Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2020

Marking Scheme

Chemistry

Higher Level

Note to teachers and students on the use of published marking schemes

Marking schemes published by the State Examinations Commission are not intended to be standalone documents. They are an essential resource for examiners who receive training in the correct interpretation and application of the scheme. This training involves, among other things, marking samples of student work and discussing the marks awarded, so as to clarify the correct application of the scheme. The work of examiners is subsequently monitored by Advising Examiners to ensure consistent and accurate application of the marking scheme. This process is overseen by the Chief Examiner, usually assisted by a Chief Advising Examiner. The Chief Examiner is the final authority regarding whether or not the marking scheme has been correctly applied to any piece of candidate work.

Marking schemes are working documents. While a draft marking scheme is prepared in advance of the examination, the scheme is not finalised until examiners have applied it to candidates' work and the feedback from all examiners has been collated and considered in light of the full range of responses of candidates, the overall level of difficulty of the examination and the need to maintain consistency in standards from year to year. This published document contains the finalised scheme, as it was applied to all candidates' work.

In the case of marking schemes that include model solutions or answers, it should be noted that these are not intended to be exhaustive. Variations and alternatives may also be acceptable. Examiners must consider all answers on their merits, and will have consulted with their Advising Examiners when in doubt.

Future Marking Schemes

Assumptions about future marking schemes on the basis of past schemes should be avoided. While the underlying assessment principles remain the same, the details of the marking of a particular type of question may change in the context of the contribution of that question to the overall examination in a given year. The Chief Examiner in any given year has the responsibility to determine how best to ensure the fair and accurate assessment of candidates' work and to ensure consistency in the standard of the assessment from year to year. Accordingly, aspects of the structure, detail and application of the marking scheme for a particular examination are subject to change from one year to the next without notice.

Coimisiún na Scrúduithe Stáit

State Examinations Commission

LEAVING CERTIFICATE EXAMINATION, 2020

CHEMISTRY – HIGHER LEVEL

Introduction

In considering the marking scheme, the following should be noted.

1. In many cases only key phrases are given which contain the information and ideas that must appear in the candidate's answer in order to merit the assigned marks.

2. The descriptions, methods and definitions in the scheme are not exhaustive and alternative valid answers are acceptable.

3. The detail required in any answer is determined by the context and the manner in which the question is asked, and by the number of marks assigned to the answer in the examination paper and, in any instance, therefore, may vary from year to year.

4. The bold text indicates the essential points required in the candidate's answer. A double solidus (//) separates points for which separate marks are allocated in a part of the question. Words, expressions or statements separated by a solidus (/) are alternatives which are equally acceptable for a particular point. A word or phrase in bold, given in brackets, is an acceptable alternative to the preceding word or phrase. Note, however, that words, expressions or phrases must be correctly used in context and not contradicted, and, where there is incorrect use of terminology or contradiction, the marks may not be awarded. Cancellation may apply when a candidate gives a list of correct and incorrect answers.

5. In general, names and formulas of elements and compounds are equally acceptable except in cases where either the name or the formula is specifically asked for in the question. However, in some cases where the name is asked for, the formula may be accepted as an alternative.

6. There is a deduction of one mark for each arithmetical slip made by a candidate in a calculation. This deduction applies to incorrect M_r values but only if a candidate shows the addition of all the correct atomic masses and the error is clearly an addition error. If the addition of atomic masses is not shown, the candidate loses the marks for an incorrect M_r.

7. Bonus marks at the rate of 10% of the marks obtained will be given to a candidate who answers entirely through Irish and who obtains less than 75% of the total marks. In calculating the bonus to be applied decimals are always rounded down, not up e.g., 4.5 becomes 4; 4.9 becomes 4, etc. The bonus table given on the next page applies to candidates who answer entirely through Irish and who obtain more than 75% of the total marks.

Candidates are required to answer eight questions in all.

These must include at least two questions from Section A.

All questions carry equal marks (50).

Marcanna Breise as ucht freagairt trí Ghaeilge

Léiríonn an tábla thíos an méid marcanna breise ba chóir a bhronnadh ar iarrthóirí a ghnóthaíonn níos mó ná 75% d'iomlán na marcanna.

N.B. Ba chóir marcanna de réir an ghnáthráta a bhronnadh ar iarrthóirí nach ngnóthaíonn níos mó ná 75% d'iomlán na marcanna don scrúdú. Ba chóir freisin an marc bónais sin **a shlánú síos**.

Tábla 400 @ 10%

Bain úsáid as an tábla seo i gcás na n-ábhar a bhfuil 400 marc san iomlán ag gabháil leo agus inarb é 10% gnáthráta an bhónais.

Bain úsáid as an ngnáthráta i gcás 300 marc agus faoina bhun sin. Os cionn an mharc sin, féach an tábla thíos.

Bunmharc	Marc Bónais
301 - 303	29
304 - 306	28
307 - 310	27
311 - 313	26
314 - 316	25
317 - 320	24
321 - 323	23
324 - 326	22
327 - 330	21
331 - 333	20
334 - 336	19
337 - 340	18
341 - 343	17
344 - 346	16
347 - 350	15

Bunmharc	Marc Bónais
351 - 353	14
354 - 356	13
357 - 360	12
361 - 363	11
364 - 366	10
367 - 370	9
371 - 373	8
374 - 376	7
377 - 380	6
381 - 383	5
384 - 386	4
387 - 390	3
391 - 393	2
394 - 396	1
397 - 400	0

Annotations used in marking Chemistry 2020

For a fully correct response examiners may award one total mark, e.g. six marks or a number of partial marks, e.g. 2 marks, 3 marks, 1 mark that add one to the same total.

For partially correct responses examiners should place the apropriate marks near the correct part of the response and/or use 0 marks to indicate the part of the answer that is incorrect or insufficient.

Examiners should annotate fully incorrect responses or responses of no merit with a 0 mark.

Colours of annotations may vary.

Annotation	**Meaning**
✔ n	n marks awarded
-1	Mathematical slip error or other penalty as per scheme
0	No marks awarded. Answer incorrect or insufficient
R	Reverse order
[	Surplus answer or part of answer
	Blank page or part of page
C	Cancellation / contradiction
	Part of answer of significance
	Incorrect charge, subscript, etc
λ	Key word, phrase omitted
✔	Correct – for use where item attempted more than once
✖	Incorrect – for use where item attempted more than once
Pn	Discount n marks Adjustment for marks for an excess question that were not automatically discounted by marking software

QUESTION 1

a	b	c	d
5	**12**	**12**	**21**

(*a*) IDENTIFY: **anhydrous sodium carbonate / Na_2CO_3** (5)
[Anhydrous omitted (3).]

