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$$

What is the catalyst in this reaction?

**(1)**

☒ **A** $CO_2$

☒ **B** $H^+$

☒ **C** $Mn^{2+}$

☒ **D** $MnO_4^-$

(d) The trend in the strength of gaseous adsorption by three transition elements is

tungsten > platinum > silver

Silver is not suitable as a replacement for platinum in a catalytic converter because the adsorption of gases is too weak to allow significant chemical reaction.

Give a possible reason why tungsten would also **not** be a suitable replacement for platinum in a catalytic converter. Refer to the mechanism of heterogenous catalysis in your answer.

**(1)**

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**(Total for Question 5 = 8 marks)**

**6** This is a question about water.

(a) Water might be expected to have a lower boiling temperature than hydrogen sulfide but it actually has a higher boiling temperature.

Comment on this statement by referring to the intermolecular forces in both these substances.

A detailed description of how the intermolecular forces arise is not required.

**(4)**

(b) Explain why both water and carbon dioxide molecules have polar bonds but only water is a polar molecule.

**(4)**

(c) Pure water ionises to form $H_3O^+$ and $OH^-$ ions, although only to a very small extent.
Draw the dot-and-cross diagrams of these ions.
Use dots (•) for the hydrogen electrons and crosses (×) for the oxygen electrons.

**(2)**

(d) An equation for the ionisation of water is

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$$

The expression for the ionic product of water is

$$K_w = [H^+(aq)]\,[OH^-(aq)]$$

The value of $K_w$ at 310 K is $2.40 \times 10^{-14}$ mol$^2$ dm$^{-6}$

(i) Calculate the pH of water at 310 K.

Give your answer to **two** decimal places.

**(2)**

(ii) Predict, with a reason, whether water is acidic, alkaline or neutral at 310 K.

**(2)**

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(iii) Predict, with a reason, the sign of the enthalpy change for the ionisation of water.

**(1)**

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**(Total for Question 6 = 15 marks)**

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*7 Colour is often used in chemistry to identify substances.

Compare and contrast the origin of the colour of a copper(II) complex with the origin of the colour of the copper(II) ion in a flame test.

You do not need to state any specific colours.

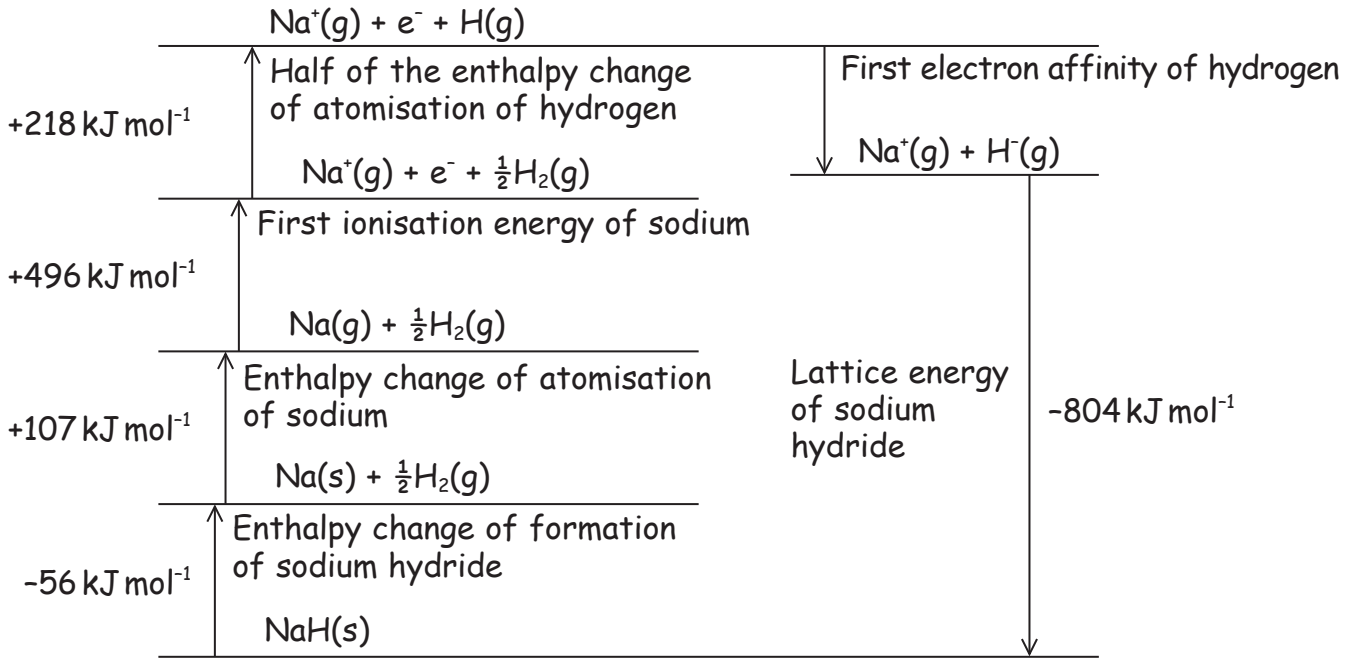
**(6)**

**(Total for Question 7 = 6 marks)**

**8** Sodium hydride, NaH, can be used to generate hydrogen for fuel cells.

(a) In order to calculate the first electron affinity of hydrogen, a student was asked to draw a Born-Haber cycle for sodium hydride.

The cycle had **two** errors but the numerical data were correct.




(i) Identify and correct the **two** errors in this Born-Haber cycle.

**(2)**

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(ii) Calculate the first electron affinity, in kJ mol$^{-1}$, of hydrogen, using the values given in the cycle.

**(1)**

(b) The equation for the formation of sodium hydride is

$$Na(s) + \tfrac{1}{2}H_2(g) \rightarrow NaH(s) \qquad \Delta_f H^{\ominus} = -56\,kJ\,mol^{-1}$$

The standard entropy change of the system, $\Delta S^{\ominus}_{system}$, for this reaction is $-76.5\,J\,K^{-1}\,mol^{-1}$.

(i) Deduce the feasibility of this reaction at 298 K by calculating the free energy change, $\Delta G$.

**(2)**

.....

.....

(ii) Calculate the temperature at which $\Delta G = 0$.

**(1)**

(c) The sodium hydride is crushed in the presence of water to release the hydrogen gas for a fuel cell.

The overall equation for the reaction occurring in the fuel cell is

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l)$$

In an alkaline fuel cell the oxidation half-equation is

$$H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(l) + 2e^-$$

Deduce the reduction half-equation for the alkaline fuel cell.

State symbols are not required.

**(1)**

(d) Lattice energies provide an indication of ionic bond strength.

Which are the lattice energies of the hydrides NaH, KH and $MgH_2$?

**(1)**

| | Lattice energy / kJ mol$^{-1}$ | | |
|---|---|---|---|
| | Sodium hydride, NaH | Potassium hydride, KH | Magnesium hydride, $MgH_2$ |
| ☒ **A** | –804 | –711 | –1018 |
| ☒ **B** | –804 | –711 | –2718 |
| ☒ **C** | –804 | –911 | –1018 |
| ☒ **D** | –804 | –911 | –2718 |

**(Total for Question 8 = 8 marks)**

**9** This is a question about buffer solutions.

(a) A buffer solution always

**(1)**

☒ **A** keeps the pH less than 7.

☒ **B** contains equimolar amounts of acid and its conjugate base.

☒ **C** keeps the pH constant if small quantities of acid or base are added.

☒ **D** resists changes in pH if small quantities of acid or base are added.

(b) A buffer solution with a pH of 3.90 is required.
Calculate the **mass**, in grams, of sodium ethanoate that should be added to 50.0 $cm^3$ of an ethanoic acid solution of concentration 0.800 $mol\,dm^{-3}$ to form this buffer solution.

Give your answer to an appropriate number of significant figures.

[$K_a$ for ethanoic acid = $1.74 \times 10^{-5}$ $mol\,dm^{-3}$]

**(5)**

(c) One of the systems controlling the pH of blood is the carbonic acid-hydrogencarbonate buffer system.

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Explain how this buffer system helps to control the pH of blood when extra carbon dioxide is present due to strenuous exercise.

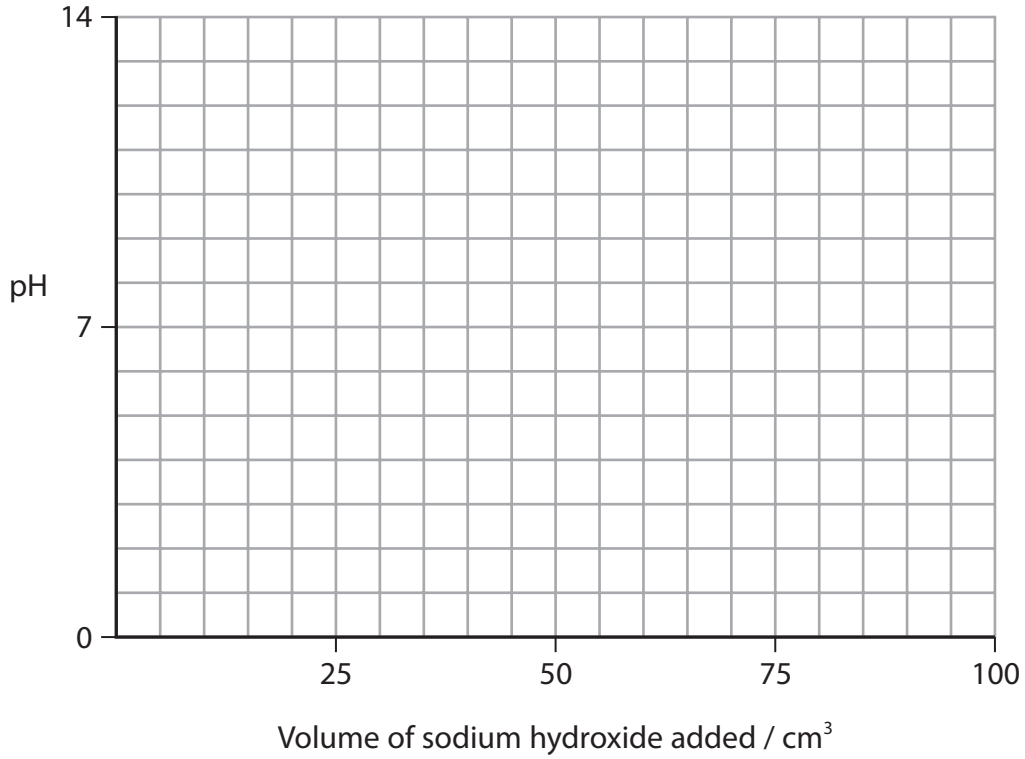
**(3)**

(d) A weak acid-strong base titration curve can be used to demonstrate buffer action.

(i) Draw a titration curve for the addition of
100 $cm^3$ of sodium hydroxide solution of concentration 0.100 mol $dm^{-3}$ to
40.0 $cm^3$ of propanoic acid solution of concentration 0.100 mol $dm^{-3}$
which has a pH of 3.0.

Show the part of the curve that demonstrates buffer action.

**(4)**




(ii) Describe, without calculation, how you would use your curve to determine the value of $K_a$ for propanoic acid.

**(2)**

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.....

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**(Total for Question 9 = 15 marks)**

**10** This question is about equilibrium systems.

(a) Sulfur dioxide and oxygen form an equilibrium with sulfur trioxide.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The composition of an equilibrium mixture at 698 K and a total pressure of 2.40 atm is shown in the table.

| Substance | $SO_2(g)$ | $O_2(g)$ | $SO_3(g)$ |
|---|---|---|---|
| Number of moles /mol | 0.0160 | 0.0120 | 0.772 |

(i) Calculate the value of $K_p$ at this temperature.

Include units, if appropriate.

**(5)**

(ii) Calculate the number of sulfur dioxide molecules present in this equilibrium mixture.

**(1)**

(iii) Deduce, by referring to $K_p$, how the number of sulfur dioxide molecules will change if more oxygen is added to the equilibrium mixture.

**(2)**

(b) An equilibrium exists in aqueous solution between the chromate(VI) ions and the dichromate(VI) ions.

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$

Explain any change in the position of equilibrium if a few drops of sodium hydroxide solution are added to this equilibrium system.

**(2)**

(c) The equilibrium for the reaction between hydrogen gas and an oxide of iron is

$$Fe_3O_4(s) + 4H_2(g) \rightleftharpoons 3Fe(s) + 4H_2O(g)$$

The $K_c$ expression for this equilibrium is

**(1)**

☒ **A** $K_c = \dfrac{[Fe] \times [H_2O]}{[Fe_3O_4] \times [H_2]}$

☒ **B** $K_c = \dfrac{[Fe]^3 \times [H_2O]^4}{[Fe_3O_4] \times [H_2]^4}$

☒ **C** $K_c = \dfrac{[H_2O]}{[H_2]}$

☒ **D** $K_c = \dfrac{[H_2O]^4}{[H_2]^4}$

**(Total for Question 10 = 11 marks)**

**TOTAL FOR PAPER = 90 MARKS**

# The Periodic Table of Elements

| 1 | 2 | | | | | | | | | | | 3 | 4 | 5 | 6 | 7 | 0 (8) (18) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 1.0 H hydrogen 1 | | | | | | | | | | 4.0 He helium 2 |
| (1) | (2) | | | | | | | | | | | (13) | (14) | (15) | (16) | (17) | |
| 6.9 Li lithium 3 | 9.0 Be beryllium 4 | | | | | | | | | | | 10.8 B boron 5 | 12.0 C carbon 6 | 14.0 N nitrogen 7 | 16.0 O oxygen 8 | 19.0 F fluorine 9 | 20.2 Ne neon 10 |
| 23.0 Na sodium 11 | 24.3 Mg magnesium 12 | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | 27.0 Al aluminium 13 | 28.1 Si silicon 14 | 31.0 P phosphorus 15 | 32.1 S sulfur 16 | 35.5 Cl chlorine 17 | 39.9 Ar argon 18 |
| 39.1 K potassium 19 | 40.1 Ca calcium 20 | 45.0 Sc scandium 21 | 47.9 Ti titanium 22 | 50.9 V vanadium 23 | 52.0 Cr chromium 24 | 54.9 Mn manganese 25 | 55.8 Fe iron 26 | 58.9 Co cobalt 27 | 58.7 Ni nickel 28 | 63.5 Cu copper 29 | 65.4 Zn zinc 30 | 69.7 Ga gallium 31 | 72.6 Ge germanium 32 | 74.9 As arsenic 33 | 79.0 Se selenium 34 | 79.9 Br bromine 35 | 83.8 Kr krypton 36 |
| 85.5 Rb rubidium 37 | 87.6 Sr strontium 38 | 88.9 Y yttrium 39 | 91.2 Zr zirconium 40 | 92.9 Nb niobium 41 | 95.9 Mo molybdenum 42 | [98] Tc technetium 43 | 101.1 Ru ruthenium 44 | 102.9 Rh rhodium 45 | 106.4 Pd palladium 46 | 107.9 Ag silver 47 | 112.4 Cd cadmium 48 | 114.8 In indium 49 | 118.7 Sn tin 50 | 121.8 Sb antimony 51 | 127.6 Te tellurium 52 | 126.9 I iodine 53 | 131.3 Xe xenon 54 |
| 132.9 Cs caesium 55 | 137.3 Ba barium 56 | 138.9 La* lanthanum 57 | 178.5 Hf hafnium 72 | 180.9 Ta tantalum 73 | 183.8 W tungsten 74 | 186.2 Re rhenium 75 | 190.2 Os osmium 76 | 192.2 Ir iridium 77 | 195.1 Pt platinum 78 | 197.0 Au gold 79 | 200.6 Hg mercury 80 | 204.4 Tl thallium 81 | 207.2 Pb lead 82 | 209.0 Bi bismuth 83 | [209] Po polonium 84 | [210] At astatine 85 | [222] Rn radon 86 |
| [223] Fr francium 87 | [226] Ra radium 88 | [227] Ac* actinium 89 | [261] Rf rutherfordium 104 | [262] Db dubnium 105 | [266] Sg seaborgium 106 | [264] Bh bohrium 107 | [277] Hs hassium 108 | [268] Mt meitnerium 109 | [271] Ds darmstadtium 110 | [272] Rg roentgenium 111 | | | | | | | |

Key: relative atomic mass / **atomic symbol** / name / atomic (proton) number

Elements with atomic numbers 112-116 have been reported but not fully authenticated

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 140 Ce cerium 58 | 141 Pr praseodymium 59 | 144 Nd neodymium 60 | [147] Pm promethium 61 | 150 Sm samarium 62 | 152 Eu europium 63 | 157 Gd gadolinium 64 | 159 Tb terbium 65 | 163 Dy dysprosium 66 | 165 Ho holmium 67 | 167 Er erbium 68 | 169 Tm thulium 69 | 173 Yb ytterbium 70 | 175 Lu lutetium 71 |
| 232 Th thorium 90 | [231] Pa protactinium 91 | 238 U uranium 92 | [237] Np neptunium 93 | [242] Pu plutonium 94 | [243] Am americium 95 | [247] Cm curium 96 | [245] Bk berkelium 97 | [251] Cf californium 98 | [254] Es einsteinium 99 | [253] Fm fermium 100 | [256] Md mendelevium 101 | [254] No nobelium 102 | [257] Lr lawrencium 103 |

* Lanthanide series

* Actinide series

# Mark Scheme Results)

## Pearson Edexcel Advanced Level In Chemistry (9CH0) Paper 01 Advanced Inorganic and Physical Chemistry

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Summer 2019
Publications Code 9CH0_01_1906_MS

**General Marking Guidance**

- All candidates must receive the same treatment. Examiners must mark the first candidate in exactly the same way as they mark the last.
- Mark schemes should be applied positively. Candidates must be rewarded for what they have shown they can do rather than penalised for omissions.
- Examiners should mark according to the mark scheme not according to their perception of where the grade boundaries may lie.
- There is no ceiling on achievement. All marks on the mark scheme should be used appropriately.
- All the marks on the mark scheme are designed to be awarded. Examiners should always award full marks if deserved, i.e. if the answer matches the mark scheme. Examiners should also be prepared to award zero marks if the candidate's response is not worthy of credit according to the mark scheme.
- Where some judgement is required, mark schemes will provide the principles by which marks will be awarded and exemplification may be limited.
- When examiners are in doubt regarding the application of the mark scheme to a candidate's response, the team leader must be consulted.
- Crossed out work should be marked UNLESS the candidate has replaced it with an alternative response.
- Mark schemes will indicate within the table where, and which strands of QWC, are being assessed. The strands are as follows:

  i) ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear
  ii) select and use a form and style of writing appropriate to purpose and to complex subject matter
  iii) organise information clearly and coherently, using specialist vocabulary when appropriate

## Using the Mark Scheme

Examiners should look for qualities to reward rather than faults to penalise. This does NOT mean giving credit for incorrect or inadequate answers, but it does mean allowing candidates to be rewarded for answers showing correct application of principles and knowledge. Examiners should therefore read carefully and consider every response: even if it is not what is expected it may be worthy of credit.

The mark scheme gives examiners:
- an idea of the types of response expected
- how individual marks are to be awarded
- the total mark for each question
- examples of responses that should NOT receive credit.

/ means that the responses are alternatives and either answer should receive full credit.
( ) means that a phrase/word is not essential for the award of the mark, but helps the examiner to get the sense of the expected answer.
Phrases/words in **bold** indicate that the meaning of the phrase or the actual word is **essential** to the answer.
ecf/TE/cq (error carried forward) means that a wrong answer given in an earlier part of a question is used correctly in answer to a later part of the same question.

Candidates must make their meaning clear to the examiner to gain the mark. Make sure that the answer makes sense. Do not give credit for correct words/phrases which are put together in a meaningless manner. Answers must be in the correct context.

**Quality of Written Communication**
Questions which involve the writing of continuous prose will expect candidates to:
- write legibly, with accurate use of spelling, grammar and punctuation in order to make the meaning clear
- select and use a form and style of writing appropriate to purpose and to complex subject matter
- organise information clearly and coherently, using specialist vocabulary when appropriate.

Full marks will be awarded if the candidate has demonstrated the above abilities.
Questions where QWC is likely to be particularly important are indicated (QWC) in the mark scheme, but this does not preclude others.

| Question Number | Answer | Mark |
|---|---|---|
| 1(a) | **The only correct answer is A**<br><br>***B*** *is not correct because oxygen atoms do not have this number of protons*<br><br>***C*** *is not correct because oxygen atoms do not have this number of protons*<br><br>***D*** *is not correct because oxygen atoms do not have this number of protons* | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| 1(b) | **The only correct answer is D**<br><br>***A*** *is not correct because there are no peaks for bromine molecules*<br><br>***B*** *is not correct because the peak for the* $^{79}Br$-$^{81}Br^+$ *molecular ion is missing*<br><br>***C*** *is not correct because the peak for the* $^{79}Br$-$^{81}Br^+$ *molecular ion is not twice the height of the other molecular ion peaks* | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| 1(c) | **The only correct answer is C**<br><br>***A*** *is not correct because this is only the number of electrons in the 3p orbitals of the chlorine atom*<br><br>***B*** *is not correct because this is only the number of electrons in the 3p orbitals of the chloride ion*<br><br>***D*** *is not correct because this is the total number of electrons in the chloride ion, not just those in the p orbitals* | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| 1(d) | **The only correct answer is A**<br><br>***B*** *is not correct because oxygen has more protons to exert an attractive force to reduce the ionic radius*<br><br>***C*** *is not correct because sodium has more protons to exert an attractive force to reduce the ionic radius*<br><br>***D*** *is not correct because aluminium has more protons to exert an attractive force to reduce the ionic radius* | **(1)** |

**(Total Question 1 = 4 marks)**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **2(a)(i)** | • equation | <u>Example of equation</u><br><br>$Cl_2 + 2KBr \rightarrow Br_2 + 2KCl$<br><br>Accept ionic equation<br>$Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$<br><br>Allow multiples<br>Ignore state symbols even if incorrect | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **2(a)(ii)** | An answer that makes reference to the following points:<br><br>• **(M1)** the precipitate is a mixture of silver chloride and silver bromide<br>**or**<br>not all of the bromide ions were oxidised **(1)**<br><br>• **(M2)** silver chloride/AgCl dissolves in dilute ammonia **(1)**<br><br>• **(M3)** silver bromide/AgBr does not dissolve in dilute ammonia **(1)** | Allow<br>Some bromide ions are still present/bromide ions were in excess/both chloride and bromide ions are present<br><br>Do not award references to $Cl^-$ dissolving<br><br>Silver bromide only dissolves in concentrated ammonia | **(3)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **2(a)(iii)** | An answer that makes reference to the following point:<br><br>• iodine is a weaker oxidising agent than chlorine<br>**or**<br>iodine cannot oxidise bromide ions<br>**or**<br>iodine is a stronger reducing agent | <br><br>Accept reverse arguments<br><br><br><br>Ignore<br>Just references to reactivity/displacement e.g. iodine is less reactive/cannot displace | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **2(b)(i)** | • balanced equation | <u>Example of equation</u><br>$3Cl_2 + 6OH^- \rightarrow 5Cl^- + ClO_3^- + 3H_2O$<br>Allow multiples<br>Ignore state symbols even if incorrect | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **2(b)(ii)**<br>**Clip with 2(b)(i)** | An explanation that makes reference to the following points:<br><br>• oxidation number for chlorine changes from 0 to -1 so it is **reduced** **(1)**<br><br>• oxidation number for chlorine changes from 0 to +5 so it is **oxidised** **(1)** | Ignore general definitions of disproportionation<br><br>Accept oxidation numbers and their changes shown with equation<br><br><br>Allow 1 out of 2 marks for three correct oxidation numbers of the chlorine | **(2)** |