(*b*) DESCRIBE: washing soda **transferred to a beaker** and **dissolved in (added to)** deionised **water /** washing soda **rinsed into beaker with** deionised **water //**

use **funnel //**

transfer solution (contents of beaker) **to** correctly prepared **volumetric flask //**

rinse beaker and glass rod **into** volumetric **flask //**

make up (top up, fill, add deionised **water)** to 250 cm^3 with **bottom of meniscus on mark //**

stopper and invert several times

(4 × 3)

(*c*) NAME: (*i*) **methyl orange / methyl red** (3)

JUSTIFY: (*ii*) **strong acid weak base** titration **/**
end point (indicator **range**) **below pH** of **7 (at pH < 7, between pH 3 and** pH **5) /**
diagram showing (description of) end point occurring within sharp rise in pH (steep vertical part of pH curve, in acidic range) /
indicator (methyl orange) **changes colour coinciding with (at) end point (below pH** of **7, at pH < 7, between pH 3 and** pH **5)** (3)

WHAT: (*iii*) from **orange (yellow) //**
to **red (pink, peach)** (2 × 3)
[Allow (3) for colours in reverse]

(*d*) FIND: (*i*) 0.**00258** (**2.58 × 10^{-3}, 129/50000**) moles HCl (3)

$\frac{21.5 \times 0.12}{1000}$ = 0.**00258** (**2.58 × 10^{-3}, 129/50000**) moles HCl (3)

(*ii*) 0.**00129** (**1.29 × 10^{-3}, 129/100000**) moles of Na_2CO_3 in 25.0 cm^3 (3)

Na_2CO_3 : HCl = 1 : 2 ⇒ 0.00258 (2.58 × 10^{-3}, 129/50000) ÷ 2 = 0.**00129** (**1.29 × 10^{-3}, 129/100000**) moles of Na_2CO_3 in 25.0 cm^3 (3) [Divide by 2 essential.]

or

$\frac{25.0 \times M}{1} = \frac{21.5 \times 0.12}{2}$ ⇒ M = 0.0516 (5.16 × 10^{-2}, 129/2500) moles /l (M) of Na_2CO_3 0.0516 (5.16 × 10^{-2}, 129/2500) ÷ 40 / [0.0516 (5.16 × 10^{-2}, 129/2500)] × (25 ÷ 1000) = 0.**00129** (**1.29 × 10^{-3}, 129/100000**) moles of Na_2CO_3 in 25.0 cm^3 (3) [Divide by 40 or multiply by (25 ÷ 1000) essential.]

(*iii*) 0.**0129** (**1.29 × 10^{-2}, 129/10000**) moles of Na_2CO_3 in 250 cm^3 (3)

0.00129 (1.29 × 10^{-3}, 129/100000) × 10 = 0.**0129 (1.29 × 10^{-2}, 129/10000)** moles Na_2CO_3 in 250 cm^3 (3) [Multiply answer in (*ii*) by 10 essential.]

or

0.0516 ÷ 4 / 0.0516 × (250 ÷ 1000) = 0.**0129 (1.29 × 10^{-2}, 129/10000)** moles Na_2CO_3 in 250 cm^3 (3) [Only from molarity Na_2CO_3 obtained in (*ii*).]

(*iv*) **1.36**74 g Na_2CO_3 in 250 cm^3 (3)

0.0129 (1.29 × 10^{-2}, 129/10000) × 106* = **1.36**74 g Na_2CO_3 in 250 cm^3 (3) [Multiply answer in (*iii*) by 106 essential.]

[**Addition must be shown for error to be treated as slip.*]

(*v*) **2.09**26 g water and 0.**116**256 moles water (6)

3.46 – 1.3674 = **2.09**26 g water (3) 2.0926 ÷ 18** = 0.**116**256 moles water (3) [Divide by 18 essential.]

[***Addition must be shown for error to be treated as slip.*]

(*vi*) **9** (3)

$\frac{0.116256}{0.0129}$ = **9** = *x* (3)

[Allow ratio 9:1 for 3 marks]
[*1 mark to be deducted for incorrect or inappropriate* ***rounding****; deduction to be made once only in (d).*]

[*1 mark to be deducted for* ***each*** *of any other mathematical slips, e.g. transposing numbers, addition error in M_r where atomic masses* ***shown*** *but added incorrectly, final answer not a whole number, etc.*

QUESTION 2

a	b	c	d	e
5	**6**	**12**	**12**	**15**

(*a*) (*i*) DESCRIBE: **colourless / pale yellow / clear / oily / liquid**

(*ii*) NAME: graduated **syringe / graduated dropper / graduated (micro) pipette / burette**
[Allow **small graduated cylinder**]

(3 + 2)

(*b*) HOW: **purple (violet)** to **//**
brown (muddy, black, dark-coloured**)** mixture (2 × 3)
[correct order essential]
[allow colourless (pale yellow) to purple (violet) to brown (muddy, black, dark-coloured) to colourless or white]

(*c*) DESCRIBE: **brown (black, dark colour, MnO_2)** solid **disappears (fades, dissolves) //**
benzoic acid **white crystals form (become visible) / white solid appears /**
white substance **precipitates** (2 × 3)

EXPLAIN: **MnO_2 {Mn(IV)} reduced (reacts) / soluble (colourless) Mn^{2+} {Mn(II)} formed //**
crystallisation (precipitation) of **benzoic acid** (2 × 3)
[Each EXPLAIN statement must linked to corresponding DESCRIBE statement but marks can be given for EXPLAIN even if DESCRIBE marks not awarded.]

(*d*) (*i*) NAME: **recrystallisation** (3)

(*ii*) DESCRIBE: **sample (crystals) in** melting point (m.p.) capillary **tube in (on) melting** point **block (apparatus)** shown in diagram **/**
sample (crystals) on aluminium (melting) block shown in diagram **//**

heat slowly while observing crystals **/ heat source shown or mentioned //**

record (note) temperature range at which (when) **melting occurs /**
record (note) the melting point **temperature (point)** range **/**
thermometer shown or mentioned (3 × 3)

[Reference to '*boiling* point' unacceptable but penalise (–3) once only.]
Diagram not essential.

(*e*) (*i*) SHOW: (12)

$1.5 \times 1.04 =$ **1.56** g phenylmethanol	(3)
$\frac{1.56}{108^{*}}$ = 0**.014**4 moles phenylmethanol	(3)
$\frac{3.16}{158^{**}}$ = 0**.02** moles $KMnO_4$	(3)

and

$\frac{0.0144 \times 4}{3}$ = 0**.0186** to 0**.019**3 moles $KMnO_4$ react with 0.0144 moles phenylmethanol

⇒ 0.0144 moles **phenylmethanol limiting** or ⇒ 0.02 moles **$KMnO_4$ sufficient (excess)** (3)

or

$\frac{0.02 \times 3}{4}$ = 0**.015** moles phenylmethanol required to react with 0.02 moles $KMnO_4$

⇒ 0.0144 moles **phenylmethanol limiting** or ⇒ 0.02 moles **$KMnO_4$ sufficient (excess)** (3)

or

$\frac{0.0144}{3} < \frac{0.02}{4}$ **/** 0**.0048** moles phenylmethanol **<** 0**.005** moles $KMnO_4$

⇒ 0.0144 moles **phenylmethanol limiting** or ⇒ 0.02 moles **$KMnO_4$ sufficient (excess)** (3)

or

required ratio phenylmethanol: $KMnO_4$ is **3 : 4 / 1 : 1.33** and
actual ratio phenylmethanol: $KMnO_4$ is **3 : 4.155 / 1 : 1.385**
⇒ 0.0144 moles **phenylmethanol limiting** or ⇒ 0.02 moles **$KMnO_4$ sufficient (excess)** (3)

(*ii*) FIND: **1.7** – **1.8** g (3)

⇒ 0.0144 moles phenylmethanol ⇒ 0.0144 moles benzoic acid

0.0144 × 122*** **= 1.7**568 g benzoic acid [**1.7** – **1.8** g] (3)

[**Addition must be shown for error to be treated as slip.*]
[***Addition must be shown for error to be treated as slip.*]
[****Addition must be shown for error to be treated as slip.*]
[*1 mark to be deducted for incorrect rounding off resulting in candidate's final numerical answer lying outside given values or given range but deduction to be made once only in (e).*]

QUESTION 3

a	b	c	d	e
9	**9**	**6**	**21**	**5**

(*a*) DESCRIBE: **flask** with thiosulfate solution only heated **in water bath (on hot plate,** with **Bunsen) //** add **HCl (acid)** and mix (stir, swirl) **//** use **thermometer (temperature probe, temperature sensor)** in flask **shown (mentioned)** to record reaction mixture temperature **/** **water bath set to** known **temperature** (3 × 3)
[Points may be available from diagram][No diagram –3]

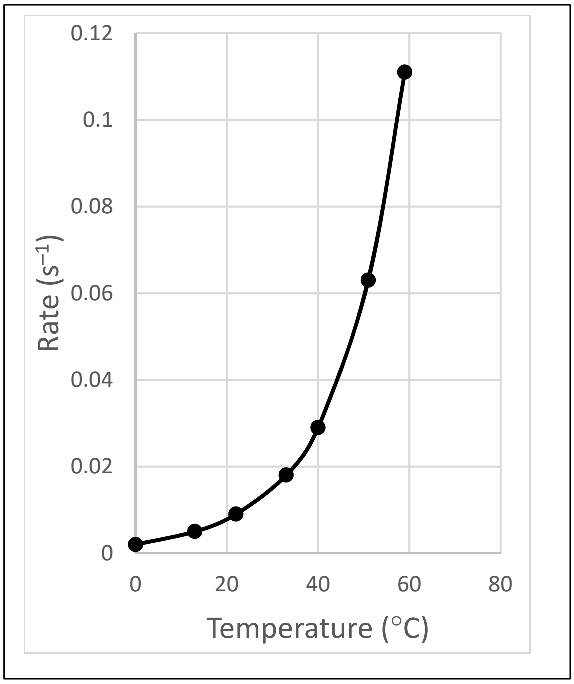
(*b*) (*i*) WHAT: appearance of **precipitate (solid, particles, suspension, off-white (**pale **yellow, cream) colour, cloudiness, etc)** / S (sulfur) **precipitated** (3)

(*ii*) DESCRIBE: **stand (put)** flask **on cross (print, mark) / cross (print, mark) under** flask **//** **record (note, measure, take) time for cross (print, mark) to be**come **obscured (invisible)** (2 × 3)
or
set up smart-phone **lux-meter** app next to flask **//** **record (note, measure, take) time for mixture to reach certain opacity using lux-meter** (2 × 3)

(*c*) COPY etc: (6 × 1)

r (s^{-1})
No mark
0.005
0.009
0.018
0.029
0.063
0.111

Apply slip penalty no more than once for not rounding or incorrect rounding in 3(*c*).



(*d*) (*i*) PLOT:
A: **axis labelled temperature (*T*, °C) and axis labelled rate (*r*, s^{-1})** (3)
B: **appropriate correct numeric scales on both axes** (3)
C: careful **plotting of all 7 points from (*c*)** [Deduct 3 if graph not on graph paper.] (3)
D: **smooth curve** of correct shape [straight line unacceptable] (3)
[Deduct (1) in D for <u>each</u> of the following:
poor curve
all pairs of points connected with straight lines.]
[Temperature *versus* rate graph acceptable.]

(*ii*) USE: **9 – 11** (6)
[Allow (3) for answers outside 9 – 11 but in the 8 – 12 range.]

(*iii*) EXPLAIN: **more effective (successful) collisions** at higher temperature **//**
activation energy more easily reached in collisions at higher temperature (3)

(*e*) (*i*) SHOW: **plotted correctly on graph paper – point not on curve** (2)

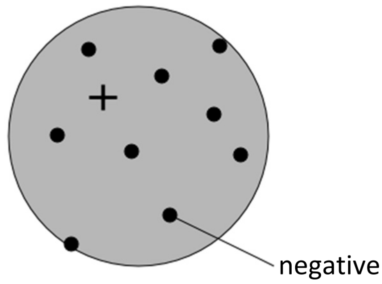
(*ii*) WAS: **lower** (2)

JUSTIFY: **takes longer (more difficult, more precipitate needed) to obscure cross / more time taken to reach same observable state (appears to have longer reaction time) / rate appears to be slower / rate appears to be smaller (lower)** (1)
[Mark consequentially in (*e*)]

QUESTION 4

Eight items to be answered. Six marks to be allocated to each item and one additional mark to be added to each of the first two items for which the highest marks are awarded.

(*a*) DRAW: small negative particles (electrons) embedded // in positive sphere (2 × 3)



(*b*) WHAT: **nickel (Ni)** (6)

(*c*) WHAT: **neptunium– / Np //**
237 (2 × 3)
or
$^{237}_{93}$**Np** (6)

(*d*) WRITE: (*i*) *magnesium sulfite:* **$MgSO_3$**
(*ii*) *copper(II) oxide:* **CuO** (2 × 3)
[Any order acceptable.]

(*e*) GIVE: **trigonal (triangular)** planar **//**
pyramidal (2 × 3)
[Accept **T-shaped** as an alternative to either answer above.]

(*f*) CALCULATE: **880000** / **8.8 × 10⁵** Pa (6)

$pV = nRT$ / $p = \frac{nRT}{V}$ / $p \times 1.0 \times 10^{-3} = 0.36 \times 8.3 \times 293$ / $p = \frac{0.36 \times 8.3 \times 293}{1.0 \times 10^{-3}}$ (3)

$p \times 1.0 \times 10^{-3} = 0.36 \times 8.3 \times 293$ / $p = \frac{0.36 \times 8.3 \times 293}{1.0 \times 10^{-3}}$

p = **8.8×10^5** Pa (3)

[Allow (5) for 875484 Pa.] [Deduct (3) if Kelvin scale not used.]

or

volume CO_2 gas at s.t.p = 22.4 × 0.36 = 8.064 litres

$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$ / $\frac{8.064\times10^{-3}\times 101325}{273.15} = \frac{1.0\times10^{-3}\times p_2}{293}$ (3)

$\frac{8.064\times10^{-3}\times 101325}{273.15} = \frac{1.0\times10^{-3}\times p_2}{293}$

p_2 = **880000** Pa (3)

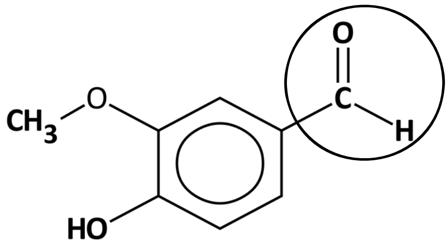
[Allow (5) for 865001 to to 876945 Pa.] [Deduct (3) if Kelvin scale not used.]