**(Total Question 2 = 8 marks)**

| Question Number | Answer | Mark |
|---|---|---|
| 3(a)(i) | **The only correct answer is D**<br><br>***A*** *is not correct because the measurement uncertainty is doubled as there are two burette readings*<br><br>***B*** *is not correct because this gives the largest measurement uncertainty*<br><br>***C*** *is not correct because the measurement uncertainty is doubled as the pipette is used twice* | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 3(a)(ii) | • calculation of Q **(1)**<br><br>• calculation of enthalpy change **(1)**<br><br>• answer to nearest whole number **and** with negative sign **(1)** | <u>Example of calculation</u><br><br>Q=(100 x 4.18 x 6.5=)<br>= 2717 (J) / 2.717 kJ<br><br>ΔH= 2.717 ÷ 0.05= (−)54.340<br><br>= −54 (kJ $mol^{-1}$)<br><br>Allow TE at each stage<br>Correct answer with no working scores (3) | **(3)** |

| Question Number | Answer | Mark |
|---|---|---|
| 3(b)(i) | **The only correct answer is B**<br><br>***A*** *is not correct because there is no extrapolation to the largest temperature increase carried out*<br><br>***C*** *is not correct because the extrapolation is at the wrong time*<br><br>***D*** *is not correct because the extrapolation extends beyond the time of addition of alkali* | **(1)** |

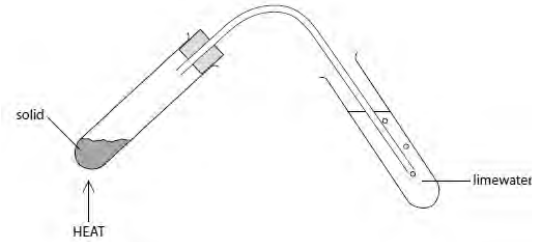
| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 3(b)(ii) | An explanation that makes reference to<br><br>• ethanoic acid is a weak(er) acid / only partially ionised/dissociated **(1)**<br><br>• (some) **energy** is used to fully/completely ionise the ethanoic acid **(1)** | <br><br>Allow hydrochloric acid is a strong(er) acid/fully ionised<br><br>Do not award 'more NaOH will react so more energy given off' | **(2)** |

**(Total Question 3 = 7 marks)**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **4(a)(i)** | An answer that makes reference to the following point:<br><br>• (Identity of gas is) oxygen/$O_2$<br>**and**<br>(test result is that the splint) relights | <br><br>Do not award just 'O'<br><br>Allow 'rekindle'/'reignites' | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **4(a)(ii)** | An answer that makes reference to the following point:<br><br>• (Identity of gas is) nitrogen dioxide<br>**and**<br>(appearance is) brown (gas/fumes) | If name and formula given then both must be correct<br>Allow $NO_2$<br><br>Do not award NO or $N_2O_4$<br>Do not award if liquid referred to<br>Do not award if two gases are given unless one of the gases stated is colourless oxygen<br><br>Ignore shades of colour | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **4(a)(iii)** | • equation | <u>Example of equation</u><br><br>$2NaNO_3 \rightarrow 2NaNO_2 + O_2$<br>Accept multiples<br><br>Ignore state symbols even if incorrect | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **4(a)(iv)** | An description that makes reference to following points:<br><br>• use of a delivery tube to bubble gas into limewater **(1)**<br><br>• compare the time taken for the limewater to go cloudy **(1)** | Allow annotated diagrams to illustrate the marking points<br><br>Example of a diagram that could be given credit<br>  <br><br>Do not award if the apparatus setting would not be feasible such as<br>• missing cork/bung or gaps around delivery tube<br>• horizontal tube with limewater in<br>• bung in the test tube with limewater<br><br>Allow<br>TE from an incorrect/unsuitable method<br>Allow<br>Any length of time, e.g. 10 minutes | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **4(b)** | An explanation that makes reference to<br><br>• the magnesium ion/cation is smaller (than the barium ion/cation) **(1)**<br><br>• which polarises the (large) carbonate (ion)/anion **(1)**<br><br>• and weakens the carbon-oxygen bond (C-O/C=O) bonds **(1)** | Accept reverse arguments<br>Penalise omission of ion once only<br><br>Allow magnesium ion/cation has a higher charge density<br>Do not award reference to just atom<br><br>Accept 'which distorts the carbonate electron cloud'<br>Do not award if molecules of carbonate are referred to<br><br>Allow 'weakens the bonds **in** the carbonate ion'<br>Allow 'less energy needed to break the C-O bond'<br>Do not award if the bonds referred to are the ionic bonds between the metal ion and the carbonate ion | **(3)** |

**(Total Question 4 = 8 marks)**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **5(a)(i)** | An answer that makes reference to the following point:<br><br>• the two negative ions repel each other | <br><br>Reference to both charge and repulsion needed | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **5(a)(ii)** | An explanation that makes reference to the following points:<br><br>• equation with oxidation of iron(II) ions **(1)**<br><br>• equation with reduction of iron(III) ions **(1)**<br><br>• (catalysis is possible because) variable oxidation state/iron has more than one oxidation state/number<br>**or**<br>both steps now involve oppositely charged ions **(1)** | <u>Example of equations</u><br><br>$2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$<br><br>$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$<br><br>Allow multiples<br>Ignore state symbols even if incorrect<br><br>Allow one mark if the two correct equation are given in the wrong order<br><br>Allow reference to iron being oxidised and reduced<br><br>Allow reference to the iron ions being positive and so not repelled | **(3)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **5(b)** | • equation with oxidation of cobalt(II) ions<br>• equation with reduction of cobalt(III) ions | Example of equations<br>$2Co^{2+} + ½O_2 + 2H^+ \rightarrow 2Co^{3+} + H_2O$<br>$2Co^{3+} + SO_3^{2-} + H_2O \rightarrow 2Co^{2+} + SO_4^{2-} + 2H^+$<br>Allow multiples<br>Ignore state symbols even if incorrect | **(2)** |

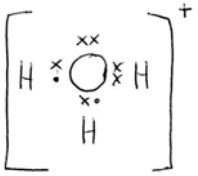
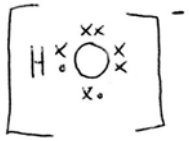
| Question Number | Answer | Mark |
|---|---|---|
| **5(c)** | **The only correct answer is C**<br>***A*** *is not correct because only* $Mn^{2+}$ *is an autocatalyst for this reaction*<br>***B*** *is not correct because only* $Mn^{2+}$ *is an autocatalyst for this reaction*<br>***D*** *is not correct because only* $Mn^{2+}$ *is an autocatalyst for this reaction* | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **5(d)** | Tungsten<br>• (because) adsorption is too strong and so desorption would be too slow | Ignore references to oxidation or reactivity series or cost<br>Do not award 'a**b**sorption' | **(1)** |

**(Total Question 5 = 8 marks)**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **6(a)** | An answer that makes reference to the following points:<br><br>• **(M1)** (a lower boiling temperature is expected) because water has fewer electrons than hydrogen sulfide **(1)**<br><br>• **(M2)** water has weaker/less London forces **(1)**<br><br>• **(M3)** (a higher boiling temperature occurs because) water has hydrogen bonding **(1)**<br><br>• **(M4)** hydrogen bonding is stronger than London forces and requires more **energy** to break (and results in a higher boiling temperature) **(1)** | Accept water has 10 electrons but hydrogen sulfide has 18 electrons (per molecule)<br>Ignore reference to Mr/size of atom<br><br>Allow van der Waals'/dispersion forces/ instantaneous dipole-induced dipole<br><br>Accept reverse arguments<br>Ignore references to permanent dipole-dipole forces | **(4)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **6(b)** | An explanation that makes reference to the following points:<br><br>• **(M1)** oxygen is more electronegative than hydrogen **and** carbon **(1)**<br><br>• **(M2)** which results in a polar bond with oxygen δ− so carbon **and** hydrogen δ+ **(1)**<br><br>• **(M3)** carbon dioxide is a symmetrical/linear molecule and so the dipole moments/vectors cancel **(1)**<br><br>• **(M4)** the lone pairs of electrons of oxygen/ the V-shape of the water molecule mean that the dipole moments/ vectors do not cancel **(1)** | Accept supporting diagrams which illustrate the following:<br><br>Accept electronegativity values stated<br>Allow oxygen has a greater force of attraction for the bonded electron pairs than hydrogen **or** carbon<br><br>Penalise the failure to refer to carbon and hydrogen once only<br><br>Allow 'symmetrical so dipoles/ polar bonds cancel'<br><br>Allow angular/bent for V-shape<br><br>Penalise reference to just 'charges' once only in M3 and M4 if dipoles not stated or shown in the answer | **(4)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **6(c)** | Two diagrams<br>• oxonium ion **(1)**<br>• hydroxide ion **(1)** | Examples of suitable diagrams<br>  <br>  <br>Ignore inner 'shell' of two electrons<br>Ignore missing brackets<br>Ignore covalent circles<br><br>Penalise all dots or all crosses or use of other symbols for electrons once only<br>Penalise omission of charges once only | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **6(d)(i)** | • square root of $K_w$ at 310K to get $[H^+]$ **(1)**<br>• calculation of pH to 2 decimal places **(1)** | Example of calculation:<br>$[H^+] = (\sqrt{2.40 \times 10^{-14}}) = 1.549..x10^{-7}$ (mol $dm^{-3}$)<br>$pH = (-\log 1.549..x10^{-7})$<br>$= (6.809894379) = 6.81$<br>Correct answer with no working scores (2)<br>Allow TE from incorrect $[H^+]$ as long as answer is in the pH range 6.00 – 7.00 inclusive | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **6(d)(ii)** | An answer that makes reference to the following points:<br>• **(M1)** neutral **(1)**<br>• **(M2)** because $[H^+(aq)] = [OH^-(aq)]$ /equal amounts of $H^+$ and $OH^-$ ions **(1)** | Acidic or alkaline scores (0)<br>Allow both $[H^+]$ and $[OH^-]$ have increased equally (from 298 K to 310 K)<br>M2 dependent on M1 | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **6(d)(iii)** | An answer that makes reference to the following point:<br><br>• positive / + sign because $K_w$ increases as the temperature increases | Allow 'positive because'<br><br>bond breaking requires energy<br>or<br>equilibrium shifts to the right<br>or<br>there is greater/more ionisation/dissociation<br><br>Ignore 'endothermic' | **(1)** |

**(Total Question 6 = 15 marks)**

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*7</td>
<td>This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.<br><br>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.<br><br>The following table shows how the marks should be awarded for indicative content.
<table>
<tr><td>Number of indicative marking points seen in answer</td><td>Number of marks awarded for indicative marking points</td></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><td></td><td>Number of marks awarded for structure of answer and sustained lines of reasoning</td></tr>
<tr><td>Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
</table>
</td>
<td>Guidance on how the mark scheme should be applied:<br>The mark for indicative content should be added to the mark for lines of reasoning.<br>For example, a response with four indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).<br>If there were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and zero marks for linkages).<br><br>If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).<br><br>More than one indicative marking point may be made within the same comment or explanation</td>
<td>(6)</td>
</tr>
</table>

| | | | | |
|---|---|---|---|---|
| | Answer is partially structured with some linkages and lines of reasoning | 1 | Deduct a reasoning mark if no comparison made | |
| | Answer has no linkages between points and is unstructured | 0 | Penalise the use of 'atom' instead of ion once only against any indicative point<br>Ignore incorrect colours | |
| | **Indicative content**<br>Similarities<br>• **(IP1)** the differences in energy levels determines the colour of the flame test and complex ion<br><br>Differences<br>Flame test<br>• **(IP2) heat** (energy) results in electron promotion<br><br>• **(IP3)** return of an (excited) electron to a lower (energy) state<br><br>Complex ion<br>• **(IP4)** d orbital**s** are split (in energy by the ligands)<br><br>• **(IP5) light** (energy) is needed for electron promotion<br><br>• **(IP6)** the colour not absorbed is the colour seen | | This can be mentioned separately or as a comparison<br><br>Allow electrons excited by **heat**<br><br>Allow electron is 'de-excited' to a lower (energy) state<br>Do not award if d-d transitions stated<br><br>Allow d subshell splitting<br>Do not award singular "d orbital" splitting<br><br>Accept "The colour seen is complimentary to that absorbed"<br>Allow 'colour reflected is the colour seen'<br>Do not award if colour attributed to 'fall' of electron to lower energy d orbital<br>Do not award 'emission of light' | |

**(Total Question 7 = 6 marks)**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **8(a)(i)** | An answer that makes reference to the following points:<br><br>• identification and correction of the first error **(1)**<br><br>• identification and correction of the second error **(1)** | Allow corrections to be made on the diagram<br><br>Error 1 – arrow for enthalpy change of formation should go down/be reversed<br><br>Error 2 – the word 'half ' should be deleted from the enthalpy change of atomisation of hydrogen | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **8(a)(ii)** | • calculation of first electron affinity of hydrogen | <u>Example of calculation</u><br><br>1st EA= −(218+496+107)−56 +804<br>= −73 (kJ $mol^{-1}$)<br><br>Allow a TE<br>1st EA = +39(kJ $mol^{-1}$) if the first arrow reversed direction is not identified | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **Penalise incorrect or missing units in (b)(i) and (b)(ii) once only** | | | |
| **8(b)(i)** | • calculation of Δ*G* **(1)**<br><br>• Δ*G* is negative/ <0 and so reaction is feasible **(1)** | Example of calculation<br>$\Delta G = -56 - \left(298 \times \frac{-76.5}{1000}\right)$<br>$= -33.203$ (kJ $mol^{-1}$)<br>or<br>$\Delta G = -56000 - (298 \times -76.5)$<br>$= -33203$ (J $mol^{-1}$)<br><br>Ignore SF except 1<br><br>Allow ≤0 and so reaction is feasible<br>Standalone mark<br>Allow TE on own Δ*G* calculated value | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **8(b)(ii)** | • calculation of *T* | Example of calculation<br>Δ*G* = 0, so $\Delta H = T\Delta S_{(system)}$ or $T = \Delta H/\Delta S_{(system)}$<br><br>T = 56/0.0765 = 732 K<br>**or**<br>T = 56000/76.5 = 732 K<br>**or**<br>T = 459°C<br>Ignore SF except 1 SF<br><br>Do not award −732K<br>TE on incorrect values penalised already in (b)(i) | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **8(c)** | • reduction half-equation | Example of half equation<br>$\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$<br>Allow multiples<br>Ignore state symbols even if incorrect | **(1)** |

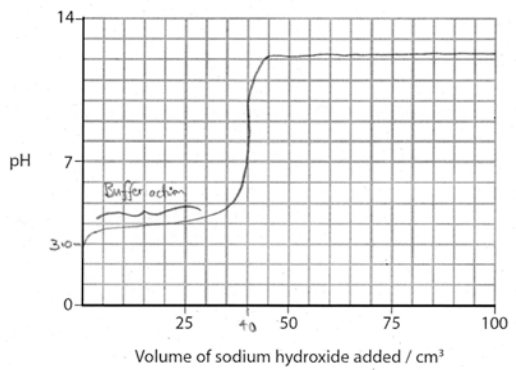
| Question Number | Answer | Mark |
|---|---|---|
| **8(d)** | **The only correct answer is B** (-804, -711, -2718)<br><br>***A*** *is not correct because the lattice energy of magnesium hydride is not exothermic enough*<br><br>***C*** *is not correct because the lattice energy of potassium hydride should be less exothermic than sodium hydride and also that the lattice energy of magnesium hydride is not exothermic enough*<br><br>***D*** *is not correct because the lattice energy of potassium hydride should be less exothermic than sodium hydride* | **(1)** |

**(Total Question 8 = 8 marks)**

| Question Number | Answer | Mark |
|---|---|---|
| 9(a) | **The only correct answer is D** (resists changes in pH if small quantities of acid or base are added)<br><br>**A** *is not correct because buffer solutions can be alkaline or acidic*<br><br>**B** *is not correct because buffers do not always contain equal numbers of moles of the acid and its conjugate base*<br><br>**C** *is not correct because a buffer does not prevent any change in pH* | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 9(b) | • **(M1)** calculation of $[H^+]$ **(1)**<br><br>• **(M2)** rearrangement of $K_a$ and calculation of ethanoate concentration **(1)**<br><br>• **(M3)** calculation of the number of moles of ethanoate in the buffer volume **(1)**<br><br>• **(M4)** calculation of the mass of sodium ethanoate in the buffer volume **(1)**<br><br>• **(M5)** answer to 2/3 SF **(1)** | Example of calculation<br>$[H^+] = 10^{-3.9} = 1.2589..\text{x } 10^{-4}$ (mol $dm^{-3}$)<br><br>$[CH_3COO^-] = (\underline{1.74 \text{ x } 10^{-5} \text{ x } 0.800}) =$ $1.2589.. \text{ x } 10^{-4}$<br><br>=0.11057.. (mol $dm^{-3}$)<br><br>n=(0.11057.. x 0.05 =) 5.5285..x $10^{-3}$ (mol)<br><br>m=(5.5285..x $10^{-3}$ x 82=) 0.453339..<br><br>m=0.45/ 0.453 (g)<br>Award this mark only if there has been some attempt at calculation using an $M_r$<br><br>TE at each stage<br><br>If Henderson-Hasselbalch equation used<br>**(M1)** for calculation of $pK_a$ = 4.759<br>**(M2)** for rearrangement and calculation of ethanoate concentration<br>Remaining marking points as above | **(5)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **9(c)** | An answer that makes reference to the following points:<br><br>• carbon dioxide dissolved in the blood forms carbonic acid (and so this concentration increases) **(1)**<br><br>• the equilibrium will shift to the right and produces more $H^+$/acid ions **(1)**<br><br>• the (high) concentration of hydrogencarbonate ions suppress the ionisation of carbonic acid (to help to control pH)<br>**or**<br>the (large) reservoir/excess of hydrogencarbonate ions combine with the $H^+$ ions (to help to control blood pH) **(1)** | Can be shown in an equation<br>Do not award '$CO_2$ reacts with $H^+$ to form carbonic acid'<br><br>Allow<br>Carbonic acid (partially) dissociates to produce $H^+$<br>Do not award '$CO_2$ reacts with $H^+$ so equilibrium shifts to the right to produce more $H^+$'<br><br>Ignore general comments about the effects of adding acid and/or alkali to a buffer which do not relate to carbon dioxide | **(3)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 9(d)(i) | • general shape of weak acid-strong base curve **(1)**<br>• curve starts at pH of 3.0 and ends at pH of 12-13 **(1)**<br>• vertical part of the curve at 40 $cm^3$ **(1)**<br>• labelling of area indicating buffer action **(1)** | Exemplar graph<br>  <br><br>Ignore missing initial rise in pH<br>Vertical part must cover 3-5 pH units between 6 – 11<br>The curve should reach pH~12-13 by 10$cm^3$ after vertical section<br>The curve must start at zero and continue to 100 $cm^3$<br>Allow buffering area to be labelled anywhere between ~5 and 35 $cm^3$ inclusive | **(4)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **9(d)(ii)** | An answer that makes reference to<br><br>• determine the pH at the point when half of the acid is neutralised **(1)**<br><br>• $K_a = 10^{-pH}$ / $K_a = 10^{-pK_a}$ **(1)** | Standalone marks<br><br>Allow 'pH at half-equivalence point'<br>Allow 'pH at half neutralisation point'<br><br>Accept description in words such as inverse log of minus pH<br>or<br>value is p$K_a$ and so inverse log of minus value gives $K_a$<br>Allow<br>p$K_a$ = -log $K_a$<br><br>Ignore any calculation | **(2)** |

**(Total Question 9 = 15 marks)**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **10(a)(i)** | • **(M1)** calculation of mole fractions **(1)**<br>• **(M2)** calculation of partial pressures **(1)**<br>• **(M3)** expression of $K_p$ **(1)**<br>• **(M4)** calculation of value of $K_p$ **(1)**<br>• **(M5)** units **(1)** | Example of calculation<br>$X_{SO_2}$ = 0.0160 ÷ 0.8 = 0.02(0)<br>$X_{O_2}$ = 0.0120 ÷ 0.8 =0.015<br>$X_{SO_3}$ = 0.772 ÷ 0.8 =0.965<br>$P_{SO_2}$ = 0.02(0) x 2.40 = 0.048<br>$P_{O_2}$ = 0.015 x 2.40 = 0.036<br>$P_{SO_3}$ = 0.965 x 2.40 =2.316<br>$K_p = \frac{(\boldsymbol{P}_{SO_3})^2}{(\boldsymbol{P}_{SO_2})^2 \times \mathbf{P}_{O_2}}$<br>Do not award square brackets<br>$K_p = \frac{2.316^2}{0.048^2 \times 0.036} =$<br>$K_p$= 64668.4..../6.46684.. x $10^4$<br>$K_p$= 65000/6.5 x $10^4$/64700/6.47 x $10^4$<br>Ignore SF except 1<br>$atm^{-1}$<br>Correct final answer without working scores (5) | **(5)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **10(a)(ii)** | • calculation of the number of molecules | Example of calculation<br>N=(n x L = 0.0160 x 6.02 x $10^{23}$)<br><br>= 9.632 x $10^{21}$<br><br>Ignore SF except 1SF<br>Do not award if any units are given | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **10(a)(iii)** | An answer that makes reference to the following points:<br><br>• to ensure that $K_p$ stays the same/ quotient stays the same **or** only temperature changes the value of $K_p$ **(1)**<br><br>• the number of (sulfur dioxide) molecules decreases **Either** because the equilibrium shifts to the right or because one of the denominators (oxygen) has increased so the other denominator (sulfur dioxide) has to decrease **(1)** | Standalone marks<br><br>Allow concentration changes have no effect on the value of $K_p$<br><br>Allow 'moles' for molecules | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **10(b)** | An explanation that makes reference to the following points:<br><br>• equilibrium position shifts to the left **(1)**<br><br>• (because) the hydroxide ions combine with/neutralise the $H^+$ ions to remove them from the equilibrium **(1)** | 'Equilibrium moves to the right' scores (0)<br><br>Allow<br>Hydroxide ions react with $H^+$ ions to make water/<br>hydroxide ions react with $H^+$ ions to reduce their number/concentration<br><br>Ignore reference to 'more products formed' | **(2)** |

| Question Number | Answer | Mark |
|---|---|---|
| **10(c)** | **The only correct answer is D** $K_c = \frac{[H_2O]^4}{[H_2]^4}$<br><br>**A** is not correct because the solids should not be included in the expression and the powers of the remaining substituents have been omitted<br><br>**B** is not correct because the solids should not be included in the expression<br><br>**C** is not correct because the powers of the substituents have been omitted | **(1)** |

**(Total Question 10 = 11 marks)**

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Please check the examination details below before entering your candidate information

| Candidate surname | Other names |
|---|---|

**Pearson Edexcel Level 3 GCE**

Centre Number | Candidate Number

# Tuesday 11 June 2019

Afternoon (Time: 1 hour 45 minutes) | Paper Reference **9CH0/02**

# Chemistry

## Advanced

## Paper 2: Advanced Organic and Physical Chemistry

**Candidates must have: Scientific calculator**
**Data Booklet**
**Ruler**

Total Marks

## Instructions

- Use **black** ink or **black** ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

## Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- For the question marked with an asterisk (*), marks will be awarded for your ability to structure your answer logically showing the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

## Advice

- Read each question carefully before you start to answer it.
- Show all your working in calculations and include units where appropriate.
- Check your answers if you have time at the end.