(*g*) HOW: **provides alternative pathway (mechanism)** for reaction (6)

(*h*) UNDER: **in** aqueous **solution / dissolved** in water **//**
molten (liquid state**, melted)** (2 × 3)

(*i*) IDENTIFY: **calcium carbonate / $CaCO_3$** (6)
[Accept magnesium carbonate / $MgCO_3$ for (6)]

(*j*) (*i*) CIRCLE: **CHO group circled //**
(*ii*) WRITE: **$C_8H_8O_3$ / $C_6H_3CH_3O(OH)CHO$**



(2 × 3)

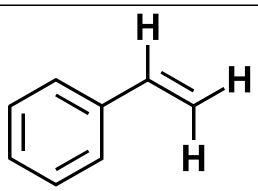
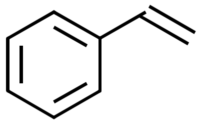
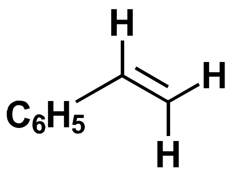
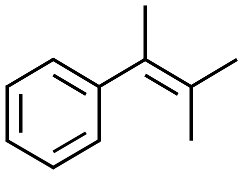
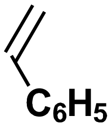
(*k*) **A** WRITE: **$O_3 \rightarrow O_2 + O^{\bullet}$**

FORMULAE: (3) BALANCING: (3)

[Allow (6) if O given for $O^{\bullet}$][O^{-} is incorrect]

or

B DRAW: (6)

			Allow 
$C_6H_5CH{=}CH_2$	**$C_6H_5CHCH_2$**		

[Delocalised benzene ring acceptable.]

QUESTION 5

a	b	c	d
5	9	15	21

(*a*) WHAT: **subatomic particle / particle orbiting** atomic **nucleus / particle located in electron cloud** of atom **/ particle located within** electron cloud of **atom //**
negative (–) //
mass 1/1840 amu / negligible mass / very small mass ANY TWO: (3 + 2)

(*b*) (*i*) WHY: **too much energy / excited / gained energy / gained heat** energy **(heated) / absorbed a photon / absorbed electrical energy** (3)

(*ii*) WHAT: **red** (3)

(*iii*) NAME: **Balmer** (3)

(*c*) (*i*) HOW: **3** (3)

(*ii*) WHAT: **space (volume, region)** around nucleus of an atom **//**
where there is a relatively **high probability (possibility) of finding an electron / where an electron is likely to be found**
['*Area*' around nucleus not acceptable.]

or

approximate **solution //**
to (of) a **Schrödinger (wave) equation** for an electron in an atom (2 × 3)

(*iii*) HOW: **4** (3)

(*iv*) WHAT: **18** (3)

(*d*) WRITE: *Be:* $1s^2\,2s^2$ / [He] $2s^2$ (3)

Ne: $1s^2\,2s^2\,2p^6$ / $1s^2\,2s^2\,2p_x^2 2p_y^2 2p_z^2$ / [He] $2s^2\,2p^6$ (3)

Mg: $1s^2\,2s^2\,2p^6\,3s^2$ / $1s^2\,2s^2\,2p_x^2 2p_y^2 2p_z^2\,3s^2$ / [Ne] $3s^2$ (3)

Kr: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6 4s^2\,3d^{10}\,4p^6$/
$1s^2\,2s^2\,2p_x^2 2p_y^2 2p_z^2\,3s^2\,3p_x^2 3p_y^2 3p_z^2 4s^2\,3d^{10}\,4p^6$ /
[Ar] $4s^2\,3d^{10}\,4p^6$ (3)
[*Allow subscripts instead of superscripts.*]
[*Arrows to represent numbers of electrons acceptable but sub-level symbols must be given.*]

EXPLAIN: (*i*) have **stable** full **outer octet (ns^2 np^6)** electrons **/**
8 electrons in outer shell (energy level) is **stable /**
satisfy octet rule /
6 electrons in outer *p*-sublevel (*p*-subshell) is **stable /**
full outer *p*-sublevel (*p*-subshell) is **stable /**
closed shell of valence electrons (8 valence electrons, valence sublevels full) is **stable** (3)

['Set of full sublevels stable' unacceptable and does not cancel.]
['Have full outer shells which is stable' incorrect but does not cancel.]

EXPLAIN: (*ii*) **do not have** stable full **outer octet (ns^2 np^6)** electrons **/**
do not have 8 electrons in outer shell (energy level) /
do not satisfy octet rule /
only **2 electrons in** an incomplete **outer shell (energy level) /**
would **need to lose** 2 **electrons to achieve Group 18 (noble gas, inert gas, stable) configuration** (3)

[Where no marks awarded above for EXPLAIN (*i*) and EXPLAIN (*ii*) allow one (3) if both '**stable** electron configuration (arrangement of electrons)' is given in (*i*) and '**unstable** electron configuration (arrangement of electrons)' is given in (*ii*).]

WHY: Mg **has greater atomic radius / more energy levels (shells)** in Mg **/**
more screening (shielding) of nucleus by electrons in inner shells in Mg **/**
Mg has **smaller ionisation energy /**
attraction of Mg **nucleus for outer electrons less /**
outer electrons of Mg **farther from nucleus** (3)
Accept opposite statements in terms of Be but Be must be specified.]

QUESTION 6

a	b	c	d
8	**15**	**6**	**21**

(*a*) EXPLAIN: *knocking:* results from petrol **autoigniting (pre-igniting, igniting too early, igniting before spark) / pinking (pinging, tapping) / etc** (4)

octane number: measure of **tendency (ability)** of a fuel **to resist knocking (autoigniting, pre-igniting, igniting too early, igniting before spark, knock)* / fuel performance rating based on its equivalence to a certain mixture of heptane and 2,2,4-trimethylpentane** (4)
[*Opposite acceptable]

(*b*) (*i*) NAME: catalytic **cracking //**
dehydrocyclisation //
isomerisation (3 × 3)
[Allow reforming for dehydrocyclisation and for isomerisation; reforming must be mentioned twice for award of 6 marks]
[Take order of question unless answers clearly labelled.]

(*ii*) DEDUCE:
FORMULA: **C_3H_6 / CH_3CHCH_2** (3)

(*iii*) GIVE: **2,2,4-trimethylpentane** (3)
[Do not accept 2,4,4-trimethylpentane.]

(*c*) (*i*) GIVE: **methanol, ethanol, propanol, butanol, MTBE (methyl *tert*-butyl ether), etc** (3)

(*ii*) WHY: **reduce pollution (harmful emissions, soot, carbon monoxide)** caused (produced) by the fuel **/ increase octane rating (number)** of fuel **/ reduce knocking** in the engine **/** etc (3)

(*d*) (*i*) DEFINE: **heat (energy)** change (released, involved) when **1 mole** of a substance **is formed // from its elements in their standard (ground) states**
(2 × 3)

(*ii*) WRITE: $\mathbf{C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O}$ BALANCED EQUATION: (3)

USE: **–2219.**0 kJ mol^{-1} (12)

$\Delta H_{combustion} = \Sigma\Delta H_{formation\ products} - \Sigma\Delta H_{formation\ reactants}$
= (**–1180.5**) kJ (3) + (**–1143.2**) (3) **– (–104.7)** kJ (3) /
= (**–1180.5**) kJ (3) + (**–1143.2**) (3) **+ 104.7** kJ (3)
$\Delta H_{combustion}$ = **–2219.**0 kJ mol^{-1} (3)

or

$3C + 3O_2 \rightarrow 3CO_2$	ΔH = **–1180.5** kJ	(3)
$4H_2 + 2O_2 \rightarrow 4H_2O$	ΔH = **–1143.2** kJ	(3)
$C_3H_8 \rightarrow 3C + 4H_2$	ΔH = **104.7** kJ	(3)
$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	$\Delta H_{combustion}$ = **–2219.**0 kJ mol^{-1}	(3)

Mixing and matching from different boxes not acceptable.
Equations not essential in second box, however:

Final Answer ΔH = +**2219.**0 kJ mol^{-1} and $\mathbf{3CO_2 + 4H_2O \rightarrow C_3H_8 + 5O_2}$
worth 9 marks **only when clearly associated** with this equation

Final Answer ΔH = +**2219.**0 kJ mol^{-1} is worth only 3 marks if linked to any other equation or to no equation

QUESTION 7

a	b	c	d	e	f
8	**6**	**6**	**12**	**6**	**12**

(*a*) WHAT: **proton (H^+) donor** (4)

HOW: **greater the tendency of** an **acid to donate protons (more** the **acid tends to dissociate into ions) the stronger it is /**
less the tendency of an **acid to donate protons (less** the **acid tends to dissociate into ions) the weaker it is** (4)

or

strong *acid:*
is a good proton (H^+) donor / has a **weak conjugate base /**
has **large (complete) degree of dissociation** into ions **/ K_a value large //**

weak *acid*:
is a **poor proton (H^+) donor /** has a **strong conjugate base /**
dissociated into ions **to small extent / slightly (**only **partly) dissociated / K_a value small**
(2 × 2)

(*b*) WHAT IS: (*i*) **H_2SO_4** (3)

(*ii*) **SO_4^{2-}** (3)

(*c*) DESCRIBE: **add (mix) barium chloride ($BaCl_2$)** solution dropwise to (with) few cm^3 of sample (water) in test-tube **//**
white (cloudiness, precipitate, solid) insoluble in HCl (remains after addition of HCl) when sulfate present (positive result) (2 × 3)

(*d*) CALCULATE:

(*i*) $[H_3O^+]$ = **2.5×10^{-6} – 2.512×10^{-6}** moles per litre (6)

$[H_3O^+]$ = **inverse log(–5.6) /** $[H_3O^+]$ = **antilog(–5.6) /** $[H_3O^+]$ = **$10^{-5.6}$**	(3)
⇒ $[H_3O^+]$ = **2.5**119 × **10^{-6}** moles per litre	(3)

(*ii*) $[OH^-]$ = **$1.58 \times 10^{-7} - 1.6 \times 10^{-7}$** moles per litre (6)

pOH = 14 – 7.2 = **6.8**	(3)
$[OH^-]$ = inverse log (–6.8) / $[OH^-]$ = antilog(–6.8) / $[OH^-]$ = $10^{-6.8}$	
$\Rightarrow$ $[OH^-]$ = **$1.58 \times 10^{-7} - 1.6 \times 10^{-7}$** moles per litre	(3)
or	
$[H_3O^+]$ = inverse log (–7.2) / $[H_3O^+]$ = antilog(–7.2) / $[H_3O^+]$ = $10^{-7.2}$	
$[H_3O^+]$ = **6.31×10^{-8}**	(3)
$\Rightarrow$ $[OH^-] = 1.0 \times 10^{-14} \div 6.31 \times 10^{-8}$ **$= 1.58 \times 10^{-7} - 1.6 \times 10^{-7}$** moles per litre	(3)

(*e*) CALCULATE:

pH = **3.1 – 3.12** (6)

pH = –log$\sqrt{K_a[\text{HA}]}$ / pH = –log$\sqrt{(4.0 \times 10^{-4}) \times (1.5 \times 10^{-3})}$	(3)
pH = **3.1 – 3.12**	(3)
[negative answer is not a slip error here] [HA] = [HX] = M = M_a = [acid] =[indicator]	

(*f*) (*i*) WRITE: **$HA + H_2O \rightleftharpoons H_3O^+ + A^-$** (3)

[Do not penalise if equilibrium arrow not used]

(*ii*) WHAT: **yellow (orange)** colour observed **/** red changes to **yellow (orange) / yellow (orange)** colour intensifies **/ colour of A^-** observed (3)

EXPLAIN: **H_3O^+ (H^+) ions removed** by OH^- ions of base to form water **/ $H_3O^+ + OH^- \rightarrow$ 2H_2O /**
$H^+ + OH^- \rightarrow H_2O$ / lower **[H^+] / lower [H_3O^+] //**
equilibrium (reaction) moves to right (products, yellow side) /
more A^- at new **equilibrium** (2 × 3)

[WHAT must be correct for EXPLAIN to be awarded marks.]

QUESTION 8

a	b	c	d	e
9	**12**	**6**	**12**	**11**

(*a*) IDENTIFY: (*i*) **4** (3)

(*ii*) **1 / 3 / 5 / 6 / 8** (3)

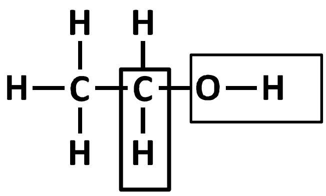
(*iii*) **2 / 7** (3)

(*b*) (*i*) WHAT: **hydrogen (H_2) //**
nickel (Ni) / platinum (Pt) / palladium (Pd) / copper (Cu) / rhodium (Rh) / ruthenium (Ru) (2 × 3)
[Accept any order of answering.]

or

$LiAlH_4$ / $NaBH_4$ (6)

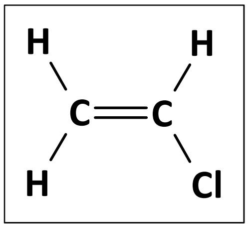
(*ii*) COPY etc: **OH** bond **//**
either **CH** bond of **carbon to which OH is attached** TWO BONDS: (2 × 3)
[Information only acceptable in diagram form.]