*Turn over* ▶

P58307A



1/1/1/1/1/1/1/

P 5 8 3 0 7 A 0 1 2 4

Pearson

**Answer ALL questions.**

**Some questions must be answered with a cross in a box ☒.**
**If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.**

**1** This question is about some reactions of alcohols.

(a) (i) Which alcohol **cannot** be oxidised by acidified potassium dichromate(VI)?

**(1)**

☒ **A** hexan-2-ol

☒ **B** 2-methylpentan-2-ol

☒ **C** hexan-3-ol

☒ **D** 2-methylpentan-3-ol

(ii) Which alcohol reacts with iodine in the presence of alkali to form a yellow solid?

**(1)**

☒ **A** hexan-2-ol

☒ **B** 2-methylpentan-2-ol

☒ **C** hexan-3-ol

☒ **D** 2-methylpentan-3-ol

(b) Which reagent is used with iodine to prepare iodoalkanes from alcohols?

**(1)**

☒ **A** red phosphorus

☒ **B** concentrated phosphoric acid

☒ **C** sulfur

☒ **D** concentrated sulfuric acid

**(Total for Question 1 = 3 marks)**

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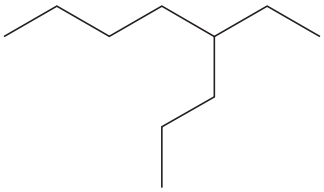
**2** This question is about alkanes and their reactions.

(a) What is the IUPAC name for this alkane?



**(1)**

☒ **A** 4-ethyloctane

☒ **B** 5-ethyloctane

☒ **C** 3-propylheptane

☒ **D** 5-propylheptane

(b) What is the name of the process that could be used to produce propane, $C_3H_8$, from decane, $C_{10}H_{22}$?

**(1)**

☒ **A** substitution

☒ **B** reforming

☒ **C** fractional distillation

☒ **D** cracking

(c) A student researched the reaction of propane with bromine and found that the reaction could be used to make 1-bromopropane.

$$C_3H_8(g) + Br_2(l) \rightarrow C_3H_7Br(l) + HBr(g)$$

(i) The first step of the reaction involves

**(1)**

☒ **A** heterolytic bond fission to form free radicals

☒ **B** heterolytic bond fission to form ions

☒ **C** homolytic bond fission to form free radicals

☒ **D** homolytic bond fission to form ions

(ii) Calculate the atom economy by mass for the formation of 1-bromopropane in the reaction in (c).

**(2)**

(iii) A source from the internet gave the percentage yield for this reaction as 31.0%. The best explanation for the low percentage yield of 1-bromopropane in this reaction is

**(1)**

☒ **A** bromine is very unreactive

☒ **B** a gaseous reactant always gives a low yield

☒ **C** the reaction is very slow

☒ **D** the reaction produces a mixture of organic products

(iv) Calculate the volume of propane, in $dm^3$, measured at room temperature and pressure, that is needed to produce 14.7 g of 1-bromopropane, assuming a percentage yield of 31.0%.
Give your answer to an appropriate number of significant figures.

[Molar gas volume at r.t.p. = 24.0 $dm^3 mol^{-1}$]

**(3)**

**(Total for Question 2 = 9 marks)**

**3** This question is about compounds of Group 5 elements.

(a) Phosphorus forms two chlorides with the formulae $PCl_3$ and $PCl_5$.

(i) Explain the shape of the $PCl_3$ molecule. The bond angle is not required.

**(3)**

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(ii) Draw a diagram to show the three-dimensional shape of the $PCl_5$ molecule in the gas phase.

Include bond angles and the name of the shape.

**(3)**

(iii) Explain why phosphorus forms $PCl_5$ but nitrogen does not form $NCl_5$.

**(2)**

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(b) Nitrogen trichloride, $NCl_3$, has a boiling temperature of 344 K, and nitrogen trifluoride, $NF_3$, has a boiling temperature of 144 K.

Explain this difference in boiling temperatures, by referring to all the intermolecular forces present.

**(5)**

(c) Which of these compounds produces hydrogen chloride when it reacts with $PCl_5$?

**(1)**

☒ **A** propanal

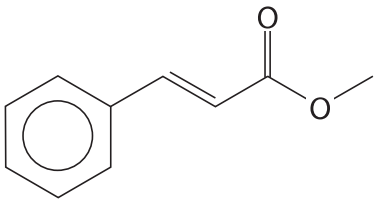
☒ **B** propan-1-ol

☒ **C** propanone

☒ **D** propyl propanoate

**(Total for Question 3 = 14 marks)**

**4** Methyl cinnamate, $C_{10}H_{10}O_2$, is a white crystalline solid used in the perfume industry.



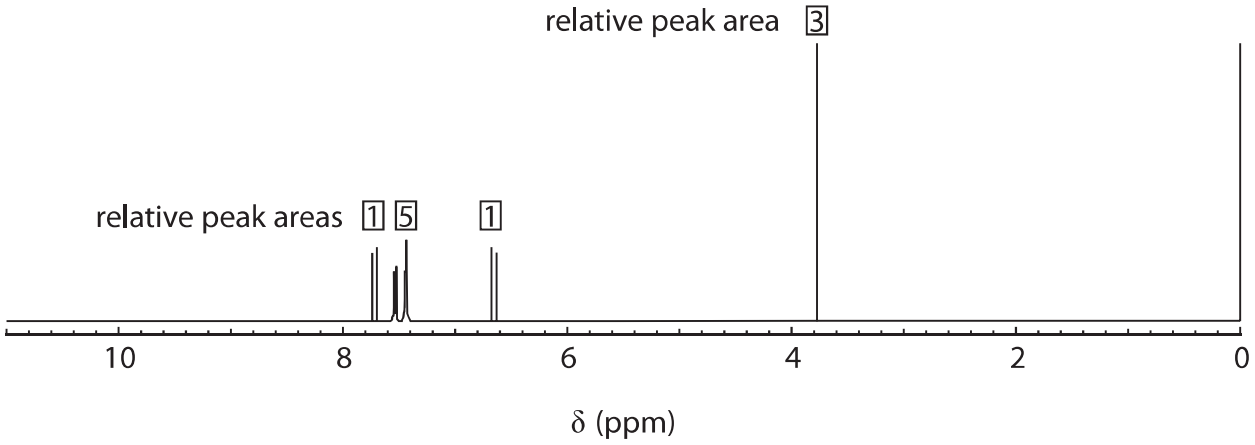

methyl cinnamate

(a) Calculate the mass of carbon in 2.34 g of methyl cinnamate.

**(2)**

(b) A sample of methyl cinnamate was analysed by high resolution proton NMR spectroscopy.

A simplified spectrum is shown.




(i) Name the compound responsible for the peak at a chemical shift of 0 ppm, stating its purpose.

**(2)**

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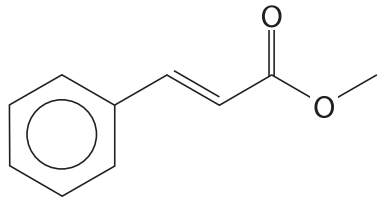
(ii) Identify the proton environment that causes the peak at a chemical shift of 3.8 ppm by circling it on the diagram shown. Fully justify your answer.

**(3)**

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(c) Methyl cinnamate undergoes an addition reaction in the dark with bromine.

(i) Draw the mechanism for the reaction between methyl cinnamate and bromine, $Br_2$.
Include curly arrows, and relevant lone pairs and dipoles.

**(4)**

(ii) Deduce the number of optical isomers of the addition product that can exist.

**(1)**

☒ **A** 2

☒ **B** 3

☒ **C** 4

☒ **D** 8

(iii) When plane-polarised light is passed through an optical isomer, the plane of polarisation is

**(1)**

☒ **A** diffracted

☒ **B** reflected

☒ **C** refracted

☒ **D** rotated

**(Total for Question 4 = 13 marks)**

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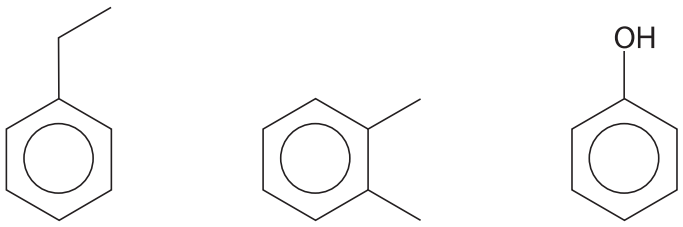
**5** This question is about the arenes, ethylbenzene, xylene, and phenol, which can be identified in wine samples using gas chromatography.




ethylbenzene xylene phenol

(a) Ethylbenzene can be formed by the reaction of a chloroalkane with benzene, catalysed by aluminium chloride, $AlCl_3$.

(i) Draw the **displayed** formula of the chloroalkane required for this reaction.

**(1)**

(ii) Draw the mechanism for this reaction.
Include equations showing the role of the catalyst and how it is regenerated.

**(5)**

(iii) Explain whether phenol is likely to be less or more reactive than benzene with the chloroalkane from (a)(i).

**(3)**

(b) A student carried out an experiment to determine the molar mass of xylene.

The student's sample of xylene vapour had a mass of 0.271 g.

At a temperature of 165 °C and a pressure of 118 kPa, this sample had a volume of 70.5 $cm^3$.

Use the Ideal Gas Equation to calculate the molar mass, in g $mol^{-1}$, of this sample.

Give your answer to an appropriate number of significant figures.

You **must** show your working.

**(4)**

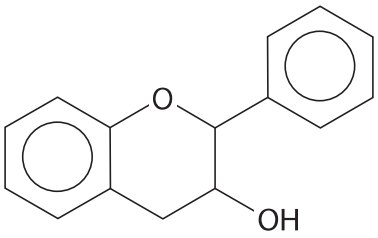
(c) The time taken for a compound to pass through the column in gas chromatography is called the retention time.

Explain why different compounds will have different retention times in the same column, under the same conditions.

**(2)**

**(Total for Question 5 = 15 marks)**

**6** The compound flavan-3-ol is found in tea, fruit and wine.




(a) Clearly label all the chiral carbon atoms in flavan-3-ol.

**(1)**

(b) Give the molecular formula for flavan-3-ol.

**(1)**

*(c) A sample of flavan-3-ol extracted from wine contained some ethanol. The sample was left in a flask, open to the air for several days. The contents were then analysed to identify any new compounds formed. Several new compounds were found to be present, including some with a distinctive fruity smell.

Identify **four** new organic compounds that could form under these conditions by considering the chemistry of alcohols. Justify your answers. Include the structure of two compounds formed from flavan-3-ol, one of which has a fruity smell.

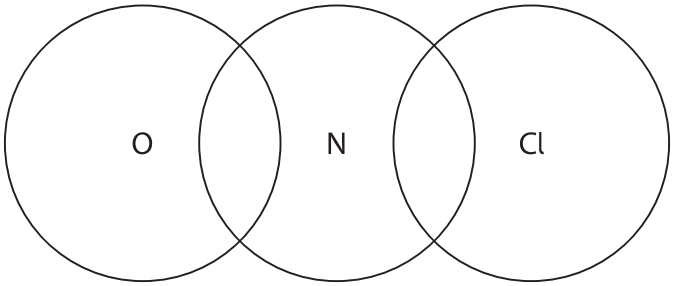
**(6)**

**(Total for Question 6 = 8 marks)**

**7** Nitrogen monoxide and chlorine react together to form nitrosyl chloride.

$$2NO(g) + Cl_2(g) \rightarrow 2NOCl(g)$$

(a) Draw a dot-and-cross diagram for nitrosyl chloride, showing only the outer shell electrons.




**(2)**

(b) The rate equation for the formation of nitrosyl chloride is

Rate = $k[NO]^2[Cl_2]$

(i) Complete the table by adding the missing values.

| Experiment | [NO] / mol dm$^{-3}$ | [$Cl_2$] / mol dm$^{-3}$ | Rate / mol dm$^{-3}$ s$^{-1}$ |
|---|---|---|---|
| 1 | 0.122 | 0.241 | $1.09 \times 10^{-2}$ |
| 2 | | 0.482 | $8.72 \times 10^{-2}$ |
| 3 | 0.366 | | $4.91 \times 10^{-2}$ |

**(2)**

(ii) Calculate the rate constant, *k*, using data from Experiment 1.
Include units with your answer.

**(3)**

(iii) Explain how using a catalyst increases the rate constant, *k*.

**(2)**

(iv) The heterogeneous catalyst palladium was suggested for use in this reaction. Explain how impurities in the gaseous reactants could make the catalyst less effective.

**(3)**

**(Total for Question 7 = 12 marks)**

**8** Gentian violet is a purple crystalline solid used as an antifungal treatment.

It can be synthesised from dimethylphenylamine, $C_6H_5N(CH_3)_2$.

(a) The dimethylphenylamine used in the synthesis can be made by the stepwise reaction of phenylamine with chloromethane.

Step **1** $2C_6H_5NH_2 + CH_3Cl \rightarrow C_6H_5NH(CH_3) + C_6H_5NH_3^+Cl^-$

Step **2** $2C_6H_5NH(CH_3) + CH_3Cl \rightarrow C_6H_5N(CH_3)_2 + C_6H_5NH_2^+(CH_3)Cl^-$

The reaction mechanism for Step **1** between phenylamine and chloromethane is the same as that in the reaction between ammonia and chloromethane.

(i) What is the reaction type and mechanism in Step **1**?

**(1)**

☒ **A** electrophilic addition

☒ **B** electrophilic substitution

☒ **C** nucleophilic addition

☒ **D** nucleophilic substitution

(ii) Draw the mechanism for the reaction in Step **1**.
Include curly arrows, and relevant lone pairs and dipoles.

**(4)**

(iii) Describe, in outline, how a sample of a solid, such as gentian violet, is purified by recrystallisation.
Specific details of the solvent used are not required.

**(4)**

(b) The rate constant for the reaction between a solution of gentian violet and aqueous sodium hydroxide was determined at different temperatures.

| Temperature ($T$) / K | 1 / Temperature ($1/T$) / $K^{-1}$ | Rate constant, $k$ / $dm^3\,mol^{-1}\,s^{-1}$ | ln $k$ |
|---|---|---|---|
| 283.5 | $3.53 \times 10^{-3}$ | $2.71 \times 10^{-3}$ | −5.91 |
| 287.5 | $3.48 \times 10^{-3}$ | $3.55 \times 10^{-3}$ | |
| 291.5 | | $4.75 \times 10^{-3}$ | −5.35 |
| 295.0 | $3.39 \times 10^{-3}$ | $6.10 \times 10^{-3}$ | −5.10 |
| 298.5 | $3.35 \times 10^{-3}$ | $7.60 \times 10^{-3}$ | −4.88 |

(i) Complete the data in the table.

**(1)**

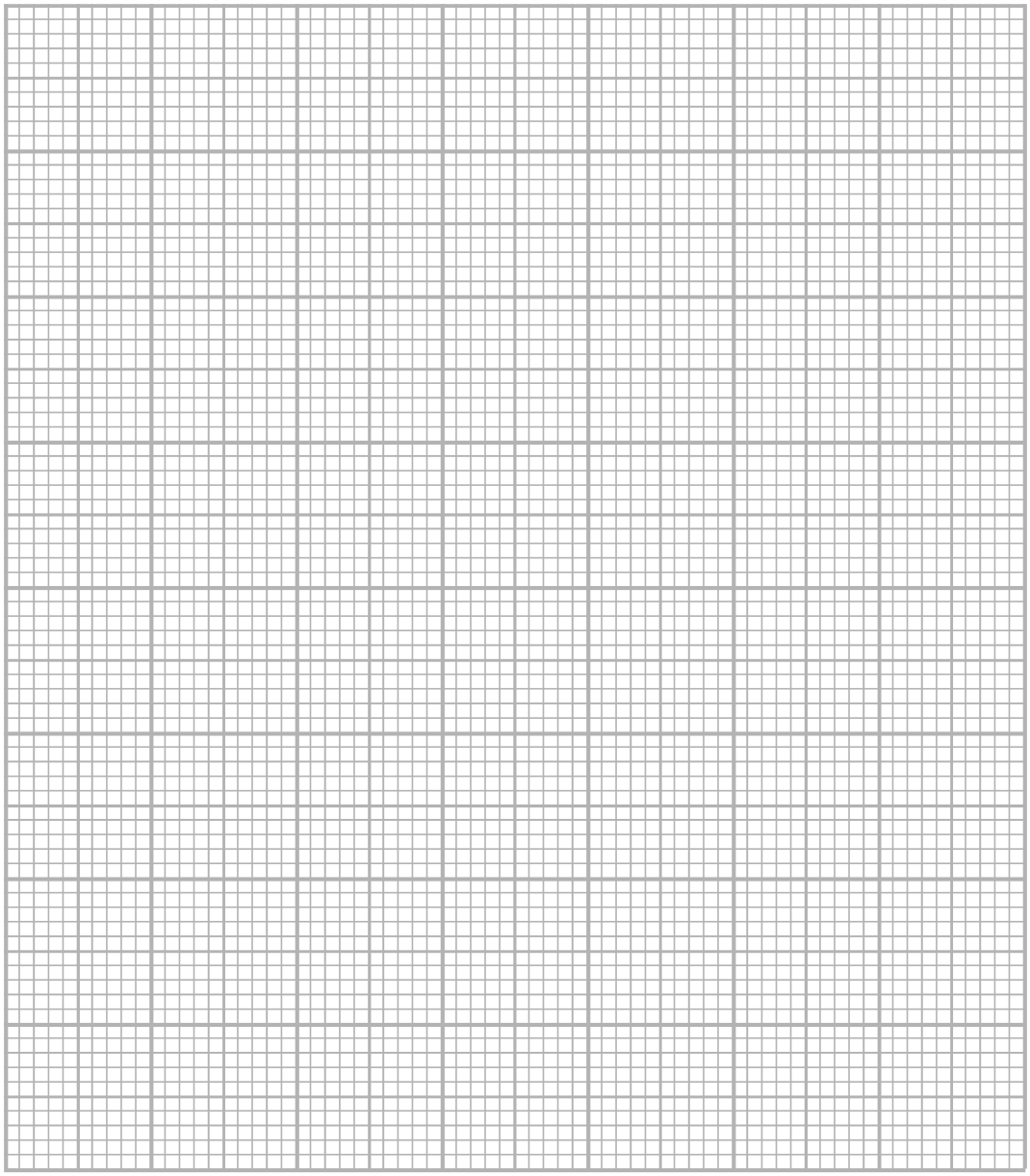
(ii) Plot a graph and use it to determine the activation energy for the reaction in $kJ\,mol^{-1}$.

You should include the value and units of the gradient of the line.

The Arrhenius equation can be shown as

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant}$$

**(6)**



Gradient

.....

Activation energy

.....

**(Total for Question 8 = 16 marks)**

**TOTAL FOR PAPER = 90 MARKS**

# The Periodic Table of Elements

| 1 | 2 | | | | | | | | | | | 3 | 4 | 5 | 6 | 7 | 0 (8) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | (18) |
| | | | | | | | 1.0 H hydrogen 1 | | | | | | | | | | 4.0 He helium 2 |
| (1) | (2) | | Key | | | | | | | | | (13) | (14) | (15) | (16) | (17) | |
| 6.9 Li lithium 3 | 9.0 Be beryllium 4 | | relative atomic mass<br>atomic symbol<br>name<br>atomic (proton) number | | | | | | | | | 10.8 B boron 5 | 12.0 C carbon 6 | 14.0 N nitrogen 7 | 16.0 O oxygen 8 | 19.0 F fluorine 9 | 20.2 Ne neon 10 |
| 23.0 Na sodium 11 | 24.3 Mg magnesium 12 | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | 27.0 Al aluminium 13 | 28.1 Si silicon 14 | 31.0 P phosphorus 15 | 32.1 S sulfur 16 | 35.5 Cl chlorine 17 | 39.9 Ar argon 18 |
| 39.1 K potassium 19 | 40.1 Ca calcium 20 | 45.0 Sc scandium 21 | 47.9 Ti titanium 22 | 50.9 V vanadium 23 | 52.0 Cr chromium 24 | 54.9 Mn manganese 25 | 55.8 Fe iron 26 | 58.9 Co cobalt 27 | 58.7 Ni nickel 28 | 63.5 Cu copper 29 | 65.4 Zn zinc 30 | 69.7 Ga gallium 31 | 72.6 Ge germanium 32 | 74.9 As arsenic 33 | 79.0 Se selenium 34 | 79.9 Br bromine 35 | 83.8 Kr krypton 36 |
| 85.5 Rb rubidium 37 | 87.6 Sr strontium 38 | 88.9 Y yttrium 39 | 91.2 Zr zirconium 40 | 92.9 Nb niobium 41 | 95.9 Mo molybdenum 42 | [98] Tc technetium 43 | 101.1 Ru ruthenium 44 | 102.9 Rh rhodium 45 | 106.4 Pd palladium 46 | 107.9 Ag silver 47 | 112.4 Cd cadmium 48 | 114.8 In indium 49 | 118.7 Sn tin 50 | 121.8 Sb antimony 51 | 127.6 Te tellurium 52 | 126.9 I iodine 53 | 131.3 Xe xenon 54 |
| 132.9 Cs caesium 55 | 137.3 Ba barium 56 | 138.9 La* lanthanum 57 | 178.5 Hf hafnium 72 | 180.9 Ta tantalum 73 | 183.8 W tungsten 74 | 186.2 Re rhenium 75 | 190.2 Os osmium 76 | 192.2 Ir iridium 77 | 195.1 Pt platinum 78 | 197.0 Au gold 79 | 200.6 Hg mercury 80 | 204.4 Tl thallium 81 | 207.2 Pb lead 82 | 209.0 Bi bismuth 83 | [209] Po polonium 84 | [210] At astatine 85 | [222] Rn radon 86 |
| [223] Fr francium 87 | [226] Ra radium 88 | [227] Ac* actinium 89 | [261] Rf rutherfordium 104 | [262] Db dubnium 105 | [266] Sg seaborgium 106 | [264] Bh bohrium 107 | [277] Hs hassium 108 | [268] Mt meitnerium 109 | [271] Ds darmstadtium 110 | [272] Rg roentgenium 111 | | | | | | | |

Elements with atomic numbers 112-116 have been reported but not fully authenticated

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 140 Ce cerium 58 | 141 Pr praseodymium 59 | 144 Nd neodymium 60 | [147] Pm promethium 61 | 150 Sm samarium 62 | 152 Eu europium 63 | 157 Gd gadolinium 64 | 159 Tb terbium 65 | 163 Dy dysprosium 66 | 165 Ho holmium 67 | 167 Er erbium 68 | 169 Tm thulium 69 | 173 Yb ytterbium 70 | 175 Lu lutetium 71 |
| 232 Th thorium 90 | [231] Pa protactinium 91 | 238 U uranium 92 | [237] Np neptunium 93 | [242] Pu plutonium 94 | [243] Am americium 95 | [247] Cm curium 96 | [245] Bk berkelium 97 | [251] Cf californium 98 | [254] Es einsteinium 99 | [253] Fm fermium 100 | [256] Md mendelevium 101 | [254] No nobelium 102 | [257] Lr lawrencium 103 |

* Lanthanide series

* Actinide series

# Mark Scheme (Results)

## Pearson Edexcel Advanced Level In Chemistry (9CH0) Paper 02 Advanced Organic and Physical Chemistry

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Summer 2019
Publications Code 9CH0_02_1906_MS

**General Marking Guidance**

- All candidates must receive the same treatment. Examiners must mark the first candidate in exactly the same way as they mark the last.
- Mark schemes should be applied positively. Candidates must be rewarded for what they have shown they can do rather than penalised for omissions.
- Examiners should mark according to the mark scheme not according to their perception of where the grade boundaries may lie.
- There is no ceiling on achievement. All marks on the mark scheme should be used appropriately.
- All the marks on the mark scheme are designed to be awarded. Examiners should always award full marks if deserved, i.e. if the answer matches the mark scheme. Examiners should also be prepared to award zero marks if the candidate's response is not worthy of credit according to the mark scheme.
- Where some judgement is required, mark schemes will provide the principles by which marks will be awarded and exemplification may be limited.
- When examiners are in doubt regarding the application of the mark scheme to a candidate's response, the team leader must be consulted.
- Crossed out work should be marked UNLESS the candidate has replaced it with an alternative response.
- Mark schemes will indicate within the table where, and which strands of QWC, are being assessed. The strands are as follows:

  i) ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear
  ii) select and use a form and style of writing appropriate to purpose and to complex subject matter
  iii) organise information clearly and coherently, using specialist vocabulary when appropriate

**Using the Mark Scheme**

Examiners should look for qualities to reward rather than faults to penalise. This does NOT mean giving credit for incorrect or inadequate answers, but it does mean allowing candidates to be rewarded for answers showing correct application of principles and knowledge. Examiners should therefore read carefully and consider every response: even if it is not what is expected it may be worthy of credit.

The mark scheme gives examiners:
- an idea of the types of response expected
- how individual marks are to be awarded
- the total mark for each question
- examples of responses that should NOT receive credit.

/ means that the responses are alternatives and either answer should receive full credit.
( ) means that a phrase/word is not essential for the award of the mark, but helps the examiner to get the sense of the expected answer.
Phrases/words in **bold** indicate that the meaning of the phrase or the actual word is **essential** to the answer.
ecf/TE/cq (error carried forward) means that a wrong answer given in an earlier part of a question is used correctly in answer to a later part of the same question.

Candidates must make their meaning clear to the examiner to gain the mark. Make sure that the answer makes sense. Do not give credit for correct words/phrases which are put together in a meaningless manner. Answers must be in the correct context.

**Quality of Written Communication**
Questions which involve the writing of continuous prose will expect candidates to:
- write legibly, with accurate use of spelling, grammar and punctuation in order to make the meaning clear
- select and use a form and style of writing appropriate to purpose and to complex subject matter
- organise information clearly and coherently, using specialist vocabulary when appropriate.

Full marks will be awarded if the candidate has demonstrated the above abilities.
Questions where QWC is likely to be particularly important are indicated (QWC) in the mark scheme, but this does not preclude others.

| Question Number | Answer | Mark |
|---|---|---|
| 1(a)(i) | **The only correct answer is B** (2-methylpentan-2-ol)<br><br>**A** *is not correct because it is a secondary alcohol*<br><br>**C** *is not correct because it is a secondary alcohol*<br><br>**D** *is not correct because it is a secondary alcohol* | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| 1(a)(ii) | **The only correct answer is A** (hexan-2-ol)<br><br>**B** *is not correct because it is a tertiary alcohol*<br><br>**C** *is not correct because it does not contain a* $CH_3CHOH$ *group*<br><br>**D** *is not correct because it does not contain a* $CH_3CHOH$ *group* | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| 1(b) | **The only correct answer is A** (red phosphorus)<br><br>**B** *is not correct because it will not form iodoalkanes with iodine and alcohols*<br><br>**C** *is not correct because it will not form iodoalkanes with iodine and alcohols*<br><br>**D** *is not correct because it will not form iodoalkanes with iodine and alcohols* | **(1)** |

**(Total Question 1 = 3 marks)**

| Question Number | Answer | Mark |
|---|---|---|
| 2(a) | **The only correct answer is A** (4-ethyloctane)<br><br>*B is incorrect because the position of the ethyl group should be shown by counting in the direction that gives the lowest possible number*<br>*C is incorrect because the longest carbon chain has 8 carbons*<br>*D is incorrect because the longest carbon chain has 8 carbons and because the position of the alkyl group should be shown by counting in the direction that gives the lowest possible number* | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| 2(b) | **The only correct answer is D** (cracking)<br><br>*A is incorrect because substitution would exchange atoms/groups in the reactant for other atoms/groups*<br>*B is incorrect because reforming would produce branched/cyclic alkanes*<br>*C is incorrect because fractional distillation would separate a mixture of alkanes* | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| 2(c)(i) | **The only correct answer is C (homolytic bond fission to form free radicals)**<br><br>*A is incorrect because such bond fission would produce ions*<br>*B is incorrect because the first step of the reaction produces free radicals by homolytic fission*<br>*D is incorrect because the first step of the reaction produces free radicals* | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 2(c)(ii) | 122.9æ(122.9 + 80.9) x 100<br>**or**<br>122.9æ(44.0 + (2 x 79.9)) x 100<br>**or**<br>(122.9æ203.8) x 100<br>(1)<br><br>= 60.304% (1) | Allow 123æ(123+81) = 60.29%<br><br>Award M1 only if final answer given as decimal 0.603 rather than %<br>Allow TE for M2 for only one incorrect $A_r$ value<br><br>Ignore SF<br>Correct answer with or without working scores (2) | **(2)** |

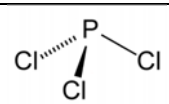
| Question Number | Answer | Mark |
|---|---|---|
| 2(c)(iii) | **The only correct answer is D** (the reaction produces a mixture of organic products)<br><br>*A is incorrect because bromine is very reactive*<br>*B is incorrect because gaseous reactants do not necessarily give a poor yield*<br>*C is incorrect because the kinetics of the reaction do not affect the yield* | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **2(c)(iv)** | Amount of 1-bromopropane (1)<br><br>So moles of propane required (1)<br><br>So volume of propane required to 2 or 3 SF (1)<br><br>**Alternative route**<br><br>Target mass of 1-bromopropane required to produce 14.7 g (with a 31.0% yield) (1)<br><br>Moles of propane required to produce the required mass of 1-bromopropane (1)<br><br>So volume of propane required to 2 or 3 SF (1) | 14.7/122.9 = 0.11961 (mol)<br><br>(0.11961/31) x 100 = 0.38584 (mol)<br><br>= 0.38584 x 24.0 = 9.2601 ($dm^3$)<br>= 9.3 / 9.26 ($dm^3$)<br>Allow 14.7/123 = 0.11951 (mol)<br>(0.11951/31) x 100 = 0.38552 (mol)<br><br>= 0.38552 x 24.0 = 9.2526 ($dm^3$)<br>= 9.3 / 9.25 ($dm^3$)<br><br>14.7 x $\frac{100}{31.0}$ = 47.4 g<br><br>$\frac{47.4}{122.9}$ = 0.3857 (mol)<br><br>0.3857 x 24.0 = 9.3 / 9.26 ($dm^3$)<br>Award (2) for a final answer of 0.890 / 0.89 ($dm^3$) (incorrect use of 31.0%)<br>Answer assuming 100% yield scores (2) for final answer of 2.87 / 2.9 ($dm^3$)<br>Penalise incorrect units in M3<br>Do not award M3 if Ideal Gas Eqtn used for propane volume<br>Penalise incorrect rounding once only<br>**Correct answer to 2 or 3 SF with or without working scores (3)** | **(3)** |

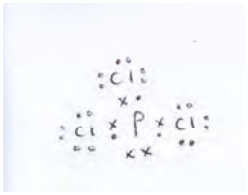
**(Total Question 2 = 9 marks)**

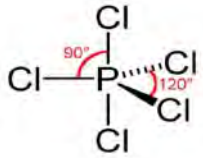
| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **3(a)(i)** | An explanation that makes reference to<br><br>• **M1** $PCl_3$ is (trigonal) pyramidal (1)<br><br>• **M2**<br>has 3 bond pairs and 1 lone pair (around central P atom) (1)<br><br>• **M3** electron pairs repel to positions of minimum repulsion / maximum separation (1) | Marking points 1 and 2 may be shown on diagrams (see below)<br><br>Award M1 for correct name of shape even if diagram(s) incorrect<br><br>Ignore lone pair – bond pair repulsions > bond pair – bond pair repulsions<br><br>Answer must state or imply somewhere that (electron) pairs repel<br>Do not award if specifically stated that 'bonds repel' or 'atoms repel'<br><br>Ignore any references to bond angles even if incorrect | **(3)** |

Example of diagram for award of M1 (a lone pair may also be shown on the P atom)




Example of diagram for award of M2
(must show 3 bond pairs and 1 lone pair)



| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 3(a)(ii) | • **M1** Diagram showing trigonal bipyramidal shape, with 3D emphasised by use of two wedges or one hatch and one wedge in the central plane (1)<br><br>• **M2** 90˚ and 120˚ angles labelled (1)<br><br>• **M3** trigonal bipyramidal (1) |  <br><br>M2 dependent on correct M1<br>Ignore 180°<br>Do not award M2 if any incorrect bond angle is shown<br><br>M3 stand alone mark<br>Both words required<br>Award “trigonal bipyramid” | (3) |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 3(a)(iii) | An answer that makes reference to the following points:<br><br>• phosphorus can expand its octet / can expand its (outer) shell / can accommodate more than 8 electrons / can accommodate 10 electrons / has available (3d-) orbitals (for promotion of electrons) (1)<br><br>• nitrogen does not have (2)d-orbitals / can only accommodate eight electrons (in its outer shell) (1) | **Comment**<br>Award reference to P accommodating 18 electrons<br><br>Ignore comparisons of size / radius of P and N atoms | (2) |

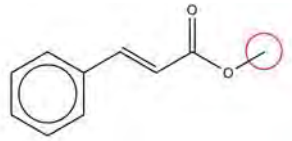
| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **3(b)** | An explanation that makes reference to the following points:<br><br>• **M1** London forces are greater in $NCl_3$ (1)<br><br>• **M2** as $NCl_3$ has more electrons / as Cl (atom) has more electrons (than F atom) (1)<br><br>• **M3 (**permanent) dipole-dipole forces / "permanent dipoles" / "dipole forces" stronger in $NF_3$ (than $NCl_3$) (1)<br><br>• **M4** as F is more electronegative than Cl (1)<br><br>• **M5**<br>**either**<br>London forces predominate / London forces are more significant<br>**or**<br>more (heat) energy needed to overcome the intermolecular forces between $NCl_3$ molecules (than $NF_3$ molecules)<br>(1) | Allow reverse arguments<br><br>Award van der Waals' / induced dipole etc<br><br>Award $NCl_3$ has 58 electrons whereas $NF_3$ has 34 electrons<br>Ignore comparisons of $M_r$<br>Do not award M2 if comparison of "**ionic** radii"<br><br>Award for M3 (permanent) dipole-dipole forces only in $NF_3$<br><br>Electronegativity difference 1.0 between N and F / No electronegativity difference between N and Cl / N-F is a more polar bond than N-Cl<br><br>Award (0) for M5 if any mention of:<br>Ionic bonds breaking in either $NF_3$ or $NCl_3$<br>**Breaking of** N-F and / or N-Cl covalent bonds scores (0) for M5<br><br>Note<br>If hydrogen bonding mentioned, can only award M1, M2 and M5 max<br>Ignore polarisation of ions | **(5)** |

| Question Number | Answer | Mark |
|---|---|---|
| 3(c) | **The only correct answer is B** (propan-1-ol)<br><br>**A** *is not correct because it does not give hydrogen chloride when $PCl_5$ is added*<br><br>**C** *is not correct because it does not give hydrogen chloride when $PCl_5$ is added*<br><br>**D** *is not correct because it does not give hydrogen chloride when $PCl_5$ is added* | **(1)** |

**(Total Question 3 = 14 marks)**

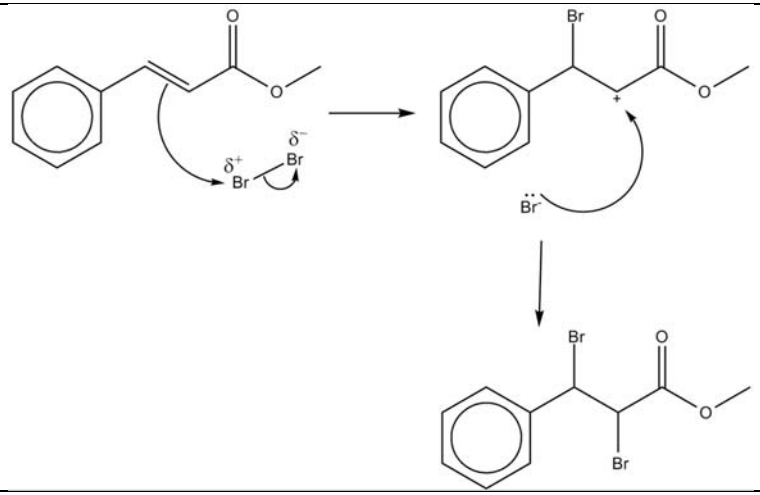
| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 4(a) | • calculation of molar mass of methyl cinnamate (1)<br>• calculation of mass of carbon (1) | Example of calculation<br>molar mass = 162 (g $mol^{-1}$)<br>2.34 x (120/162) = 1.73333 = 1.73 (g)<br>TE on incorrect molar mass for M2<br>**Correct answer with no working scores 2 marks**<br>Ignore SF except 1 | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 4(b)(i) | An answer that makes reference to the following points:<br>• peak due to tetramethylsilane (1)<br>• so (chemical) shifts (due to other hydrogen atoms) can be compared (1) | Allow TMS / $Si(CH_3)_4$<br>Name must be correct if given<br>Allow<br>"a reference" / "a standard"<br>"calibration"<br>Ignore<br>"to allow other molecules to be compared" | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **4(b)(ii)** | An answer that makes reference to the following points:<br><br>• **M1** circle around $-CH_3$ group in $-OCH_3$ (1)<br><br>• **M2** singlet as no neighbouring hydrogen atoms (1)<br><br>• **M3** peak area of 3 means there are 3 hydrogen atoms in this environment (1) | Allow 'protons' for hydrogen atoms<br><br>  <br>Award whole $-OCH_3$ circled<br>Do not award if C=O included in circle<br>M1 is a stand alone mark<br><br>Award "has no adjacent hydrogen atoms"<br>Award "no hydrogens on adjacent carbon"<br>Ignore "there is no adjacent C atom"<br><br>Award "(relative) peak area of three for a $-CH_3$ group"<br>For M3 must relate to (relative) peak area / integral<br>Ignore references to chemical shift value for ester δ = 3.0 to 4.0 (ppm)<br><br>Ignore references to relative heights of peaks<br><br>**Comment**<br>M2 and / or M3 dependent on $-CH_3$ group being included in the circled group | **(3)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 4(c)(i) | • **M1** arrow from double bond to (δ+)Br in $Br_2$ (1)<br>• **M2** arrow from bond in $Br_2$ to $Br^{\delta-}$ (1)<br>• **M3** structure of carbocation (1)<br>• **M4** arrow from **lone pair** on $Br^-$ to $C^+$ in carbocation **and** final product (1) | Example of mechanism<br>**See below**<br>Penalise lack of dipole only once in M1 and M2<br>Award $C^+$ in intermediate on either C from the double bond<br>Do not award M3 if four bonds are shown on carbocation<br>Br atoms can be shown either upwards or downwards in final product<br>Award (0) if just electrophilic substitution mechanism given.<br>If **both** electrophilic substitution and addition shown allow 2 max<br>Penalise errors in structure of methyl cinnamate once only in either M3 or M4<br>Do not award **M4** if the two Br atoms have been added to the same carbon atom in the addition product<br>Penalise use of half arrows once only | **(4)** |

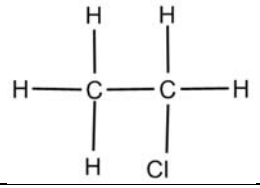
Example of mechanism

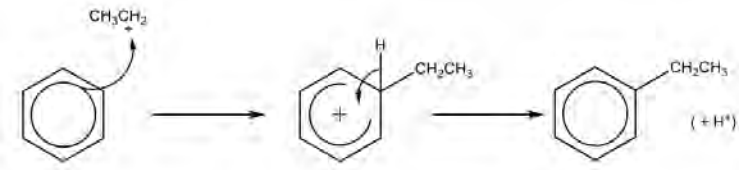



| Question Number | Answer | Mark |
|---|---|---|
| 4(c)(ii) | **The only correct answer is C** (4)<br><br>**A** *is not correct because 2 chiral centres form in reaction, so 4 possible combinations of +/- forms*<br>**B** *is not correct because 2 chiral centres form in reaction, so 4 possible combinations of +/- forms*<br>**D** *is not correct because 2 chiral centres form in reaction, so 4 possible combinations of +/- forms* | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| 4(c)(iii) | **The only correct answer is D** (rotated)<br><br>**A** *is not correct because diffracted is the wrong term*<br>**B** *is not correct because reflected is the wrong term*<br>**C** *is not correct because refracted is the wrong term* | **(1)** |

**(Total Question 4 = 13 marks)**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 5(a)(i) |  | Do not award skeletal or structural formulae | (1) |

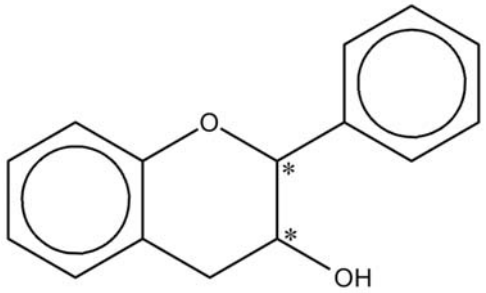
| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 5(a)(ii) | • **M1 equation** to show formation of electrophile (1)<br>• **M2** curly arrow from anywhere on the central ring to positive carbon (1)<br>• **M3** structure of intermediate (1)<br>• **M4** curly arrow from C-H bond to reform the ring (1)<br>• **M5 equation** showing regeneration of catalyst (1) | Example of mechanism<br>Penalise incorrect halogenoalkane in (a)(i) only<br>$CH_3CH_2Cl + AlCl_3 \rightarrow CH_3CH_2^+ + AlCl_4^-$<br>Ignore any curly arrows given in the equation<br>Allow curly arrow from anywhere within the hexagon<br>Do not award if curly arrow to $CH_3$ carbon in $CH_3CH_2^+$<br>Do not award if curly arrow to $C_2H_5^+$<br>Horseshoe facing the tetrahedral carbon and covering at least three carbon atoms<br>Some part of the positive charge in the horseshoe<br>Do not award dotted lines unless clearly part of a 3D structure<br>$AlCl_4^- + H^+ \rightarrow AlCl_3 + HCl$<br>Ignore regeneration step if part of the mechanism<br>**Mechanism**<br>  <br><br>Allow TE from (a)(i) | (5) |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **5(a)(iii)** | An explanation that makes reference to the following points:<br><br>Phenol is likely to be more reactive because<br><br>• **M1 lone pair** on **oxygen** (atom of –OH group) delocalises / is incorporated into the (benzene) ring / donated to the ring (1)<br><br>• **M2** which increases the electron density (of the ring) (1)<br><br>• **M3** making the ring / phenol more susceptible to electrophilic attack (1) | Do not award M2 if mention of "charge density" / "electronegativity"<br>Ignore references to "the ring becomes more negative"<br><br>Award "making the ring more nucleophilic" / "making the ring more susceptible to attack by a positive ion"<br><br>Ignore references to "activation of the ring " | **(3)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **5(b)** | • **M1** conversion of pressure and temperature (1)<br>• **M2** conversion of volume units (1)<br>• **M3** rearrangement of gas equation and calculation of *n* (1)<br>• **M4** calculation of the molar mass with the final answer given to **2 or 3 SF** (1) | Example of calculation<br>118 000 ($Nm^{-2}$) and 438 (K)<br>$70.5 \times 10^{-6}$ / $7.05 \times 10^{-5}$ ($m^3$)<br>$n = \frac{pV}{RT}$<br>$n = \frac{(118000 \times 70.5 \times 10^{-6})}{(8.31 \times 438)}$<br>$n = 2.2855777 \times 10^{-3}$ (mol)<br>$\frac{0.271}{2.2855777 \times 10^{-3}}$<br>= 118.5696<br>= 119 / 120 (g $mol^{-1}$)<br>If use $M_r = \frac{mRT}{pV}$ (since $n = \frac{m}{M_r}$ )<br>can score both **M3 and M4**<br>$M_r = \frac{0.271 \times 8.31 \times 438}{118\,000 \times 70.5 \times 10^{-6}}$<br>$M_r$ = 118.5695<br>$M_r$ = 119 / 120 (g $mol^{-1}$)<br>Award TE at each stage<br>Ignore units even incorrect | **(4)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **5(c)** | An explanation that makes reference to the following points:<br><br>EITHER<br>• retention time depends on the polarity **or** attraction / affinity / solubility / of the component for the stationary phase (1)<br><br>• The greater attraction / affinity / solubility / of the component for the stationary phase the greater the retention time (1)<br><br>OR<br><br>• retention time depends on the boiling temperature of the compound (1)<br><br>• higher boiling temperature compounds spend less time in the gas phase / mobile phase so have longer retention time (1) | Allow 'solid phase' or 'liquid phase' for 'stationary phase'<br>Allow 'retention time depends interaction with stationary phase'<br><br>Ignore attractions to the mobile / gas phase<br><br>Ignore comments related to mass of compounds | **(2)** |

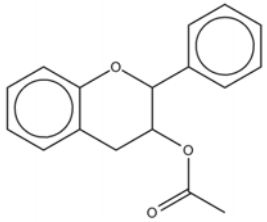
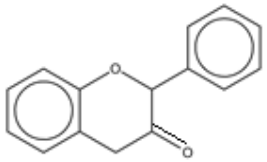
**(Total Question 5 = 15 marks)**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **6(a)** |  | | **(1)** |

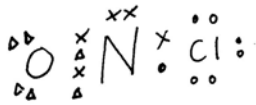
| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **6(b)** | $C_{15}H_{14}O_2$ | Allow symbols in any order e.g. $H_{14}O_2C_{15}$ | **(1)** |

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*6(c)</td>
<td>
This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.<br><br>
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.<br><br>
The following table shows how the marks should be awarded for indicative content.
<table>
<tr><td>Number of indicative marking points seen in answer</td><td>Number of marks awarded for indicative marking points</td></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><td></td><td>Number of marks awarded for structure of answer and sustained lines of reasoning</td></tr>
<tr><td>Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
</table>
</td>
<td>
Guidance on how the mark scheme should be applied:<br>
The mark for indicative content should be added to the mark for lines of reasoning.<br>
For example, a response with four indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).<br>
If there were no linkages between the points, then the same indicative marking points would yield and overall score of 3 marks (3 marks for indicative content and zero marks for linkages).<br><br>
Typically<br><br>
Number of IPs Reasoning mark<br><br>
6 or 5 scores 2<br><br>
4 or 3 scores 1<br><br>
2 or 1 or 0 scores 0
</td>
<td>(6)</td>
</tr>
</table>

| | | | | |
|---|---|---|---|---|
| | Answer is partially structured with some linkages and lines of reasoning | 1 | | |
| | Answer has no linkages between points and is unstructured | 0 | | |

| | | | |
|---|---|---|---|
| | **Indicative content**<br><br>• **IP1** any mention of **oxidation** of ethanol **or oxidation** of flavan-3-ol (by oxygen in the air)<br><br>• **IP2** for formation of **either** ethanoic acid **or** ethanal (from ethanol)<br><br>• **IP3** for formation of ethyl ethanoate (from the reaction between ethanol and ethanoic acid)<br><br>• **IP4** for structure / name of flavan-3-one<br><br>• **IP5** for (-OH group on) flavan-3-ol forms an ester with ethanoic acid<br><br>• **IP6** correct structure of the ester formed between flavan-3-ol and ethanoic acid<br><br>  <br>**This is the structure of the ester formed between flavan-3-ol and ethanoic acid** | Allow names or formulae **but** if both are given **both** must be correct<br><br>  <br><br>**Comment**<br>For correct structure of the ester formed between flavan-3-ol and ethanoic acid award both **IP5** and **IP6**<br><br>Do not award IP4 if the product is described as an aldehyde | |