(*c*) IDENTIFY: **ethanol (C_2H_5OH, CH_3CH_2OH) / ethanal (CH_3CHO)** (3)

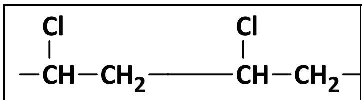
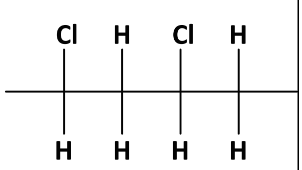
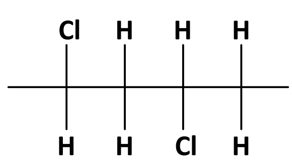
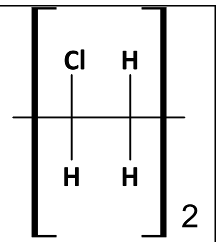
JUSTIFY: **hydrogen (H) bonding** with water (3)

(*d*) (*i*) IDENTIFY: **chloroethene** / 1-**chloroethene /** 1-**chloroethylene /** mono**chloroethene / CH_2CHCl / C_2H_3Cl / vinylchloride** (3)



(*ii*) HOW: **tetrahedral** to **//**
planar (2 × 3)
[correct order essential]

(*iii*) DRAW: (3)

			
-$CHClCH_2CHClCH_2$-			
Allow **-($CHClCH_2CHClCH_2$)-$_n$** or equivalent with n			

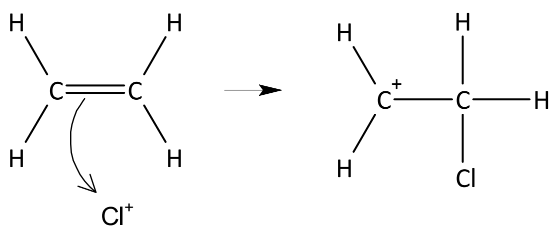
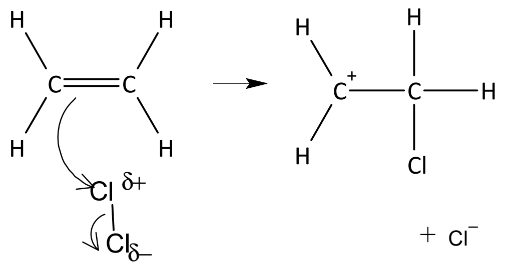
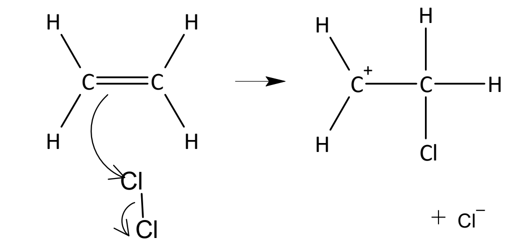
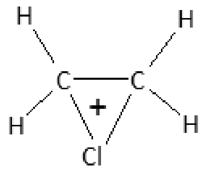
Correct carbon skeleton (4 carbons) with chlorines on alternate carbons
[End bonds need not be shown but terminal Hs not acceptable.]

(*e*) DESCRIBE: (3 + 3 + 3 + 2)

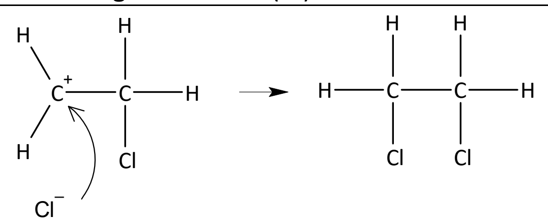
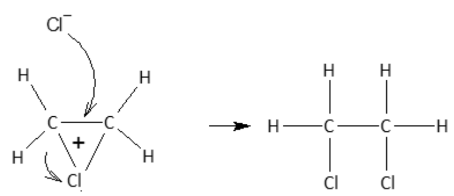
1. **chlorine (Cl_2) undergoes heterolytic fission / $Cl_2 \rightarrow Cl^+ + Cl^-$ / $Cl^{\delta+}—Cl^{\delta-} \rightarrow Cl^+ + Cl^-$**
   or
   chlorine (Cl_2) polarised approaching double bond / $Cl_2 \rightarrow Cl^{\delta+}—Cl^{\delta-}$ // (✓)
   [bond (line) essential in $Cl^{\delta+}—Cl^{\delta-}$][bond (line) must not be shown between Cl^+ and Cl^-]

2. **attraction of Cl^+ to double bond / interaction of Cl^+ with double bond /**
   or
   attraction of positive end of $Cl^{\delta+}—Cl^{\delta-}$ (polarised Cl_2 molecule**) to double bond /**
   positive end of $Cl^{\delta+}—Cl^{\delta-}$ (polarised Cl_2 molecule**) interacts with double bond**
   or
   breaking of double bond in ethene **and** polarised **bond in chlorine (Cl_2)** (✓)

3. **carbononium ion (carbocation, C^+, positively-charged intermediate,** bridged **chloronium ion) formed** (✓)

Left sides of equations = Second (✓) Right sides of equations = Third (✓)	[Hs need not be shown explicitly]
	 *or*  Cl^- product need not be shown in these diagrams
 Accept bridged chloronium ion as product instead of carbonium ions above	

4. **addition of Cl^- to carbonium ion (carbocation, C^+, intermediate, bridged chloronium ion) gives product (1,2-dichloroethane)** (✓)

Either diagram for last (✓)	[Hs need not be shown explicitly]
	

QUESTION 9

a	b	c	d	e
14	**6**	**12**	**12**	**6**

(*a*) EXPLAIN: state reached at which **concentrations of reactants and products** are **constant /** state reached when **rates of forward and reverse reactions are equal** (5)

WHY: forward and reverse (both) **reaction(s) continue(s) /** forward and reverse (both) **reaction(s) doesn't (don't) stop** (3)

STATE: systems **in (at) equilibrium //** react to **oppose (minimise, relieve)** applied **stress(es) {disturbance(s)}** (2 × 3)
[Instead of 'stress(es){disturbance(s)}' accept 'change in temperature, pressure or number of moles (concentrations)' if all three {temperature, pressure and moles (concentrations)} are given.]

(*b*) WRITE: $K_c = \frac{[\mathbf{CO_2}][\mathbf{H_2}]}{[\mathbf{CO}][\mathbf{H_2O}]}$ (6)
[Square brackets essential.][Marks may be awarded for this formula given in CALCULATE.]