**(Total Question 6 = 8 marks)**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **7(a)** | • electrons for double bond, single bond and lone pair around N (1)<br>• rest of electrons on Cl and O (1) | Example of dot-and-cross diagram<br>  <br>Allow any combination of dots/crosses/triangles for electrons<br>Allow bond pairs in double bond shown horizontally<br>Ignore lines drawn between atoms to show covalent bonds | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **7(b)(i)** | • concentration of NO in experiment 2 (1)<br>• concentration of $Cl_2$ in experiment 3 (1) | Example of calculation<br>0.244<br>0.121<br>Do not award 0.1205<br>**Both** values must be to **3SF** | **(2)** |

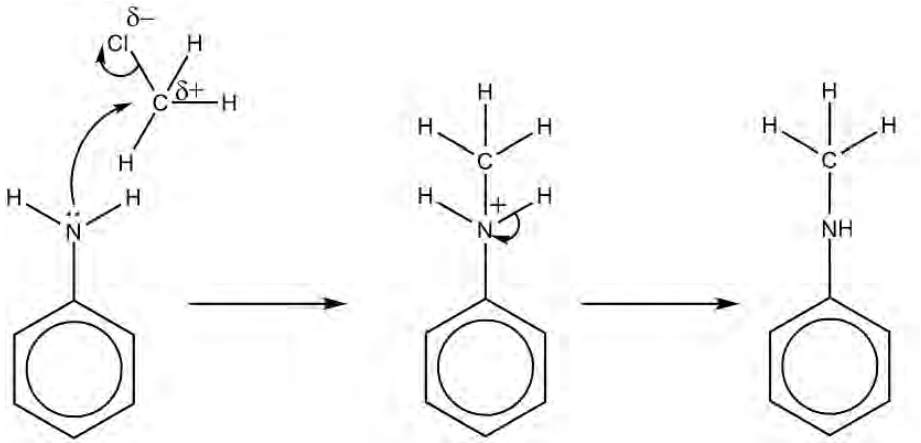
| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **7(b)(ii)** | • **M1** rearrangement of rate equation to find *k* (1)<br>• **M2** calculation of *k* (1)<br>• **M3** correct units for *k* (1) | Example of calculation<br>*k* = rate / $[NO]^2[Cl_2]$<br>$1.09 \times 10^{-2}$ / $(0.122 \times 0.122 \times 0.241)$<br>=3.03871 = 3.04<br>Ignore SF<br>Correct numerical answer for *k* scores both M1 and M2<br>$dm^6\ mol^{-2}\ s^{-1}$<br>Allow units in any order<br>M3 stand alone mark | **(3)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **7(b)(iii)** | An explanation that makes reference to the following points:<br><br>*k* increases because<br><br>• the catalyst provides an alternative pathway of lower activation energy (1)<br><br>• so a greater proportion of molecules / more molecules have energy greater than the activation energy (so faster reaction) (1) | Award 'particles' instead of 'molecules'<br>Do not award "atoms" instead of 'molecules' | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **7(b)(iv)** | An explanation that makes reference to the following points:<br>Catalysts will be less effective because<br><br>• **M1**<br>impurities **ad**sorb onto (catalyst) surface<br>**or**<br>impurities occupy active sites<br>**or**<br>impurities bond / bind to (catalyst) surface<br>(1)<br><br>• **M2**<br>impurities prevent bond weakening in the reactants<br>**or**<br>less surface area (of catalyst) / fewer active sites available for reaction<br>(1)<br><br>• **M3**<br>impurities form strong bonds (to surface)<br>**or**<br>impurities less likely to desorb (from surface)<br>(1) | Do not award "**<u>ab</u>**sorb" for M1<br>Ignore impurities "react"<br><br>Allow 'no active sites available'<br><br>Allow 'impurities remain on surface' | **(3)** |

**(Total Question 7 = 12 marks)**

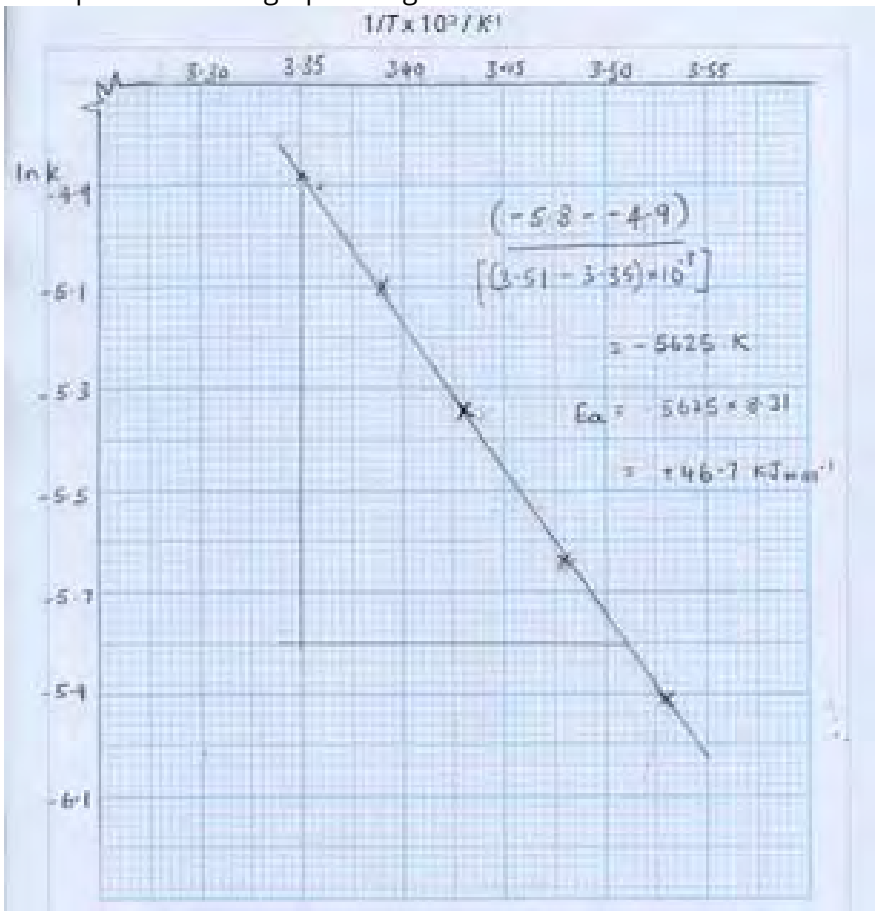
| Question Number | Answer | Mark |
|---|---|---|
| 8(ai) | **The only correct answer is D** (nucleophilic substitution)<br><br>**A** *is not correct because it is not electrophilic or addition*<br><br>**B** *is not correct because it is not electrophilic*<br><br>**C** *is not correct because it is not addition* | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| 8(a)(ii) | • **M1** arrow from lone pair on nitrogen atom to carbon atom (1)<br><br>• **M2** dipole shown **and** arrow from C–Cl bond to Cl or just beyond (1)<br><br>• **M3** formula of intermediate including the **+** charge on the N atom (1)<br><br>• **M4** arrow from N-H bond to $N^+$ and formula of organic product (1) | <u>Example of mechanism</u><br>  <br>(+ $H^+$ / HCl)<br>**Comment** M2 is a stand alone mark<br>Allow access to full marks for correct use of other halogenomethanes<br>Ignore any SN2 transition states<br>Ignore use of a second molecule of phenylamine behaving as a base | **(4)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **8(a)(iii)** | An answer that makes reference to the following points:<br><br>• **M1** dissolve (impure product) in a **minimum** volume of **hot** solvent (1)<br><br>• **M2** cool (in ice) **or** leave to recrystallise (1)<br><br>• **M3** filter using vacuum filtration / Buchner filtration / filter under suction (1)<br><br>• **M4** dry solid in desiccator / between filter papers (1) | Allow any named solvent<br><br>Ignore hot filtration after M1<br><br>Allow dry in a **warm** oven<br>Ignore references to rinsing<br>Do not award M4 if drying agent added to the crystals / solution | **(4)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **8(b)(i)** | • calculation of missing 1/*T* value<br><br>**and**<br><br>calculation of missing ln *k* value | <u>Example of calculation</u><br><br>$3.43 \times 10^{-3}$<br><br>-5.64<br><br>Ignore SF | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| **8(b)(ii)** | • **M1** axes correct way round and labelled with units on *x*-axis (1)<br><br>• **M2** suitable scale, must be uniform (1)<br><br>• **M3** all points plotted correctly, with straight line of best fit (1)<br><br>• **M4** calculation of gradient, including minus sign (1)<br><br>• **M5** units of gradient (1)<br><br>• **M6** calculation of activation energy with units (1)<br><br>**Comment**<br>If ln*k* plotted with most negative value at the top or -ln*k*, then all marks can still be scored, but gradient should still be negative | <u>Example of calculation and graph</u><br><br>award 1/T x $10^3$ / $K^{-1}$ **or** 1/T / $10^{-3}$ $K^{-1}$ or 1/T / $K^{-1}$ ($10^{-3}$)<br>Do not award 1/T x $10^{-3}$ / $K^{-1}$<br>Do not award **M1** if units given for ln *k* on *y*-axis<br>Do not award small "t" for "T"<br><br>Points must cover at least half the graph paper in each direction<br><br>-5775 (± 400)<br>Award gradient value between -5375 to -6175<br><br>**K**<br><br>(+)48.0 / (+)48 kJ $mol^{-1}$ ; allow TE for gradient outside range<br>Award $E_a$ values (+)44.7 to (+)51.3 kJ $mol^{-1}$<br>Award $E_a$ if correct in J $mol^{-1}$<br>Do not award M6 if given in just "kJ" or "J"<br>Ignore SF<br>Do not award M6 if final answer is a negative $E_a$ value<br>See next page for graph<br>**Comment**<br>If 1/*T* (*y*-axis) plotted against ln *k* (*x*-axis)<br>Can only award **M2, M3** and TE for **M4**<br>If either or both variables incorrect, then only **M2** can be scored | **(6)** |

| | | | |
|---|---|---|---|
| | | Example of suitable graph and gradient<br>  <br> | |

**(Total Question 8 = 16 marks)**
**TOTAL FOR PAPER = 90 MARKS**

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**Pearson Edexcel Level 3 GCE**

Centre Number | Candidate Number

# Wednesday 19 June 2019

Morning (Time: 2 hours 30 minutes) | Paper Reference **9CH0/03**

# Chemistry

## Advanced

## Paper 3: General and Practical Principles in Chemistry

**Candidates must have: Scientific calculator**
**Data Booklet**
**Ruler**

Total Marks

### Instructions

- Use **black** ink or **black** ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

### Information

- The total mark for this paper is 120.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- For the question marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically showing the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

### Advice

- Read each question carefully before you start to answer it.
- Show all your working in calculations and include units where appropriate.
- Check your answers if you have time at the end.

*Turn over* ▶

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1/1/1/1/1/

P 5 8 3 0 8 A 0 1 3 2

Pearson

**Answer ALL questions.**

**Write your answers in the spaces provided.**

**1** This question is about acids and bases.

(a) State what is meant by a Brønsted-Lowry acid.

**(1)**

.....

(b) Identify the acid-base conjugate pairs in this reaction.

**(1)**

$$CH_3COOH + HCOOH \rightarrow CH_3COOH_2^+ + HCOO^-$$

..... ..... ..... .....

(c) Write the expression that defines the pH of a solution.

**(1)**

(d) Calculate the concentration of hydrogen ions, in mol $dm^{-3}$, in a solution with a pH of 2.76

**(1)**

(e) Explain why the pH of a $1 \times 10^{-8}$ mol dm$^{-3}$ solution of nitric acid, $HNO_3$, is not 8.

[Ionic product of water, $K_w = 1.00 \times 10^{-14}$ mol$^2$ dm$^{-6}$]

**(2)**

**(Total for Question 1 = 6 marks)**

**2** This question is about the $Ag^+(aq)|Ag(s)$ half-cell.

(a) A student was asked to plan an experiment to measure the standard electrode potential of the $Ag^+(aq)|Ag(s)$ half-cell.

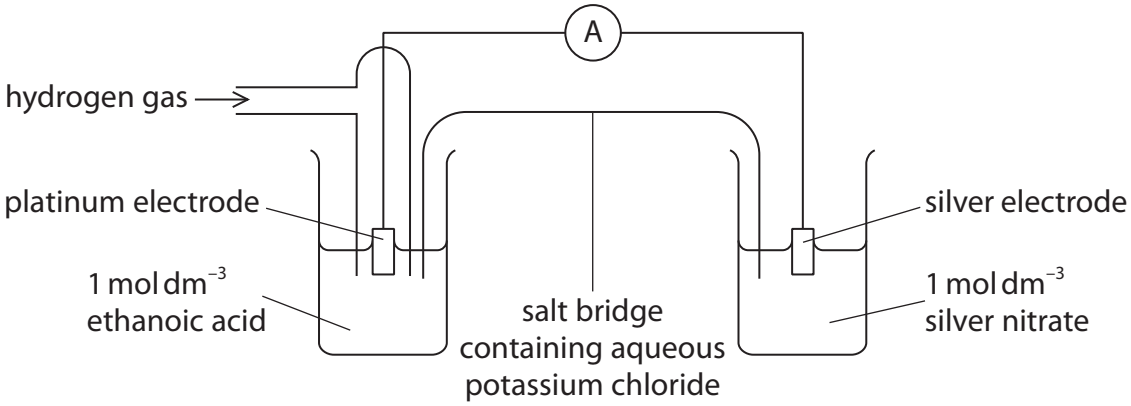
(i) State the conditions of temperature and pressure under which standard electrode potentials are measured.

**(1)**

.....

.....

(ii) The student drew the diagram shown.




Identify **three** mistakes in this diagram and the modifications that should be made to correct them.

**(3)**

| Mistake in diagram | Modification needed to correct mistake |
|---|---|
| | |
| | |
| | |

(b) The standard electrode potential, $E^{\ominus}$, of the $Ag^+(aq)|Ag(s)$ half-cell is +0.80 V.

The effect of changing the concentration of the ions on the value of the electrode potential, $E$, in this half-cell is calculated using the equation

$$E = E^{\ominus} + \frac{RT}{96500} \times \ln[Ag^+(aq)]$$

where $T$ is the temperature in kelvin and $R$ is the gas constant.

The electrode potential of a $Ag^+(aq)|Ag(s)$ half-cell was measured at 20 °C and found to be +0.72 V.

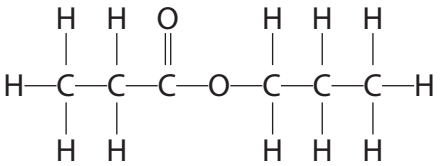
Calculate the concentration of silver ions, in mol $dm^{-3}$, in this half-cell.

**(3)**

**(Total for Question 2 = 7 marks)**

**3** This question is about esters with the molecular formula $C_6H_{12}O_2$.

(a) Propyl propanoate has the structure shown.



Devise a synthetic pathway to prepare propyl propanoate starting with 1-bromopropane as the **only** organic compound.

Include the reagents for each step in the synthesis, and the names or structures of the intermediate compounds.

**(5)**

(b) Another ester, **A**, with molecular formula $C_6H_{12}O_2$, was hydrolysed.
It produced ethanoic acid, and an alcohol, **B**, with molecular formula $C_4H_{10}O$.

Alcohol **B** undergoes an elimination reaction to produce a mixture of but-1-ene and but-2-ene.

Deduce the structures of **B** and **A**. Justify your structure of **B**.

**(3)**

**(Total for Question 3 = 8 marks)**

**4** Compound **C** is a pink crystalline solid containing two cations and one anion.

(a) Three tests were carried out on **C**. The observation made for each test was recorded in the table.

(i) Complete the statements in the inference column by writing the names or formulae of the species.

**(6)**

| Test | Observation | Inference |
|---|---|---|
| **Test 1**<br><br>Aqueous sodium hydroxide was added to solid **C** and the mixture warmed<br><br>The gas evolved was tested with damp red litmus paper | The red litmus paper turned blue | The gas evolved was<br>.....<br>One of the cations in **C** is<br>..... |
| **Test 2**<br><br>Concentrated hydrochloric acid was added to an aqueous solution of **C** | The pink solution turned blue | The other cation in **C** is<br>.....<br>The formula of the complex ion in the blue solution is<br>..... |
| **Test 3**<br><br>Dilute hydrochloric acid and aqueous barium chloride were added to an aqueous solution of **C** | A white precipitate formed | The white precipitate is<br>.....<br>The anion in **C** is<br>..... |

(ii) Use the results of the tests in (a)(i) to give a formula of **C**.
Do not include water of crystallisation.

**(1)**

.....

(b) Write the **ionic** equation for the reaction between the cation in **C** and sodium hydroxide producing the gas in **Test 1**.
State symbols are not required.

**(1)**

(c) State the type of reaction occurring in **Test 2**.

**(1)**

(d) Give a reason why dilute hydrochloric acid is needed in **Test 3**.

**(1)**

**(Total for Question 4 = 10 marks)**

**5** This question is about redox reactions.

(a) Name the ion with formula $PO_3^{3-}$. Include the relevant oxidation number.

**(1)**

.....

(b) State what happens to a reducing agent during a reaction, in terms of oxidation number **and** electrons.

**(1)**

.....

.....

(c) Identify the species that is the strongest reducing agent from the list of standard electrode potentials in the Data Booklet.

**(1)**

.....

(d) Manganese(IV) oxide, $MnO_2$, and manganate(VII) ions, $MnO_4^-$, react in alkaline solution to form manganate(VI) ions, $MnO_4^{2-}$.

(i) Write the **ionic** equation for this reaction.
State symbols are not required.

**(2)**

(ii) Give a reason why this reaction is **not** disproportionation.

**(1)**

.....

.....

.....

.....

(e) Sodium tetrahydridoborate(III), $NaBH_4$, is used in organic chemistry.
It is an alternative reagent to lithium tetrahydridoaluminate(III) for the reduction of carbonyl compounds.

(i) Draw a dot-and-cross diagram of the $BH_4^-$ ion.

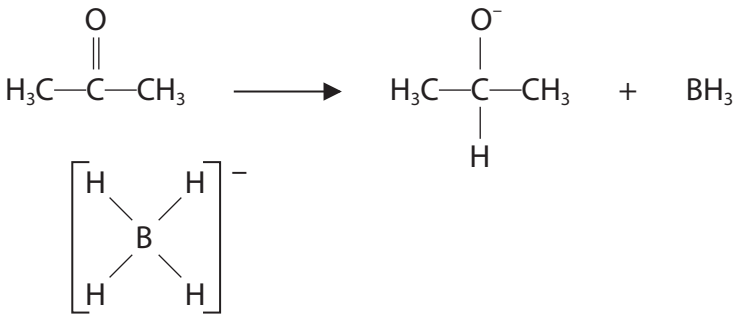
Use crosses (×) for the boron electrons, dots (•) for the hydrogen electrons and triangles (△) for the additional electron forming the negative ion.

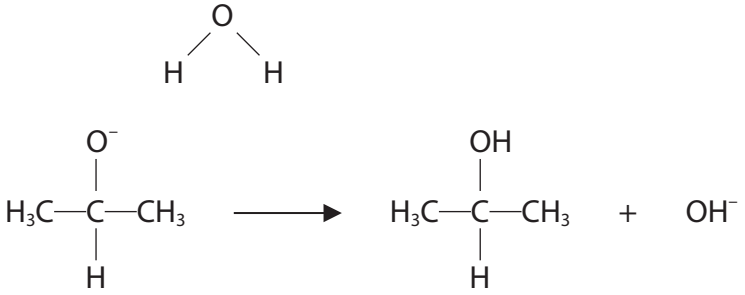
**(1)**

(ii) The $BH_4^-$ ions reduce carbonyl compounds to alcohols in aqueous solution.

Complete the mechanism for the reduction of propanone to propan-2-ol by adding curly arrows, and any relevant lone pairs and dipoles.

**(4)**




**(Total for Question 5 = 11 marks)**

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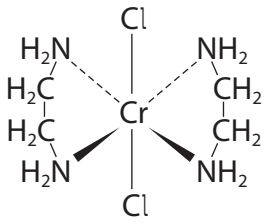
**6** This question is about transition metals and their ions.

(a) The **shape** of a complex ion formed from $Cr^{3+}$ ions is shown.




(i) State the coordination number of $Cr^{3+}$ in this complex ion.

**(1)**

(ii) State the overall charge on this complex ion.

**(1)**

(b) The complex ions of transition metals have different colours in aqueous solution.

Two factors that affect the colour of the solution are the oxidation number of the central metal ion, and the ligands present.

Give examples to illustrate these factors by referring to complex ions of iron and/or copper. Include the formula and colour of each complex.

An explanation of why transition metal ions are coloured is **not** required.

**(3)**

(c) Tungsten wire catalyses the decomposition of ammonia.

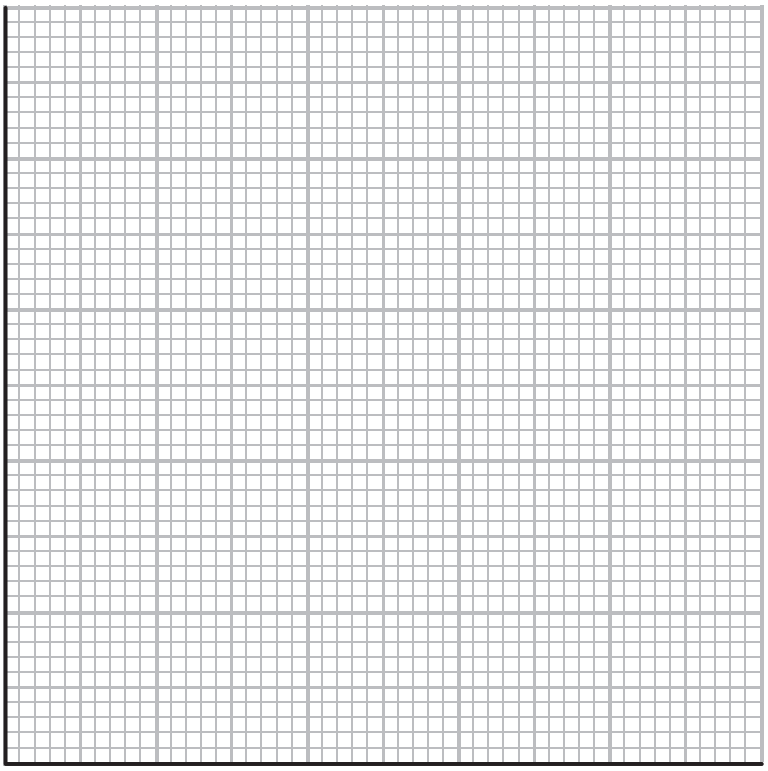
$$2NH_3(g) \rightarrow N_2(g) + 3H_2(g)$$

In an experiment, the following results were obtained.

| Time /s | Partial pressure of ammonia / kPa |
|---|---|
| 0 | 0.350 |
| 100 | 0.335 |
| 200 | 0.319 |
| 300 | 0.303 |
| 400 | 0.287 |
| 500 | 0.271 |

(i) Plot a graph of partial pressure of ammonia against time.

**(2)**



(ii) Deduce the rate equation for this reaction by using your graph in (c)(i).
Justify your answer.

**(2)**

(iii) Use the graph to calculate the rate constant. Include units in your answer.

**(2)**

(iv) Describe the stages in the catalytic decomposition of ammonia by tungsten.

**(3)**

**(Total for Question 6 = 14 marks)**

**7** A group of students analysed a hydrated salt with the formula $KH_3(C_2O_4)_y.zH_2O$ where **y** and **z** are whole numbers.

The students carried out experiments to determine the values of **y** and **z**.

(a) **Experiment 1** – to determine the value of **y**

One student was provided with a 0.0235 mol $dm^{-3}$ solution of the salt.

25.0 $cm^3$ portions of the salt solution were acidified with excess dilute sulfuric acid and heated to about 60 °C.

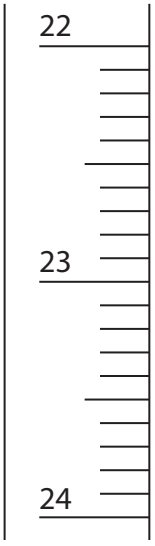
Each portion was titrated with 0.0203 mol $dm^{-3}$ potassium manganate(VII).

The results of four titrations are shown in the table.

| Titration number | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Final burette reading / $cm^3$ | 23.85 | 47.20 | 24.05 | 48.10 |
| Initial burette reading / $cm^3$ | 0.00 | 24.00 | 0.50 | 25.00 |
| Titre / $cm^3$ | 23.85 | 23.20 | 23.55 | 23.10 |

(i) Complete the diagram to show the final burette reading in **Titration 1**.

**(2)**




(ii) Explain why this student should use a mean titre of 23.15 $cm^3$ and not 23.43 $cm^3$ in the calculation.

**(2)**

.....

.....

.....

.....

(iii) The uncertainty in each burette reading is ±0.05 $cm^3$.

Calculate the percentage uncertainty in the titre volume of potassium manganate(VII) solution used in **Titration 2**.

**(1)**

(iv) The equation for the reaction is

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

Deduce, by calculation, the value of **y**, to the nearest whole number, in the formula $KH_3(C_2O_4)_{\mathbf{y}}.\mathbf{z}H_2O$.

Use the mean titre of 23.15 $cm^3$ and other data from **Experiment 1**.

You **must** show your working.

**(4)**

(b) **Experiment 2** – to determine the value of **z**

Another student wrote an account of the method for this experiment.

*A crucible was weighed.*

*A sample of the hydrated salt was added to the crucible and it was reweighed.*

*The crucible and salt were heated to remove the water of crystallisation and then allowed to cool.*

*The crucible and contents were weighed again.*

*Results*

| | |
|---|---|
| *Mass of crucible* | *= 19.56 g* |
| *Mass of crucible + $KH_3(C_2O_4)_y.\mathbf{z}H_2O$* | *= 22.97 g* |
| *Mass of crucible + $KH_3(C_2O_4)_y$* | *= 22.52 g* |

(i) Deduce, by calculation, the value of **z**, to the nearest whole number, in the formula $KH_3(C_2O_4)_{\mathbf{y}}.\mathbf{z}H_2O$.

You must use the data from **Experiment 2** and your value of **y** in (a)(iv).

You **must** show your working.

**(3)**

(ii) A third student carried out Experiment 2 and calculated a value of **z** that was lower than expected.

This student evaluated the experiment and gave two suggestions for **z** being lower.

Suggestion **1**
"Some of the crystals jumped out of the crucible while it was being heated."

Suggestion **2**
"It was difficult to tell when all the water of crystallisation had been lost."

Evaluate these two suggestions to decide whether they could account for the lower value of **z** obtained from the experimental results.

Include an explanation of the effect each suggestion would have on the calculated value of **z** and how the method could be improved to prevent these errors.

**(5)**

**(Total for Question 7 = 17 marks)**

**8** 1-bromobutane can be prepared from butan-1-ol and hydrogen bromide.

$$CH_3CH_2CH_2CH_2OH + HBr \rightarrow CH_3CH_2CH_2CH_2Br + H_2O$$

Hydrogen bromide can be made from sodium bromide and 50% concentrated sulfuric acid.

(a) The steps for the preparation of impure 1-bromobutane are summarised.

Step **1** Dissolve the sodium bromide in distilled water in a pear-shaped flask and then add 20.0 $cm^3$ of butan-1-ol.

Step **2** Surround the flask with an ice bath to **cool the mixture**, before adding concentrated sulfuric acid drop by drop.

Step **3** Remove the flask from the ice bath and add a few **anti-bumping granules** to the reaction mixture.

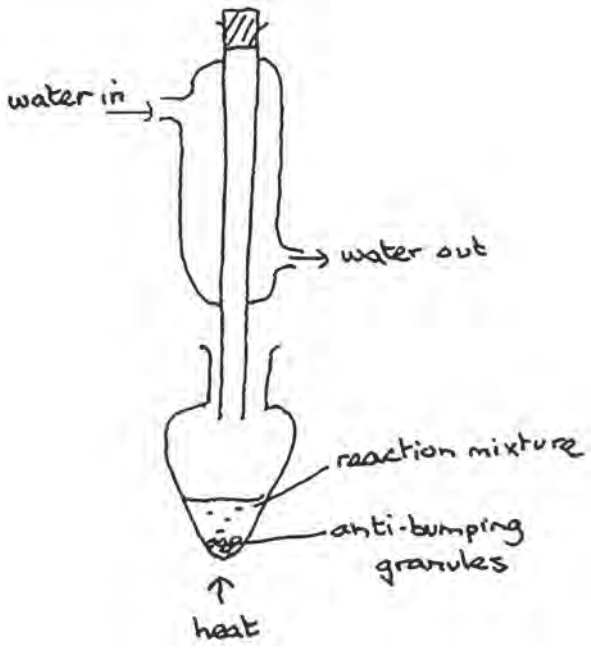
Step **4** Set up the apparatus for **heating under reflux**. Heat the mixture in the flask for 30 minutes and then allow the apparatus to cool.

Step **5** Rearrange the apparatus for distillation and heat the mixture until no more 1-bromobutane distils over.

(i) Parts of the method are given in **bold** type in Steps **2**, **3** and **4**. Give a reason why each of these parts is necessary.

**(3)**

(ii) A student drew a diagram of the apparatus used for heating under reflux in Step **4**. There are three errors in the apparatus shown in the diagram. Assume the apparatus is suitably clamped.




Identify the three errors, including the effect of each error.

**(3)**

(iii) The student corrected the errors.
While the mixture was heating under reflux, the student noticed a small amount of a brown vapour was formed.

Explain why the brown vapour forms.

**(2)**

.....

.....

.....

.....

(b) The distillate collected in Step **5** is a mixture consisting of two layers.
There is an aqueous layer and a layer containing impure 1-bromobutane.

**Data**

Densities:

| | |
|---|---|
| water | 1.00 g $cm^{-3}$ |
| butan-1-ol | 0.81 g $cm^{-3}$ |
| 1-bromobutane | 1.27 g $cm^{-3}$ |

Boiling temperature of 1-bromobutane = 102 °C

The steps for the purification of the 1-bromobutane are summarised.

Step **6** Transfer the mixture from Step **5** to a separating funnel and remove the aqueous layer.

Step **7** Wash the impure 1-bromobutane with concentrated hydrochloric acid in the separating funnel. Remove the aqueous layer.

Step **8** Add aqueous sodium hydrogencarbonate to the impure 1-bromobutane in the separating funnel.

Step **9** Shake the mixture in the separating funnel and, from time to time, invert the funnel and open the tap.

Step **10** Collect the 1-bromobutane layer from Step **9** in a small conical flask. Add anhydrous sodium sulfate and swirl the flask until the liquid becomes clear.

Step **11** Decant the 1-bromobutane into a clean pear-shaped flask and redistil it. Measure the volume of 1-bromobutane produced.

(i) State the position of the aqueous layer in the separating funnel at the start of Step **6**. Justify your answer.

**(1)**

.....

.....

(ii) Concentrated hydrochloric acid is used to remove any unreacted butan-1-ol in the mixture in Step **7**.

Give the reasons for carrying out Steps **8**, **9** and **10**.

**(3)**

.....

.....

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.....

.....

(iii) Give a suitable temperature **range** over which to collect the pure 1-bromobutane in the redistillation in Step **11**.

**(1)**

.....

(iv) The volume of 1-bromobutane collected was 12.0 $cm^3$.

Calculate the number of molecules of 1-bromobutane produced in this experiment.

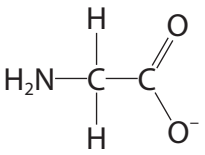
Give your answer to an appropriate number of significant figures.

**(2)**

**(Total for Question 8 = 15 marks)**

**9** Some organic compounds contain metals.

(a) Glycinate ions are formed from the amino acid glycine.



glycinate ion

(i) Explain the effect, if any, of an aqueous solution containing glycinate ions on plane-polarised monochromatic light.

**(2)**

(ii) A hot aqueous solution of glycine is added to a hot solution of copper(II) ethanoate.
When the mixture is cooled, crystals of copper(II) glycinate are formed.

Write the equation for this reaction.
State symbols are not required.

**(2)**

(iii) In an experiment, the crystals are filtered, weighed and the percentage yield calculated.

Student **1** obtained a yield of 102.6%.

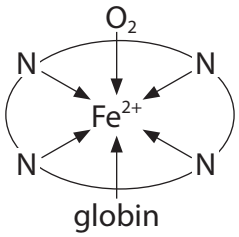
Student **2** obtained a yield of 56.4%.

The expected yield is 82% and the students carried out the calculation correctly.

Discuss possible reasons for the yields obtained by these students.

**(4)**

(b) Haemoglobin is an iron(II) complex. It carries oxygen around the body.
Part of the structure of haemoglobin is shown.




The four nitrogen atoms are part of a multidentate ligand in the haem group.

Explain why inhaling carbon monoxide can be fatal.

**(2)**

*(c) Grignard reagents contain a metal.

Discuss how Grignard reagents are formed and used in adding one or more carbon atoms to the carbon chain in 1-bromopropane to produce primary, secondary and tertiary alcohols and a carboxylic acid.

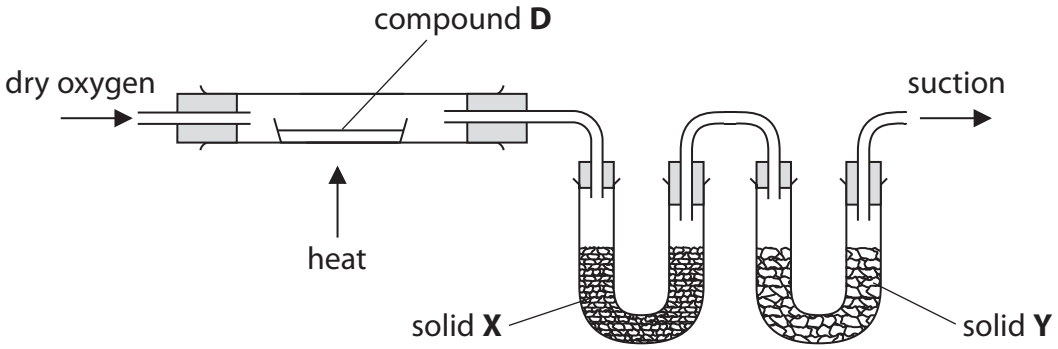
Include a suitable example for each reaction and give reagents, conditions and products. You may include equations in your answer.

**(6)**

**(Total for Question 9 = 16 marks)**

**10** Organic compound **D** contains the elements carbon, hydrogen, oxygen and nitrogen only.

(a) A sample of **D** was burned completely in the apparatus shown.
Solid **X** absorbed the water formed in the combustion.
Solid **Y** absorbed the carbon dioxide.




(i) The masses of solids **X** and **Y** increased during the experiment.

Explain the effect, if any, on the changes in mass of **X** and **Y** if the oxygen gas was not dry.

**(3)**

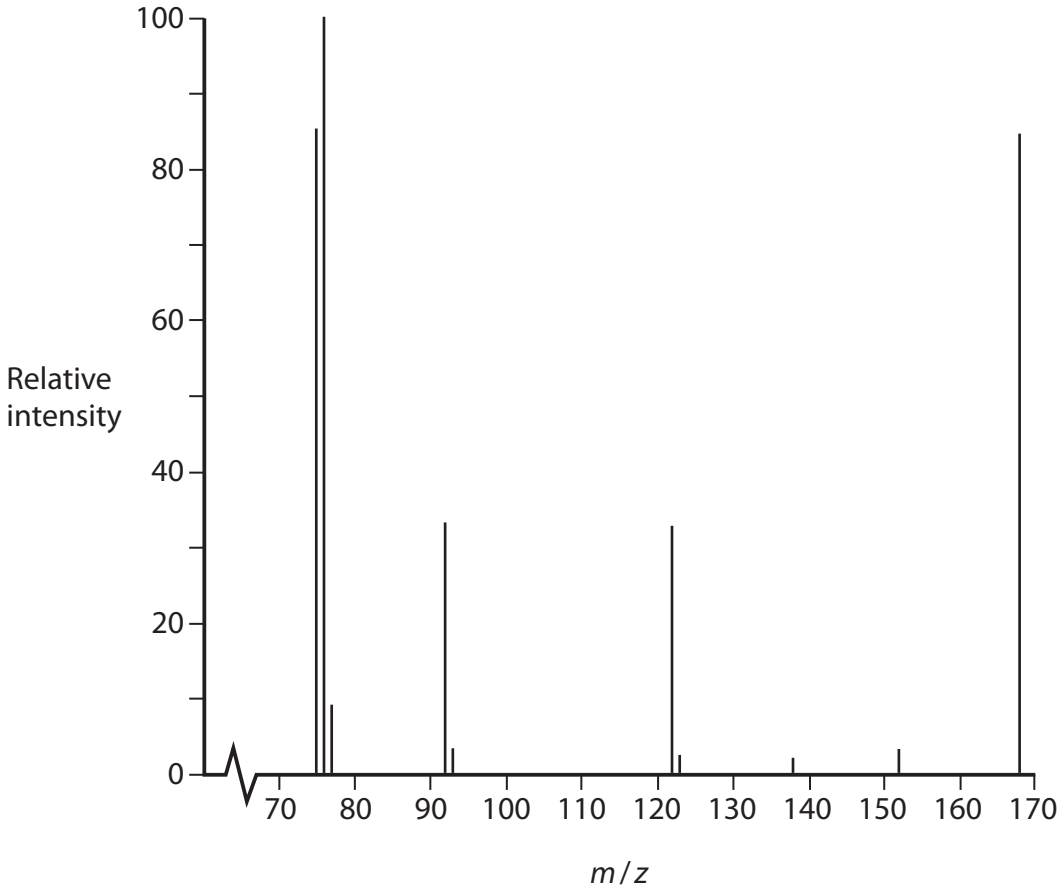
(ii) On combustion in dry oxygen, 3.36 g of **D** produced 0.72 g of water and 5.28 g of carbon dioxide.
This sample of **D** also contained 0.56 g of nitrogen.

Use these data to calculate the empirical formula of compound **D**.

You **must** show your working.

**(5)**

(b) Part of the mass spectrum of **D** is shown.




Deduce the molecular formula of **D**. Justify your answer.

**(2)**

(c) Compound **D** contains a benzene ring.

(i) Give the molecular formula of the species that causes the peak at $m/z = 76$ in the mass spectrum of **D**.

**(1)**

(ii) Draw the structures of the **three** possible isomers of **D** containing a benzene ring.

**(2)**

(iii) The $^{13}C$ NMR spectrum of compound **D** has four peaks.

Identify the structure of **D**. Justify your answer by labelling the different carbon environments in **all** the structures drawn in (c)(ii).

**(3)**

**(Total for Question 10 = 16 marks)**

**TOTAL FOR PAPER = 120 MARKS**

# The Periodic Table of Elements

| 1 | 2 | | | | | | | | | | | 3 | 4 | 5 | 6 | 7 | 0 (8) (18) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 1.0 H hydrogen 1 | | | | | | | | | | 4.0 He helium 2 |
| (1) | (2) | | | | | | | | | | | (13) | (14) | (15) | (16) | (17) | |
| 6.9 Li lithium 3 | 9.0 Be beryllium 4 | | | | | | | | | | | 10.8 B boron 5 | 12.0 C carbon 6 | 14.0 N nitrogen 7 | 16.0 O oxygen 8 | 19.0 F fluorine 9 | 20.2 Ne neon 10 |
| 23.0 Na sodium 11 | 24.3 Mg magnesium 12 | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | 27.0 Al aluminium 13 | 28.1 Si silicon 14 | 31.0 P phosphorus 15 | 32.1 S sulfur 16 | 35.5 Cl chlorine 17 | 39.9 Ar argon 18 |
| 39.1 K potassium 19 | 40.1 Ca calcium 20 | 45.0 Sc scandium 21 | 47.9 Ti titanium 22 | 50.9 V vanadium 23 | 52.0 Cr chromium 24 | 54.9 Mn manganese 25 | 55.8 Fe iron 26 | 58.9 Co cobalt 27 | 58.7 Ni nickel 28 | 63.5 Cu copper 29 | 65.4 Zn zinc 30 | 69.7 Ga gallium 31 | 72.6 Ge germanium 32 | 74.9 As arsenic 33 | 79.0 Se selenium 34 | 79.9 Br bromine 35 | 83.8 Kr krypton 36 |
| 85.5 Rb rubidium 37 | 87.6 Sr strontium 38 | 88.9 Y yttrium 39 | 91.2 Zr zirconium 40 | 92.9 Nb niobium 41 | 95.9 Mo molybdenum 42 | [98] Tc technetium 43 | 101.1 Ru ruthenium 44 | 102.9 Rh rhodium 45 | 106.4 Pd palladium 46 | 107.9 Ag silver 47 | 112.4 Cd cadmium 48 | 114.8 In indium 49 | 118.7 Sn tin 50 | 121.8 Sb antimony 51 | 127.6 Te tellurium 52 | 126.9 I iodine 53 | 131.3 Xe xenon 54 |
| 132.9 Cs caesium 55 | 137.3 Ba barium 56 | 138.9 La* lanthanum 57 | 178.5 Hf hafnium 72 | 180.9 Ta tantalum 73 | 183.8 W tungsten 74 | 186.2 Re rhenium 75 | 190.2 Os osmium 76 | 192.2 Ir iridium 77 | 195.1 Pt platinum 78 | 197.0 Au gold 79 | 200.6 Hg mercury 80 | 204.4 Tl thallium 81 | 207.2 Pb lead 82 | 209.0 Bi bismuth 83 | [209] Po polonium 84 | [210] At astatine 85 | [222] Rn radon 86 |
| [223] Fr francium 87 | [226] Ra radium 88 | [227] Ac* actinium 89 | [261] Rf rutherfordium 104 | [262] Db dubnium 105 | [266] Sg seaborgium 106 | [264] Bh bohrium 107 | [277] Hs hassium 108 | [268] Mt meitnerium 109 | [271] Ds darmstadtium 110 | [272] Rg roentgenium 111 | | | | | | | |

Key

relative atomic mass
**atomic symbol**
name
atomic (proton) number

Elements with atomic numbers 112-116 have been reported but not fully authenticated

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 140 Ce cerium 58 | 141 Pr praseodymium 59 | 144 Nd neodymium 60 | [147] Pm promethium 61 | 150 Sm samarium 62 | 152 Eu europium 63 | 157 Gd gadolinium 64 | 159 Tb terbium 65 | 163 Dy dysprosium 66 | 165 Ho holmium 67 | 167 Er erbium 68 | 169 Tm thulium 69 | 173 Yb ytterbium 70 | 175 Lu lutetium 71 |
| 232 Th thorium 90 | [231] Pa protactinium 91 | 238 U uranium 92 | [237] Np neptunium 93 | [242] Pu plutonium 94 | [243] Am americium 95 | [247] Cm curium 96 | [245] Bk berkelium 97 | [251] Cf californium 98 | [254] Es einsteinium 99 | [253] Fm fermium 100 | [256] Md mendelevium 101 | [254] No nobelium 102 | [257] Lr lawrencium 103 |

* Lanthanide series

* Actinide series

# Mark Scheme (Results)

## Summer 2019

Pearson Edexcel Advanced Level
In Chemistry (9CH0) Paper 03 General and Practical Principles in Chemistry

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Summer 2019
Publications Code 9CH0_03_1906_MS

**General Marking Guidance**

- All candidates must receive the same treatment. Examiners must mark the first candidate in exactly the same way as they mark the last.
- Mark schemes should be applied positively. Candidates must be rewarded for what they have shown they can do rather than penalised for omissions.
- Examiners should mark according to the mark scheme not according to their perception of where the grade boundaries may lie.
- There is no ceiling on achievement. All marks on the mark scheme should be used appropriately.
- All the marks on the mark scheme are designed to be awarded. Examiners should always award full marks if deserved, i.e. if the answer matches the mark scheme. Examiners should also be prepared to award zero marks if the candidate's response is not worthy of credit according to the mark scheme.
- Where some judgement is required, mark schemes will provide the principles by which marks will be awarded and exemplification may be limited.
- When examiners are in doubt regarding the application of the mark scheme to a candidate's response, the team leader must be consulted.
- Crossed out work should be marked UNLESS the candidate has replaced it with an alternative response.
- Mark schemes will indicate within the table where, and which strands of QWC, are being assessed. The strands are as follows:

  i) ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear
  ii) select and use a form and style of writing appropriate to purpose and to complex subject matter
  iii) organise information clearly and coherently, using specialist vocabulary when appropriate

**Using the Mark Scheme**

Examiners should look for qualities to reward rather than faults to penalise. This does NOT mean giving credit for incorrect or inadequate answers, but it does mean allowing candidates to be rewarded for answers showing correct application of principles and knowledge. Examiners should therefore read carefully and consider every response: even if it is not what is expected it may be worthy of credit.

The mark scheme gives examiners:
- an idea of the types of response expected
- how individual marks are to be awarded
- the total mark for each question
- examples of responses that should NOT receive credit.

/ means that the responses are alternatives and either answer should receive full credit.
( ) means that a phrase/word is not essential for the award of the mark, but helps the examiner to get the sense of the expected answer.
Phrases/words in **bold** indicate that the meaning of the phrase or the actual word is **essential** to the answer.
ecf/TE/cq (error carried forward) means that a wrong answer given in an earlier part of a question is used correctly in answer to a later part of the same question.

Candidates must make their meaning clear to the examiner to gain the mark. Make sure that the answer makes sense. Do not give credit for correct words/phrases which are put together in a meaningless manner. Answers must be in the correct context.

**Quality of Written Communication**
Questions which involve the writing of continuous prose will expect candidates to:
- write legibly, with accurate use of spelling, grammar and punctuation in order to make the meaning clear
- select and use a form and style of writing appropriate to purpose and to complex subject matter
- organise information clearly and coherently, using specialist vocabulary when appropriate.

Full marks will be awarded if the candidate has demonstrated the above abilities.
Questions where QWC is likely to be particularly important are indicated (QWC) in the mark scheme, but this does not preclude others.