(*c*) CALCULATE: **2.0**97 **– 2.1** moles carbon monoxide — Each tick 3 marks (4 × 3)

Let x = number of moles of CO_2 (or H_2) produced

	$CO_{(g)}$	+ $H_2O_{(g)}$	⇌ $CO_{2\,(g)}$	+ $H_{2\,(g)}$	
Initially:	3 mol	1 mol	0 mol	0 mol	
Change:	$-x$ mol	$-x$ mol	$+x$ mol	$+x$ mol	
Equil:	**3**.0 – ***x***	**1**.0 – ***x***	***x*** mol	***x*** mol	**/**
Equil:	$\frac{3.0-x}{V}$ mol/l	$\frac{1.0-x}{V}$ mol/l	$\frac{x}{V}$ mol/l	$\frac{x}{V}$ mol/l	A = (✓)

Relate K_c to equilibrium concentrations

$4.0 = \frac{x^2}{(3.0-x)(1.0-x)}$ or $4.0 = \frac{\frac{x^2}{V^2}}{\frac{(3.0-x)(1.0-x)}{V^2}}$ or $4.0 = \frac{x^2}{x^2-4x+3}$ $\Rightarrow$ $\mathbf{3x^2 - 16x + 12} = 0$ B = (✓)

solving quadratic $\Rightarrow x = \frac{16 \pm \sqrt{16^2-4(3)(12)}}{6} \Rightarrow x$ = 0.**90**28 mol or 4.4305 C = (✓)

3 − 0.9028 **= 2.0**97 **– 2.1** moles carbon monoxide D = (✓)

[Last 3 marks available (consequentially) only when x < no. moles CO] (*d*) PREDICT: (*i*) **no effect / none** (3)

JUSTIFY: (*i*) **changing concentration** at equilibrium **does not change K_c** / **only temperature** change **affects (changes) K_c** / **system reacts (adjusts) to use up steam / system reacts (adjusts) to produce more products (carbon dioxide and hydrogen)** (3)
[PREDICT must be correct for JUSTIFY to be awarded marks.]

PREDICT: (*ii*) **larger (increased)** yield of hydrogen / **more** hydrogen (3)

JUSTIFY: (*ii*) equilibrium (reaction) **moves (goes) to right (RHS) /**
Le Châtelier's predicts additional steam **favours right hand (products, forward reaction, exothermic)** side of equilibrium (3)
[PREDICT must be correct for JUSTIFY to be awarded marks.]

(*e*) STATE: K_c **smaller (decreases)** (3)

EXPLAIN: **endothermic (reverse) reaction favoured** at higher temperature **/**
` **formation reactants favoured** at higher temperature **/**
equilibrium pushed left at higher temperature **/**
exothermic (forward) reaction not favoured at higher temperature **/**
formation products not favoured at higher temperature **/** (3)
[STATE must be correct for EXPLAIN to be awarded marks.]

QUESTION 10

a	b	c
25	**25**	**25**

(*a*) (*i*) DEFINE: **amount of dissolved oxygen** in ppm **consumed by** bio**chemical (biological) activities (reactions) //**
over a five day period in the dark at 20 °C (2 × 3)
[Allow 20 $\pm$ 1 °C]

(*ii*) WHAT: **physical removal of** suspended **solids / settlement** suspended solids **/ screening** of suspended solids (3)
[Allow filtration.]

(*iii*) WHAT: **breakdown (oxidation)** of organic matter (effluent, sewage) by / **aerobic (anaerobic)** reaction **//**
by **biological (biochemical)** process **/** involving **microorganisms (bacteria)** (2 × 3)
['Removal of nutrients' insufficient but does not cancel]

(*iv*) UNDER: **high concentrations (amounts, levels) nitrates (phosphates, nutrients) / to reduce levels of** certain **microorganisms (to disinfect) / where** waste **water is to be discharged to a lake (river)** (3)

(*v*) WHY: **cost**ly (3)

(*vi*) WHAT: **eutrophication / excessive plant growth / algal bloom (growth) / oxygen depletion (hypoxia) / fish kill / shellfish poisoning / impaired** water **colour (taste, smell, aesthetic value, usefulness as source for drinking, value for leisure) /** water **unsafe to drink / etc** (4) (*b*) DEFINE: (*i*) **loss** of electrons

(*ii*) **increase** in oxidation number (4 + 3)

(*iii*) ASSIGN: $LiC_6 + CoO_2 \rightarrow C_6 + LiCoO_2$

Accept oxidation numbers for individual atoms or groups of atoms

LiC_6	+	CoO_2 →	C_6	+	$LiCoO_2$
1 6(**−1/6**)		**4** 2(**−2**)	**0**		**1** **3** 2(**−2**)

or

LiC_6	+	CoO_2 →	C_6	+	$LiCoO_2$	
1 (**−1**)		**4** (**−4**)	**0**		**1** **3** (**−4**)	(3)

WHICH: **cobalt / Co** (3)

(*iv*) IDENTIFY: **cobalt / Co** (3)

(*v*) BALANCE: $\mathbf{Pb + PbO_2 + 4H^+ \rightarrow 2Pb^{2+} + 2H_2O}$ (6)

(3) for correct oxidation numbers if balancing not correct

Pb	+	PbO_2	+	H^+	→	Pb^{2+}	+	H_2O
0		**4** 2(**−2**)		**1**		**2**		2(**1**)(**−2**)

or

Pb	+	PbO_2	+	H^+	→	Pb^{2+}	+	H_2O	
0		**4**(**−4**)		**1**		**2**		**2**(**−2**)	(3)

(*vi*) WHY: **to avoid pollution** of waterways by heavy metals **/** heavy metals (contents) **damage health (toxic, poisonous) /** recycling **better for environment / metals (chemicals) in limited supply / sustainable methods of energy provision / economically desirable /etc** (3) (*c*) (*i*) WHAT MASS: **7.2** g Al_4C_3 (13)

$\frac{3.6 \times 10^{23}}{6.0 \times 10^{23}}$ = 0.**6 / $^{3}/_{5}$** moles hydrogen atoms in $Al(OH)_3$	(3)
0.6 ÷ 3 ⇒ 0.**2 / $^{1}/_{5}$** moles $Al(OH)_3$	(3)
0.2 ÷ 4 ⇒ 0.**05 / $^{1}/_{20}$** moles Al_4C_3	(3)
M_r Al_4C_3 = **144**	(1)
144 × 0.05 = **7.2** g	(3)

(*ii*) WHAT VOLUME: **3.36** litres CH_4 (6)

0.05 moles Al_4C_3 × 3 / 0.2 moles $Al(OH)_3$ × $^{3}/_{4}$ ⇒ 0.**15** moles CH_4	(3)
0.15 **× 22.4** = **3.36** litres CH_4 / **3360** cm^3 CH_4	(3)

[24 litres unacceptable for molar volume here.]

(*iii*) FIND VOLUME: **10.8** cm^3 water (6)

0.05 moles Al_4C_3 × 12 / 0.2 moles $Al(OH)_3$ × 3 ⇒ 0.**6** moles water	(3)
0.6 × 18* × 1.0 = **10.8** cm^3 water	(3)

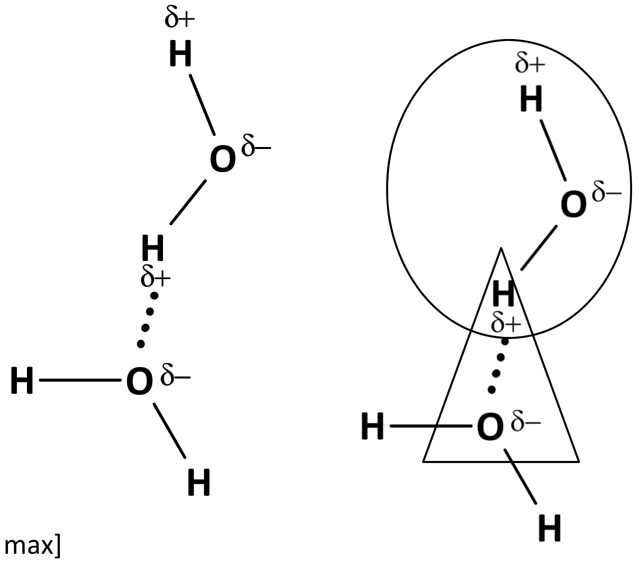
[**Addition must be shown for error to be treated as slip.*]