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 1(a) | • (a Brønsted-Lowry acid is a) proton donor | Allow donates / gives away protons / $H^+$ (ions) / hydrogen ions<br><br>Allow releases / loses protons / $H^+$ / hydrogen ions<br><br>Do not award 'donates $H_3O^+$ (ions)' | (1) |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 1(b) | • correct acid-base pairs identified **and** linked | <u>Examples of acid-base pairs</u><br><br>$CH_3COOH + HCOOH \rightarrow CH_3COOH_2^+ + HCOO^-$<br>base 2/B2 acid 1/A1 acid 2/ A2 base 1/B1<br>**or**<br><br>$CH_3COOH + HCOOH \rightarrow CH_3COOH_2^+ + HCOO^-$<br>base acid acid base<br><br>**or**<br><br>$CH_3COOH + HCOOH \rightarrow CH_3COOH_2^+ + HCOO^-$<br>base / B acid / A conjugate acid / CA conjugate base / CB<br><br>Allow any clear identification of acid and base **and** connection between the correct pairs | (1) |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **1(c)** | • (pH =) $-\log[H^+(aq)]$<br>**or**<br>(pH =) $-\log[H_3O^+(aq)]$ | Allow $\log_{10}$ / lg for log<br>Ignore missing (aq)<br>Do not award –log conc $H^+$<br>Do not award round brackets / no brackets for concentration but allow round brackets around the square brackets e.g. $-\log([H^+(aq)])$ | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **1(d)** | • calculation of $[H^+(aq)]$ | <u>Example of calculation</u><br>$[H^+(aq)] = 10^{-pH} = 10^{-2.76}$<br><br>$= 1.7378 \times 10^{-3}$ / $1.738 \times 10^{-3}$ /<br>$1.74 \times 10^{-3}$ / $1.7 \times 10^{-3}$ / 0.0017378 /<br>0.001738 / 0.00174 / 0.0017 (mol $dm^{-3}$)<br><br>Ignore units even if incorrect<br><br>Correct answer to 2 or more SF with no working scores (1) | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **1(e)** | An explanation that makes reference to the following points:<br><br>• $[H^+]$/ $[H_3O^+]$/ concentration of hydrogen ions from water is 1(.0) x $10^{-7}$ (mol $dm^{-3}$) **(1)**<br><br>• so total $[H^+]$ is greater than 1(.0) x $10^{-7}$ (mol $dm^{-3}$) / is 1.1 x $10^{-7}$ (mol $dm^{-3}$)<br><br>**or**<br>the pH cannot be more than 7 / alkaline (for an acid)<br><br>**or**<br>concentration of hydrogen ions from water is not negligible / cannot be ignored<br><br>**or**<br>$10^{-8}$ is only the concentration of ions from the acid, it doesn't include those from the water **(1)** | Penalise reference to nitric acid as a weak acid in M2 only<br><br>Allow $[H^+]$ from water = $\sqrt{1(.00) \times 10^{-14}}$ / $\sqrt{K_w}$<br>Allow this shown as part of a calculation<br><br>Allow $[H_3O^+]$/ concentration of hydrogen ions for $[H^+]$<br>Allow$[H^+]$ is greater than 1 x $10^{-8}$ (mol $dm^{-3}$)<br>Allow $[H^+]$ cannot be less than $[OH^-]$ / $[OH^-]$ cannot be more than $[H^+]$<br>Allow the addition of nitric acid to water decreases pH by increasing $[H^+]$<br><br>Allow pH is 6.96<br>Allow pH 8 / >7 is alkaline<br>Allow acid must have pH below 7<br>Do not award $10^{-14}/10^{-8} = 10^{-6}$ so pH = 6 for M2 only<br><br>Allow water also dissociates to form $H^+$ ions | **(2)** |

**(Total for Question 1 = 6 marks)**

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **2(a)(i)** | • correct temperature **and** pressure | Examples of values<br>Temperature: 298 K / 25°C<br><br>Pressure: 1 atm / 1 bar<br>100 kPa/ 1 x $10^5$ Pa /<br>101 kPa / 1.01 x $10^5$ Pa /<br>1 x $10^5$ $Nm^{-2}$ / 1.01 x $10^5$ $Nm^{-2}$<br><br>Values **and** units are needed<br><br>Ignore reference to concentration even if incorrect | **(1)** |

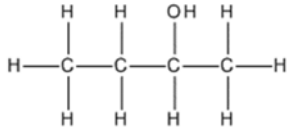
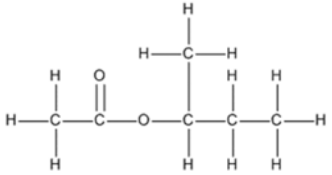
| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 2(a)(ii) | • ammeter / symbol for ammeter **and** replace with (high resistance) voltmeter / symbol for voltmeter **(1)**<br><br>• ethanoic acid **and** replace with solution that is 1.0 mol $dm^{-3}$ with respect to $H^+(aq)$ **(1)**<br><br>• potassium chloride / chemical in salt bridge **and** replace with potassium nitrate / $KNO_3$ / sodium nitrate / $NaNO_3$ **(1)** | The mistakes can be in any order<br>Ignore any other errors<br>Ignore reasons for replacements<br><br>Allow replace with potentiometer / Wheatstone bridge<br>Do not award voltameter<br><br>Allow replace with (1.0 / 1.16-1.18 mol $dm^{-3}$) hydrochloric acid / HCl / nitric acid / $HNO_3$ **or**<br>Allow 0.5 mol $dm^{-3}$ sulfuric acid / $H_2SO_4$<br>Ignore just 'replace with a strong acid'<br><br>Allow replace chloride with a nitrate anion<br>Ignore replace with a different anion that will not react with $Ag^+$ | **(3)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **2(b)** | • substitution of correct values into expression **(1)**<br>• calculation of $\ln[Ag^+(aq)]$ **(1)**<br>• calculation of $[Ag^+(aq)]$ **(1)** | Example of calculation<br>$0.72 = 0.80 + \frac{8.31 \times 293}{96500} \times \ln[Ag^+(aq)]$<br>$\ln[Ag^+(aq)] = (0.72 - 0.80) \times \frac{96500}{8.31 \times 293}$<br>$= -3.1707$<br>$[Ag^+(aq)] = e^{\ln[Ag+(aq)]}$<br>$= 0.041976 / 4.1976 \times 10^{-2}$ (mol $dm^{-3}$)<br>TE on $\ln[Ag^+(aq)]$<br>Ignore SF except 1 SF<br>Correct answer with no working scores full marks<br>Expression can be rearranged before substitution of values | **(3)** |

**(Total for Question 2 = 7 marks)**

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **3(a)** | A synthetic pathway that includes:<br><br>**Conversion to alcohol**<br>• (aqueous ethanolic) potassium / sodium hydroxide **(1)**<br><br>• name or structure of propan-1-ol **(1)**<br><br>**EITHER ROUTE 1**<br>**Conversion to carboxylic acid**<br>• (oxidise some of the propan-1-ol using) potassium dichromate((VI)) **and** (dilute) sulfuric acid **(1)**<br><br>• name or structure of propanoic acid **(1)**<br><br>**Formation of ester**<br>• react propan-1-ol and propanoic acid together **and** using (concentrated) sulfuric acid (catalyst) **(1)**<br><br>**PTO for ROUTE 2** | Allow names or formulae for reagents but if both are given, both must be correct<br>Allow correct species in unbalanced equations<br>Allow any combination of structural, displayed or skeletal formulae for the intermediates<br>Penalise missing H once only<br>Ignore conditions e.g. heat / reflux<br><br>Allow hydroxide ions / $OH^-$<br>Ignore concentration<br>Do not award just ethanol / ethanolic<br><br>Stand alone mark e.g. $CH_3CH_2CH_2OH$<br>Allow propanol if correct structure shown somewhere<br><br>Allow acidified potassium dichromate((VI)) / $Cr_2O_7^{2-}$ **and** $H^+$<br>Allow acidified manganate((VII))<br>Ignore concentration of acid / formation of aldehyde<br>Do not award hydrochloric acid / HCl<br><br>Stand alone mark<br>e.g. $CH_3CH_2COOH$<br><br>Stand alone mark for $C_3$ compounds<br>Allow (concentrated hydrochloric) acid / $H^+$ / $H_3O^+$ instead of sulfuric acid<br>Ignore concentration of acid<br><br>Ignore incorrect structure of ester e.g. with H or O missing | **(5)** |

| | | | |
|---|---|---|---|
| | **OR ROUTE 2**<br>**Conversion to acyl chloride**<br>• (oxidise some of the propan-1-ol using) potassium dichromate((VI)) **and** (dilute) sulfuric acid<br><br>**and**<br>add phosphorus(V) chloride to propanoic acid **(1)**<br><br>• name or structure of propanoyl chloride **(1)**<br>**Formation of ester**<br>• react propan-1-ol and propanoyl chloride together **(1)** | Allow acidified potassium dichromate((VI)) / $Cr_2O_7^{2-}$ **and** $H^+$<br>Allow acidified manganate((VII))<br>Ignore concentration of acid / formation of aldehyde<br>Do not award hydrochloric acid / HCl<br><br>Stand alone mark<br>e.g. $CH_3CH_2COCl$<br><br>Stand alone mark for $C_3$ compounds<br><br>Ignore incorrect structure of ester e.g. with H or O missing | |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **3(b)** | **Identifications**<br>• structure of alcohol **B** **(1)**<br>• structure of ester **A** **(1)**<br><br>**Justification**<br>• butan-2-ol / $CH_3CH_2CHOHCH_3$ is the **only** alcohol (with formula $C_4H_{10}O$) that (undergoes elimination and) produces (but-1-ene and) but-2-ene **(1)** | Allow any combination of structural, displayed or skeletal formulae / correct species in unbalanced equations<br>Allow structures not labelled **A** and **B**<br>Penalise missing H once only<br>Examples of identification<br>**(B)**<br>  <br>Ignore connectivity of the OH group unless horizontal<br>**(A)**<br>  <br>Ignore incorrect name for **A**<br>TE on incorrect alcohol<br><br>Allow butan-2-ol can form a double bond either side of the C with OH / between the 1st and 2nd carbon atoms and the 2nd and 3rd carbon atoms – this can be shown on diagram / equation<br>Allow OH must be on the 2nd carbon atom / secondary alcohol to form but-1-ene and but-2-ene<br>Allow butan-1-ol gives but-1-ene **and** 2-methylpropan-1-ol / 2-methylpropan-2-ol gives (2-)methylpropene<br>Allow the other alcohols (with formula $C_4H_{10}O$) do not give but-2-ene | **(3)** |

**(Total for Question 3 = 8 marks)**

| Question Number | Acceptable Answers | | Additional Guidance | Mark |
|---|---|---|---|---|
| **4(a)(i)** | **Test 1**<br>• (gas is) ammonia / $NH_3$<br>• (cation is) ammonium / $NH_4^+$<br><br>**Test 2**<br>• (cation is) cobalt(II) / $Co^{2+}$ / $[Co(H_2O)_6]^{2+}$<br>• (complex ion is) $[CoCl_4]^{2-}$<br><br>**Test 3**<br>• (precipitate is) barium sulfate / $BaSO_4$<br>• (anion is) sulfate((VI)) / $SO_4^{2-}$ | **(1)**<br>**(1)**<br><br><br>**(1)**<br>**(1)**<br><br><br>**(1)**<br>**(1)** | If name and formula are given, both must be correct<br>Mark independently<br><br>Do not award gas is ammonium / $NH_4$<br>Do not award cation is ammonia / $NH_3^+$<br><br>Oxidation number of cobalt is needed in the name but allow cobalt **with** $Co^{2+}$<br>Charge is needed on the ion<br>Allow +2 and −2 for the charges on the ions<br>Allow brackets around Cl<br>Ignore missing square brackets in complex ions<br>Do not award $[CoCl_6]^{4-}$<br>**Note**<br>If cation in Test 2 is identified as copper(II) / $Cu^{2+}$, do not award M3 but M4 can be awarded as TE for $[CuCl_4]^{2-}$<br><br>Oxidation number of sulfate is not needed but if given must be correct e.g. do not award sulfate(IV) | **(6)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 4(a)(ii) | • correct formula | Examples of correct formula<br>$(NH_4)_2Co(SO_4)_2$<br>$(NH_4)_2SO_4.CoSO_4$<br><br>Allow $NH_4$, Co and $SO_4$ in any order<br><br>Allow multiples<br><br>Allow any combination of $Co^{2+}$ / $NH_4^+$ / $SO_4^{2-}$ that gives a neutral complex<br><br>TE on the **three** ions identified in (a)(i)<br><br>Ignore missing dot in second formula<br><br>Ignore any amount of water of crystallisation | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 4(b) | • correct equation | Example of equation<br>$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$<br><br>Allow multiples<br><br>Allow $Na^+$ on both sides if crossed through<br><br>Ignore state symbols even if incorrect | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 4(c) | • ligand exchange | Allow ligand substitution / ligand replacement<br><br>Ignore change in co-ordination number<br><br>Do not award ligand change<br><br>Do not award any other type of reaction in addition to correct answer e.g. reduction / acid-base / deprotonation | (1) |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 4(d) | An answer that makes reference to the following point:<br><br>• to react with / remove any carbonate / sulfite / sulfate(IV) (ions) | Allow equation for the reaction with acid e.g. $2H^+ + CO_3^{2-} \rightarrow H_2O + CO_2$<br><br>Allow to prevent any other ions forming a precipitate (with barium ions / $Ba^{2+}$)<br><br>Allow to rule out the possibility of carbonate / sulfite / sulfate(IV) ions giving a false result<br><br>Ignore just 'to remove impurities / other (an)ions' / 'react with precipitates'<br><br>Ignore to dissolve barium carbonate / sulfite<br><br>Ignore reference to hydrogencarbonate | (1) |

**(Total for Question 4 = 10 marks)**

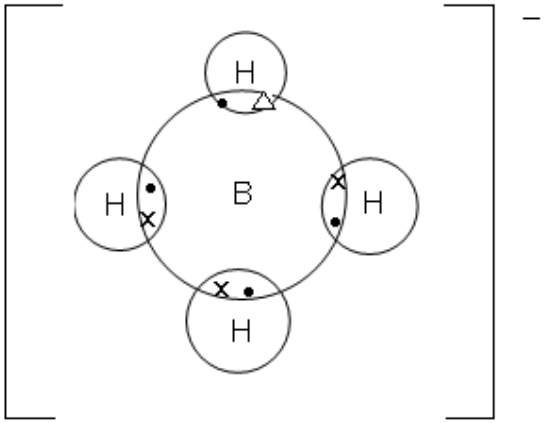
| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **5(a)** | • phosphate(III) (ion) | Name **and** oxidation number are required<br><br>Allow gap between name and oxidation number<br><br>Allow phosphate and +3<br><br>Ignore missing brackets around oxidation number<br><br>Do not award phosphorus / trioxide / phosphite(III) | **(1)** |

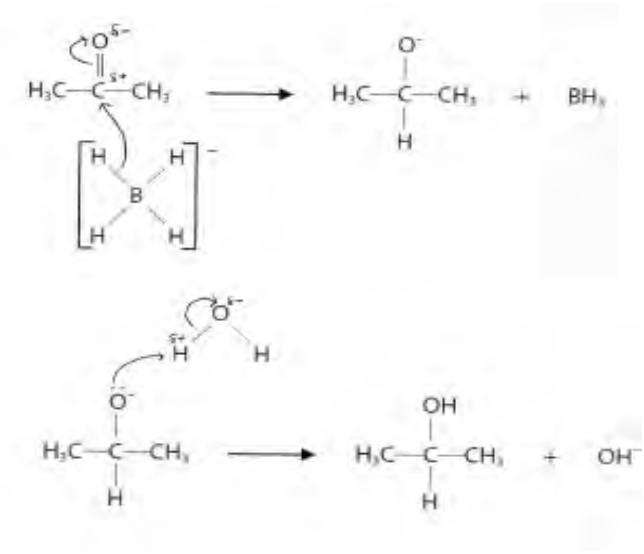
| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **5(b)** | • (a reducing agent) increases in oxidation number<br>**and**<br>loses electron(s) | Allow oxidation number becomes more positive / gets larger<br><br>Allow donates / gives electrons / number of electrons decreases<br><br>Ignore a reducing agent decreases the oxidation number of another substance | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **5(c)** | • Na / sodium | Do not award $Na^+$ | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 5(d)(i) | • $MnO_2$, $MnO_4^-$, $OH^-$ and $MnO_4^{2-}$ species correct in a single equation **(1)**<br><br>• $H_2O$ on right **and** balancing **(1)** | Example of equation<br>$MnO_2 + 2MnO_4^- + 4OH^- \rightarrow 3MnO_4^{2-} + 2H_2O$<br>Ignore state symbols, even if incorrect<br>Do not award M1 if $H^+$ is on the left<br><br>Allow cancelled electrons<br><br>Allow multiples | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 5(d)(ii) | An answer that makes reference to:<br><br>• 2 different species are oxidised and reduced (to form the same species)<br>**or**<br>there is not 1 species that is being oxidised and reduced<br>**or**<br>2 different oxidation states are not produced from one oxidation state<br>**or**<br>only 1 oxidation state / +6 is formed as a product<br>**or**<br>Mn changes from +4 and +7 to +6 (only) | This mark can be awarded even if (i) is incorrect<br><br>Allow manganate(VI) / $MnO_4^{2-}$ is oxidised and reduced in the reverse reaction<br>Allow Mn in the same species is not being oxidised and reduced<br><br>Ignore just 'Mn is not simultaneously oxidised and reduced'<br><br>Ignore this is reverse disproportionation / comproportionation<br><br>Do not award O / H is oxidised / reduced<br>Do not award molecules / compounds for species | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 5(e)(i) | • dot-and-cross diagram | Example of diagram<br>  <br><br>Electrons must have the correct symbols i.e. 3 bonds with • and x and 1 bond with • and Δ<br><br>Circles do not need to be shown<br><br>Allow missing brackets but charge needs to be shown<br><br>Allow charge anywhere on or close to diagram<br><br>Ignore lines representing covalent bonds e.g. x •<br><br>Ignore missing atom labels / inner shell of 2 electrons on B | (1) |

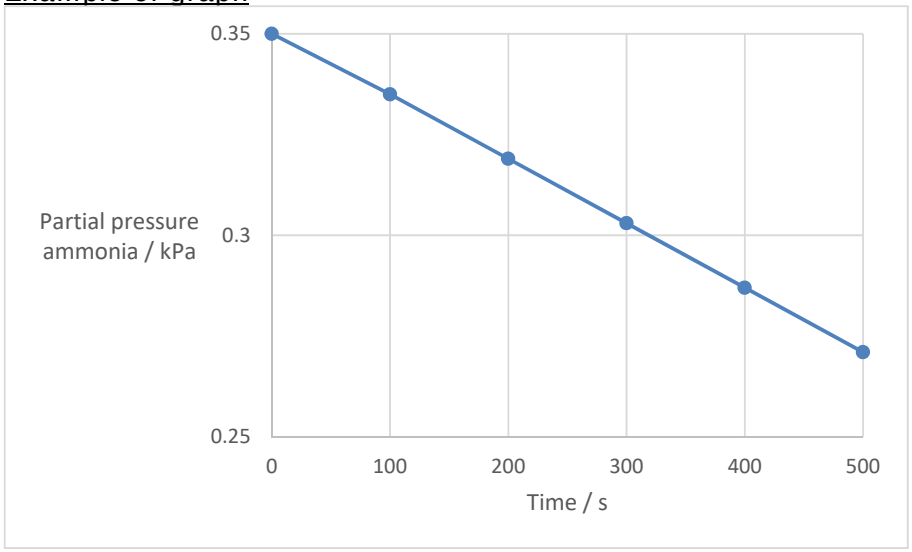
| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **5(e)(ii)** | • curly arrow from B-H bond to C of C=O<br>Allow curly arrow from B-H bond to H **and** curly arrow from H to C **(1)**<br><br>• dipole on C=O<br>**and**<br>curly arrow from C=O bond to or just beyond O **(1)**<br><br>• lone pair on $O^-$<br>**and**<br>curly arrow from lone pair to H of $H_2O$ **(1)**<br><br>• curly arrow from O-H bond to O<br>**and**<br>dipole on H-O bond **(1)** | Example of mechanism<br>  <br>Allow curly arrow from any B-H bond<br><br>Ignore lone pair on O in $H_2O$<br><br>Penalise half-headed curly arrow once only | **(4)** |

**(Total for Question 5 = 11 marks)**

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 6(a)(i) | • six / 6 | | (1) |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 6(a)(ii) | • 1+ / +1 | Allow + / one positive charge<br><br>Ignore positive / plus | (1) |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **6(b)** | Oxidation state:<br>• Two ions of the **same metal** (iron or copper) with different oxidation states and the same ligands with appropriate colours **(1)**<br><br>Ligands:<br>• formula and colour of complex with first ligand **(1)**<br>• formula and colour of complex with second ligand **(1)** | Ignore ions of metals other than iron or copper<br>Ignore use of precipitates instead of complex ions<br>Ignore names of complex ions, even if incorrect<br>Penalise additional incorrect species / colours once only<br><br><u>Examples of ions</u><br>$[Fe(H_2O)_6]^{2+}$ is green **and** $[Fe(H_2O)_6]^{3+}$ is yellow / orange / red/ brown<br>$[CuCl_4]^{2-}$ is yellow **and** $[CuCl_2]^{-}$ is colourless<br><br>$[Cu(H_2O)_6]^{2+}$ is (pale) blue **and** $[CuCl_4]^{2-}$ is yellow<br>$[Cu(H_2O)_6]^{2+}$ is (pale) blue **and** $[Cu(NH_3)_4]^{2+}$ / $[Cu(NH_3)_4(H_2O)_2]^{2+}$ / $[Cu(H_2O)_2(NH_3)_4]^{2+}$ is a **darker** blue than in the aqua ion<br>$[CuCl_4]^{2-}$ is yellow and $[Cu(NH_3)_4]^{2+}$ / $[Cu(NH_3)_4(H_2O)_2]^{2+}$ / $[Cu(H_2O)_2(NH_3)_4]^{2+}$ is (deep / dark) blue<br>Allow any correct example of the **same metal** in the same oxidation state with different ligands and their corresponding colours, including colourless – the metal can be different to that in M1<br><br>**Note**<br>Formulae **and** colours must be correct but ignore missing square brackets<br>e.g. Do not award mention of green for $[CuCl_4]^{2-}$<br>Do not award $[Cu(NH_3)_6]^{2+}$<br>Ignore qualifications of colour e.g. pale / dirty | **(3)** |

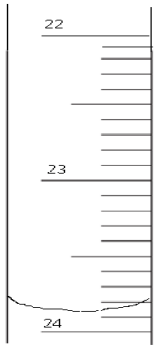
| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 6(c)(i) | • axes with time on x axis **and** labelled, including units **and** suitable scale **(1)**<br><br>• **all** points plotted correctly **and** best fit line **(1)** | Example of graph<br>  <br><br><br>Allow y axis labelled with partial pressure / pressure and unit<br><br>Do not allow partial pressure axis starting at 0<br>Both axes must cover at least half the graph paper<br><br>Allow ± ½ square<br>M2 can be awarded if axes the wrong way around in M1 | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 6(c)(ii) | • rate = $k$ / rate = $k$ x $p(NH_3)^0$ **(1)**<br><br>• (zero / 0 order)<br>because the rate is independent of the partial pressure of ammonia / rate is constant<br>**or**<br>because the graph is a straight line / linear **(1)** | Allow r for rate<br>Allow −rate = $k$ / rate = $k[NH_3]^0$<br>Ignore $[H_2]^0$ or $[N_2]^0$<br><br>Conditional on M1<br>Allow because the gradient is constant | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 6(c)(iii) | • calculation of gradient of graph / rate / rate constant **(1)**<br><br>• corresponding units for rate constant **(1)** | Example of calculation<br>$\frac{(0.271 - 0.350}{500} = (-)\frac{0.079)}{500}$<br>$k$= 1.58 x $10^{-4}$ / 0.000158<br>Allow any value in the range 1.50 to 1.65 x $10^{-4}$<br><br>1.58 x $10^{-4}$ / 0.000158 kPa $s^{-1}$<br>Allow 158 x $10^{-6}$ kPa $s^{-1}$ / 0.158 Pa $s^{-1}$ / 1.58 x $10^{-1}$ Pa $s^{-1}$<br><br>Do not award units of mol $dm^{-3}$ $s^{-1}$<br><br>Ignore SF except 1 SF<br>Ignore negative value for $k$<br><br>Correct answer with corresponding units and no working scores (2) | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 6(c)(iv) | A description that makes reference to the following points:<br><br>• adsorption of ammonia / reactant onto surface of tungsten / catalyst **(1)**<br><br>• breaking bonds in ammonia / reactant<br>**or**<br>breaking N-H bonds **(1)**<br><br>• desorption of nitrogen and hydrogen / products / gases from surface of tungsten / catalyst **(1)** | Ignore reference to heterogeneous / homogeneous / active sites<br><br>Allow gas for ammonia<br>Allow adsorb / adsorp for adsorption<br>Ignore "stick"<br>Do not award absorption<br><br>Allow bonds weaken instead of break<br>Ignore mention of atoms / radicals<br><br>Allow products released / detached from catalyst surface<br>Allow de-adsorbed / desorped for desorption<br><br>Do not award desorption of ammonia | **(3)** |

**(Total for Question 6 = 14 marks)**

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 7(a)(i) | • bottom of meniscus between 23.8 and 23.9 ($cm^3$) **(1)**<br>• meniscus curved downwards **(1)** | Example of diagram<br>  <br><br>Ignore shading below the meniscus<br><br>Do not award M2 if there is shading above the meniscus | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 7(a)(ii) | An explanation that makes reference to the following points:<br><br>• 23.15 ($cm^3$) should be used as it is the mean of the concordant titres / titres 2 and 4 /23.10 and 23.20 ($cm^3$) **(1)**<br><br>• 23.43 ($cm^3$) should not be used as it includes the inaccurate / non-concordant / rough values / titres 1 and 3 / 23.85 and 23.55 ($cm^3$) **(1)** | Allow other descriptions of concordant e.g. titres within 0.1 / 0.2 $cm^3$<br>Allow (23.1(0) + 23.2(0))/2 = 23.15 ($cm^3$)<br>Allow only the concordant titres / titres 2 and 4 / 23.20 and 23.20 ($cm^3$) should be used / are used(in the mean)<br><br>Allow the inaccurate / non-concordant / rough values / titres 1 and 3 / 23.85 and 23.55 ($cm^3$) should not be used / are used (in the mean) | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 7(a)(iii) | • calculation of percentage uncertainty | Example of calculation<br>$\frac{2 \times 0.05}{23.20} \times 100$<br><br>= (±)0.431 / 0.43 / 0.4 (%)<br><br>Ignore SF including 1 SF<br><br>Correct answer with no working scores (1) | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 7(a)(iv) | • calculation of moles of $MnO_4^-$ **(1)**<br><br>• calculation of moles $C_2O_4^{2-}$ in 25.0 $cm^3$ **(1)**<br><br>• calculation of moles $C_2O_4^{2-}$ in 1.00 $dm^3$ **(1)**<br><br>• calculation of **y** to nearest whole number **(1)** | Example of calculation<br>moles $MnO_4^-$ = 23.15 x 0.0203/1000<br>= 0.00046995 / 4.6995 x $10^{-4}$ (mol)<br><br>moles $C_2O_4^{2-}$ in 25.0 $cm^3$ = 4.6995 x $10^{-4}$ x 5/2<br>= 0.0011749 / 1.1749 x $10^{-3}$ (mol)<br>TE on moles $MnO_4^-$<br><br>moles $C_2O_4^{2-}$ in 1.00 $dm^3$ = 1.1749 x $10^{-3}$ x $\frac{1000}{25.0}$<br>= 0.046995 / 4.6995 x $10^{-2}$ (mol)<br>TE on moles $C_2O_4^{2-}$ in 25.0 $cm^3$<br><br>Ratio moles salt : moles $C_2O_4^{2-}$<br>= 0.0235 : 0.046995 = 1 : 1.9998<br>**y** = 2<br>TE on moles $C_2O_4^{2-}$ in 1.00 $dm^3$<br><br>Alternative method for M3 and M4<br>moles salt in 25.0 $cm^3$ = 0.0235 x 25.0/1000<br>= 5.875 x $10^{-4}$ (1)<br>Ratio moles salt : moles $C_2O_4^{2-}$<br>= 5.875 x $10^{-4}$ : 1.1749 x $10^{-3}$<br>= 1 : 1.9998<br>**y** = 2<br>TE on moles salt and $C_2O_4^{2-}$ in 25.0 $cm^3$ (1)<br><br>Ignore SF in working except 1 SF<br>Correct answer with no working scores (1)<br>Allow M4 for correct answer using charges on ions | **(4)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 7(b)(i) | • calculation of mol of anhydrous salt **(1)**<br><br>• calculation of mol $H_2O$ **(1)**<br><br>• calculation of ***z*** to nearest whole number **(1)** | <u>Example of calculation</u><br>mol anhydrous salt = 2.96/218.1<br>= 0.013572 / 1.3572 x $10^{-2}$ (mol)<br><br>TE on $M_r$ of anhydrous salt from value of **y** in (a)(iv) or an assumed value of ***y***<br>Allow 0.013578 from $M_r$ 218<br><br>mol $H_2O$ (= 0.45/18) = 0.025 / 2.5 x $10^{-2}$ (mol)<br><br>Ratio mol salt : mol $H_2O$<br>= 0.013572 : 0.025<br>= 1 : 1.842<br>**z** = 2<br><br>TE on moles anhydrous salt and moles $H_2O$<br><br>Ignore SF in working except 1 SF<br><br>Correct answer with some working scores (3)<br><br>Penalise **y** and **z** not given to nearest whole number once only in (a)(iv) and (b)(i)<br><br>Allow alternative correct methods | **(3)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 7(b)(ii) | An answer which includes the following points:<br><br>Crystals jumped out of crucible<br>• value of ***z*** increases<br>**and**<br>because it appears that more mass / mol / water is lost (than expected) **(1)**<br><br>• (this can be prevented by) placing a lid on the crucible<br>**or**<br>heat more gently / carefully **(1)**<br><br>Not all water of crystallisation lost<br>• less mass / mol /water is lost (than expected) **(1)**<br><br>• (this can be prevented by) heating to constant mass<br>**or**<br>description of heating to constant mass **(1)**<br><br>• so this accounts for the lower value of ***z*** / value of ***z*** decreases **(1)** | Ignore just 'loss in mass / mol'<br><br>Stand alone mark<br>Allow just 'cover the crucible'<br>Ignore use an electrical heater / larger crucible / evaporating basin / conical flask / test tube etc<br>Do not award add anti-bumping granules<br><br>Stand alone mark<br>Ignore just 'heat for longer'<br>Do not award the idea of repeating the experiment / using a drying agent<br><br>Conditional on M3 | **(5)** |

**(Total for Question 7 = 17 marks)**

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **8(a)(i)** | An answer that makes reference to the following points:<br><br>• cool the mixture because the reaction (with concentrated sulfuric acid / $H_2SO_4$) is (very) exothermic / releases (a lot of) heat **(1)**<br><br>• anti-bumping granules are added to prevent violent / sudden / localised boiling<br>**or**<br>to prevent superheating / large bubbles forming<br>**or**<br>to promote smooth / even / controlled boiling<br>**or**<br>to promote the formation of small bubbles<br>**or**<br>to provide nucleation centres / (rough) surface for bubble formation **(1)**<br><br>• heating under reflux is used to prevent the loss of any volatile substances / volatile reactants / volatile products / organic compound / named organic compound<br>**or**<br>to make sure the vapour / gas condenses<br>**or**<br>to prevent vapour escaping **(1)** | Ignore reaction is violent / to prevent splashing / to slow down the reaction / to stop reactants evaporating<br><br>Do not award to quench the reaction / reference to explosion<br><br>Ignore to stop bumping / spitting / explosion / liquid splashing out / vigorous reaction / loss of reactants / to distribute heat more evenly / any reference to rate / to promote smooth heating<br><br>Allow so that the reaction goes to completion<br>Ignore just 'to prevent gas escaping' / just 'to prevent loss of reactants / products' / just 'reactants / products are volatile' / 'because 1-bromobutane / butan-1-ol is flammable' / to increase yield / reference to safety<br><br>Do not award for reference to oxidation or reduction | **(3)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **8(a)(ii)** | An answer that makes reference to the following points:<br><br>• there is a gap between the condenser and the flask / seal the joint between the flask and condenser<br><br>**and**<br>so vapour / gas / reactants / products will escape **(1)**<br><br>• the water is flowing the wrong way through the condenser / the water should go in at the bottom (and out at the top)<br>**and**<br>so it doesn't fill with water / is only part filled /there is an airlock **(1)**<br><br>• there is a stopper on the condenser / there should not be a stopper on the condenser<br>**and**<br>so there will be a build-up of pressure (if the gap between condenser and flask is closed) **(1)** | Allow answers shown on annotated diagram e.g. gap circled<br>Ignore any additional errors<br>Ignore additional suggested modifications even if incorrect<br><br>Do not award just 'the apparatus is not sealed' unless it is clear it means between the condenser and flask<br><br>Allow so this will lower the yield of product / 1-bromobutane<br><br>Ignore condenser is fitted the wrong way up<br><br>Allow so there will be inefficient condensation / cooling<br><br>Allow so the stopper will blow off / there will be an explosion / it will be dangerous | **(3)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **8(a)(iii)** | An explanation that makes reference to the following points:<br><br>• (brown vapour / it) is bromine / $Br_2$ **(1)**<br><br>• bromide ions / $Br^-$ / HBr oxidised (by concentrated sulfuric acid) **(1)** | <br><br>Stand alone mark<br>Do not award just 'Br'<br>Do not award any other brown gas in addition to bromine<br><br>Allow bromide ions / $Br^-$ / HBr reduce sulfuric acid / act as a reducing agent<br>Ignore sodium bromide / NaBr is oxidised<br>Ignore just 'redox reaction'<br>Do not award bromine is oxidised<br>Do not award oxidation by anything other than sulfuric acid | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **8(b)(i)** | An answer that makes reference to the following:<br><br>• aqueous layer is on the top<br>**and**<br>because water / it has a lower density than 1-bromobutane | <br>Allow 'it' for aqueous layer<br>Allow because 1-bromobutane has a higher density than water<br><br>Ignore reference to butanol unless in a third layer<br><br>Do not award water is 'lighter'<br>Do not award reference to three layers | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **8(b)(ii)** | An answer that makes reference to the following points:<br><br>Step **8**<br>• (aqueous sodium hydrogencarbonate / $NaHCO_3$) reacts with / neutralises / removes the (hydrochloric) acid / $H^+$ (ions) in the mixture **(1)**<br><br>Step **9**<br>• (the tap is opened) to release the carbon dioxide / gas (formed)<br>**or**<br>to allow the carbon dioxide / gas to escape<br>**or**<br>to prevent the build-up of pressure **(1)**<br><br>Step **10**<br>• (anhydrous sodium sulfate is added) to remove / absorb water **(1)** | Do not award reacts with incorrect acid e.g. $H_2SO_4$ / HBr / ethanoic acid<br>Ignore removes water<br><br>Do not award an incorrect gas e.g. hydrogen<br><br>Allow (anhydrous) sodium sulfate is a drying agent / added to dry the product<br><br>Do not award dehydration / reacts with water | **(3)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **8(b)(iii)** | • starting temperature 99 or 100 or 101 (°C)<br>**and**<br>final temperature 103 or 104 or 105 (°C) | Do not award just one value / 102 (°C)<br><br>Do not award 102 (°C) with another temperature | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 8(b)(iv) | • calculation of mol of 1-bromobutane **(1)**<br><br>• calculation of number of molecules **and** answer to 2/3 SF **(1)** | Example of calculation<br><br>mol of 1-bromobutane = $\frac{12.0 \times 1.27}{136.9}$<br><br>= 0.11132 (mol)<br>Do not award 0.1<br><br>number of molecules = $0.11132 \times 6.02 \times 10^{23}$<br><br>= $6.7 \times 10^{22}$ / $6.70 \times 10^{22}$<br><br>TE on a calculated mol 1-bromobutane using $M_r$<br><br>Correct answer to 2 or 3 SF with no working scores (2) | **(2)** |

**(Total for Question 8 = 15 marks)**

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **9(a)(i)** | An explanation that makes reference to the following points:<br><br>• glycinate ions / they do not contain a carbon atom with four different atoms / groups attached<br>**or**<br>the glycinate ion is superimposable on its mirror image **(1)**<br><br>• so there will be no effect (on plane-polarised monochromatic light) **(1)** | An answer that states there will be an effect scores (0)<br><br>Allow not chiral / achiral /<br>has no enantiomers /<br>has no asymmetric carbon atom<br>Allow the carbon atom attached to $NH_2$ is only attached to 3 different atoms / groups / is not attached to 4 different atoms / groups<br><br>Ignore glycinate ions are not optically active / do not exhibit optical isomerism<br><br>Do not award it is a racemic mixture / there are equal amounts of the two isomers / four different molecules attached<br><br>M2 is conditional on M1<br>Do not award the (monochromatic) light will not be polarised | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 9(a)(ii) | • correct formula of one of the copper species **(1)**<br>• rest of equation correct **(1)** | Example of equation<br>$(CH_3COO)_2Cu + 2\ NH_2CH_2COOH \rightarrow (NH_2CH_2COO)_2Cu + 2CH_3COOH$<br>Allow $Cu(CH_3COO)_2$ / $Cu(NH_2CH_2COO)_2$<br>Allow both charges shown e.g. $(CH_3COO^-)_2Cu^{2+}$<br>Allow displayed / skeletal formulae for organic substances but not molecular formulae<br>Ignore state symbols, even if incorrect<br>Do not award M1 if covalent bond between Cu and O in any species but M2 can still score | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **9(a)(iii)** | An answer that makes reference to any **four** of the following points:<br><br>Student **1** / higher yield<br>• the crystals were not dry / still damp when they were weighed **(1)**<br><br>• there are impurities in the crystals **(1)**<br><br>Student **2** / lower yield<br>• reaction was incomplete **(1)**<br><br>• not all of the copper(II) glycinate had crystallised / some is left in solution **(1)**<br><br>• description of a specific handling loss **(1)** | Ignore reference to weighing errors for both students<br><br>Allow the student did not subtract the mass of filter paper / product container<br>Do not award the crystals contain water of crystallisation / are (partially) hydrated<br><br>Allow a specific impurity e.g. glycine<br><br>Allow the reaction reached equilibrium / side reactions occur / by-products form<br><br>Ignore just 'the solution has not cooled enough'<br><br>Allow any specific example e.g. some crystals left on the walls of the container / beaker / flask / lost during filtration / lost during transfer<br>Ignore just 'transfer error' / lost when handling | **(4)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **9(b)** | An explanation that makes reference to any **TWO** of the following points:<br><br>• carbon monoxide replaces / takes the place of the oxygen molecule **(1)**<br><br>• (and may be toxic because) it binds strongly to the $Fe^{2+}$ (ion) **(1)**<br><br>• effect on the body **(1)** | Allow carbon monoxide displaces the oxygen molecule<br>Allow ligand substitution / exchange reaction between oxygen and carbon monoxide<br><br>Allow carbon monoxide forms a stronger bond / binds more tightly to / has a stronger affinity for $Fe^{2+}$<br><br>Allow reduces the amount of oxygen that can bind to $Fe^{2+}$<br><br>Allow carbon monoxide binds (almost) irreversibly / permanently to $Fe^{2+}$<br><br>Allow CO forms a more stable complex ion with $Fe^{2+}$ / has a larger equilibrium constant / K<br><br>Ignore CO bonds more easily to $Fe^{2+}$<br>Ignore just 'CO bonds more strongly to haemoglobin'<br><br>Allow prevents oxygen being carried to the cells / organs / around the body / blood<br><br>Allow reduces the amount of oxygen that can be carried to the cells / organs / around the body / blood | **(2)** |

<table>
<tr><th>Question Number</th><th>Acceptable Answers</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>9(c)*</td>
<td>This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.<br>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.<br>The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5–4</td><td>3</td></tr>
<tr><td>3–2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
The following table shows how the marks should be awarded for structure and lines of reasoning.</td>
<td>Guidance on how the mark scheme should be applied:<br>The mark for indicative content should be added to the mark for lines of reasoning.<br>For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).<br>If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).</td>
<td>(6)</td>
</tr>
</table>

| | | | | |
|---|---|---|---|---|
| | | Number of marks awarded for structure of answer and sustained line of reasoning | In general it would be expected that 5 or 6 indicative points would get 2 reasoning marks, and 3 or 4 indicative points would get 1 mark for reasoning, and 0, 1 or 2 indicative points would score zero marks for reasoning. | |
| | | Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout. — 2 | | |
| | | Answer is partially structured with some linkages and lines of reasoning. — 1 | | |
| | | Answer has no linkages between points and is unstructured. — 0 | | |

| | | | |
|---|---|---|---|
| | **Indicative content**<br><br>• **IP1 - Reagents and conditions**<br>magnesium **and** dry ether / dry ethoxyethane / dry $(CH_3CH_2)_2O$<br><br>• **IP2 - Hydrolysis of product**<br>add dilute (hydrochloric) acid / $H^+(aq)$ /HCl(aq) (to hydrolyse the intermediate / protonate …O–)<br><br>• **IP3 – Primary alcohol**<br>react with methanal to form butan-1-ol / $CH_3CH_2CH_2CH_2OH$<br><br>• **IP4 – Secondary alcohol**<br>react with ethanal to form pentan-2-ol / $CH_3CH_2CH_2CH(OH)CH_3$<br><br>• **IP5 – Tertiary alcohol**<br>react with propanone to form 2-methylpentan-2-ol / $CH_3CH_2CH_2C(CH_3)(OH)CH_3$<br><br>• **IP6 – Carboxylic acid**<br>react with carbon dioxide to form butanoic acid / $CH_3CH_2CH_2COOH$ | This may be shown as part of any specific reaction.<br>Ignore errors in an equation to make the Grignard.<br><br>This only needs to be mentioned once<br>Do not award this point if acid is clearly added at the same time as magnesium / dry ether / a reactant<br><br>Allow other specific aldehydes with corresponding product<br><br>Allow other specific ketones with corresponding product | |

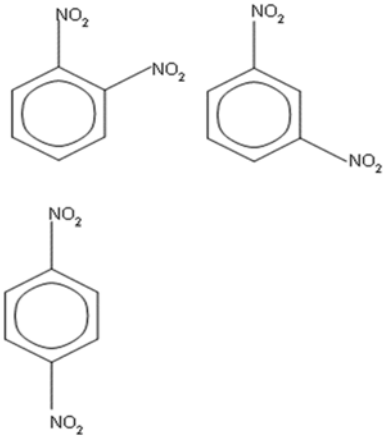
**(Total for Question 9 = 16 mark)**

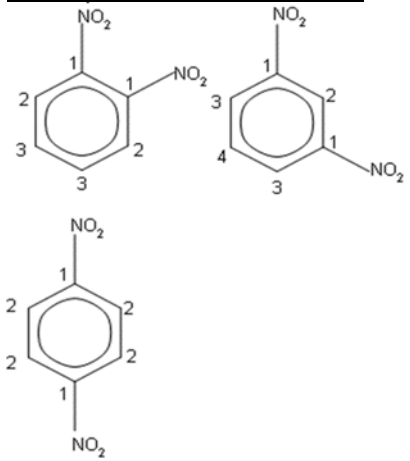
| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **10(a)(i)** | An explanation that makes reference to the following points:<br><br>• (the increase in mass of) **X** will increase<br>**and**<br>(the increase in mass of) **Y** will stay the same **(1)**<br><br>• because **X** will also absorb the water / moisture in the oxygen **(1)**<br><br>• (**Y** stays the same) because the water / moisture has already been absorbed by **X** **(1)** | Allow greater change in mass for **X** if it is clear that it is an increase<br><br>Allow **X** reacts with the water in oxygen<br><br>Do not award **X** absorbs oxygen<br><br>Allow because **Y** only absorbs carbon dioxide / $CO_2$<br><br>Allow because **Y** does not absorb water<br><br>Allow because the amount of carbon dioxide / $CO_2$ does not change | **(3)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 10(a)(ii) | • calculation of mol C/ $CO_2$ **(1)** | Example of calculation<br>mol $CO_2$ = 5.28/44 = 0.12 = mol C<br>**or**<br>mass C = 5.28 x 12/44 = 1.44 (g)<br>mol C = 1.44/12 = 0.12 | **(5)** |
| | • calculation of mol H **(1)** | mol $H_2O$ = 0.72/18 = 0.04<br>mol H = 2 x mol $H_2O$ = 0.08<br>**or**<br>mass H = 0.72 x 2/18 = 0.08<br>mol H = 0.08 x 1 = 0.08 | |
| | • calculation of mol N **(1)** | mol $N_2$ = 0.56/28 = 0.02<br>mol N = 2 x mol $N_2$ = 0.04<br>**or**<br>mass N = 0.56<br>mol N = 0.56/14 = 0.04 | |
| | • calculation of mol O **(1)** | mass O = 3.36 – (12 x 0.12 + 1 x 0.08 + 14 x 0.04) = 1.28 (g)<br>mol O = 1.28/16 = 0.08<br>TE on masses of C, H and N | |
| | • empirical formula **(1)** | (0.12 C : 0.08 H : 0.04 N : 0.08 O)<br>$C_3H_2NO_2$<br>Allow symbols in any order<br>TE on incorrect moles but the ratio must be a whole number and include C, H, N and O if no O, only M1, M2 and M3 can be awarded<br>Ignore use of $O_2$ / O / $N_2$ / N in the 'words'<br>Correct empirical formula with some working at each stage scores (5) but correct empirical formula with no working scores M5 only | |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 10(b) | • molecular ion is at *m*/z = 168<br>**or**<br>168 is equal to the $M_r$ of **D** / twice the empirical formula / 2 x 84 / 168÷2 = 84 / $M_r$ of empirical formula is 84 **(1)**<br><br>• (so the molecular formula is) $C_6H_4N_2O_4$ **(1)** | Allow 168 shown on spectrum along with the rest of the explanation<br>Do not award M1 for any other value<br><br>Stand alone mark<br>Ignore structural / displayed / skeletal formula<br><br>Do not award $C_6H_4N_2O_4^+$ | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| 10(c)(i) | • $C_6H_4^+$ | Allow $H_4C_6^+$<br><br>Do not award just $C_6H_4$ | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **10(c)(ii)** | • 3 correct formulae **(2)** | Examples of formulae<br>  <br><br>Allow (1) for any 2 correct formulae<br><br>Allow (2) for three disubstituted benzenes with incorrect substituents / (1) for any two disubstituted benzenes with incorrect substituents<br><br>Allow incorrectly displayed formulae of $NO_2$ groups<br><br>**In (c)(ii) and (iii):**<br>Allow Kekule structures<br>Allow hydrogen atoms shown on benzene<br>Ignore connectivity of $NO_2$ groups<br>Penalise missing circle in benzene once only | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **10(c)(iii)** | • **D** identified as 1,3-dinitrobenzene **and** 4 different carbon environments labelled **(1)**<br><br>• 3 different carbon environments labelled on 1,2-dinitrobenzene **(1)**<br><br>• 2 different carbon environments labelled on 1,4-dinitrobenzene **(1)** | <u>Examples of identification</u><br>  <br><br>These labels may be shown on the structures in (c)(ii)<br><br>The identification of **D** can be assumed if it is the only structure with 4 carbon environments labelled<br><br>Allow any form of identification of the carbon environments e.g. numbers, letters, equivalent carbon environments circled<br><br>TE on disubstituted benzene substituents in (ii)<br><br>Penalise only half the carbon environments labelled once only | **(3)** |

**(Total for Question 10 = 16 marks)**

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