QUESTION 11

a		b		cA		cB	
i, ii	**iii, iv, v**	**i, ii**	**iii, iv**	**i, ii**	**iii, iv, v**	**i, ii**	**iii, iv, v**
12	**13**	**15**	**10**	**15**	**10**	**10**	**15**

(*a*) (*i*) DEFINE: number expressing the **relative (measure of) attraction of an atom //** **for shared** pair(s) of **electrons / for electrons in a covalent bond** (2 × 3)

(*ii*) DECRIBE: **water molecule**s **with δ+ and δ– polarity marked fully and correctly (as in circle) //** **hydrogen bond drawn between H and O atoms of two separate water molecules correctly labelled δ+ and δ– and clearly labelled or indicated by a dotted line (as in triangle)** (2 × 3)



[no diagram …..(3) max]

(*iii*) WHY: **small** and **electronegative atom (element)** needed in hydride for H-bonding to occur **/** hydrogen bonding **involves oxygen (O), nitrogen (N) or fluorine (F) /** **sulfur (S), selenium (Se) and tellurium (Te) much less electronegative than oxygen (O) /** **others (other hydrides**) **have less polarity (smaller electronegativity difference)** that results in dipole-dipole interactions (3)

(*iv*) WHY: H_2Se has **more (stronger) intermolecular (van der Waals, dipole-dipole) forces (bonds, interactions) /** H_2Se has **more (stronger) dipoles /** H_2Se **electron cloud** that produces intermolecular forces **bigger /** H_2Se has **more electrons /** H_2Se has **higher molecular mass /** H_2Se has **bigger molecules** (3)
[Reference to breaking covalent bonds unacceptable and cancellation applies.]
[Opposite statements explaining lower boiling point of hydrogen sulfide acceptable but hydrogen sulfide must be specified.]

(*v*) EXPLAIN: **methane (CH_4)** molecule **non-polar / centre**s **of negative and positive charge coincide (cancel) in methane (CH_4) / methane (CH_4) has no** overall **dipole moment / highly (very) symmetrical distribution (arrangement of)** polar **bonds around carbon (central atom) in 3d space in methane (CH_4) /** valence **electron pairs in methane (CH_4)** arranged in **perfect tetrahedral / no lone pairs in methane (CH_4)**
[methane (CH_4) *molecule* polar unacceptable and cancels]
[methane (CH_4) *bond(s)* polar unacceptable but no cancellation]

hydrogen selenide (H_2Se) molecule **is polar / centre**s **of negative and positive charge do not coincide (cancel) in hydrogen selenide (H_2Se) / hydrogen selenide (H_2Se) has** overall **dipole moment / distribution (arrangement) of bonds around selenium only symmetrical in 2d space in hydrogen selenide (H_2Se) / lone pairs in hydrogen selenide (H_2Se)** (4 + 3)
[Statement about one substance not taken to imply statement about the other.]
Where no other marks awarded:
non-polar (with no dipole, with no charge separation, highly symmetric) molecules insoluble in water (4)

(*b*) (*i*) FIND: **CH_2O** (12)

$\frac{40.0}{12}$ = **3.33 / $^{10}/_3$** moles carbon [Allow 3.3]	(3)
$\frac{6.67}{1}$ = **6.67 / $^{20}/_3$** moles hydrogen [Allow 6.7]	(3)
$\frac{53.33}{16}$ **= 3.33 / $^{10}/_3$** moles oxygen [Allow 3.3]	(3)
Dividing by smallest 1 : 2 : 1	
$\Rightarrow$ **CH_2O**	(3)
[Formula must be explicitly written, number ratio insufficient.]	

(*ii*) WHAT: **$C_2H_4O_2$** (3)

(*iii*) GIVE: **ethanoic acid / CH_3COOH //**
methyl methanoate / $HCOOCH_3$ //
hydroxyethanal / $HOCH_2CHO$ ANY TWO: (2 × 3)

(*iv*) WHAT: **acid**ic group present **/ carboxylic group** present **/** unknown is **ethanoic acid (CH_3COOH)** (4)

(*c*)

A (*i*) GIVE: **steel-making / rocket fuel oxidant / oxyacetylene flame (welding, cutting metals) / supports fuel combustion / combat pollution** in water **/ beauty (skin) treatment / use in bomb calorimeter (measuring heats of combustion) / photosynthesis / etc** (3)

(*ii*) DESCRIBE: **filter air / remove of dust (non gaseous impurities) / remove carbon dioxide (CO_2) / remove water vapour (H_2O) //**

compress air (refrigerate air, cool air) and allow to expand quickly to **liquefy //**

liquid **air boils (vaporises, heats up, warms up) in fractionating column /** use **fractional distillation / allow temperature to rise to distil mixture (air, gases) //**

nitrogen (N_2) gas **at top** of column **/** liquid **oxygen (**liquid **O_2) at base** of column **/ nitrogen (N_2) collected (boils, distils, vaporises) first / nitrogen (N_2) has lower boiling point / oxygen (O_2) has higher boiling point** (4 × 3)
[Marks may be awarded for information given in a clear labelled diagram.]

(*iii*) IDENTIFY: **nitrogen (N_2)** (3)

(*iv*) GIVE: **packaging food** to prevent oxidation **/ packaging** to prevent crushing of **food (delicate items) / flushing (purging) tanks of flammable liquids (gases, vapours, oil tank) / inert atmosphere** in industry **/ freezing (preserving) food (biological specimens, sperm, semen) / remove unwanted skin cells / remove skin cancer (wart**s, **verruca**e**) /** feedstock for **ammonia industry, etc** (3)

(*v*) EXPLAIN: very strong (high energy) **triple bond / N≡N / non-polar /** high degree of **symmetry** perpendicular bond axis **/ no dipole moment / no unpaired electrons** (4)

or

B (*i*) WHAT: **oxidation** of surface of metal **/ reaction** of surface of metal **when exposed to air (water, dampness, acid,** the **environment) / return to ore state** (4)

(*ii*) COMPARE: **aluminium** resists corrosion **better / iron** resists corrosion **less well //**
[Allow ' **iron corrodes (rusts) more easily**']

oxide of aluminium adheres / oxide of iron (rust) flakes off (2 × 3)

(*iii*) WHAT: **steel contains carbon (other elements, elements other than iron) / steel is an alloy of iron / steel is a mixture of elements** (4)

(*iv*) WHAT: **creating (thickening)** layer of **aluminium oxide (Al_2O_3)** on aluminium **//**

by electrolysis / aluminium made the **anode in electrochemical cell / by generating oxygen** gas **on (at) aluminium electrode** in voltameter (4 + 3)

(*v*) WHY: **valence electrons free to move / valence electrons delocalised / valence electrons shared between all atoms (positive ions)** (4)