Leaving Certificate 2016
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.
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 3 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 obtained more than 75% of the total marks.
Marcanna Breise as ucht freagairt trí Ghaeilge

Léirionn an tábla thíos an méid marcanna breise ba chóir a bhronadh ar iartróirí a ghnóthaíonn níos mó ná 75% d’iomlán na marcanna.

N.B. Ba chóir marcanna de réir an ghnáthráta a bhronadh ar iartróirí nach ngnóthaíonn níos mó ná 75% d’iomlán na marcanna don scrúdú. Ba chóir freisin an marc bónais sin a sblánú 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.

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<thead>
<tr>
<th>Bunmharc</th>
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<tbody>
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<td>301 - 303</td>
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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).
QUESTION 1

(a) MEASURE: use 25 cm³ pipette ( burette ) //
previously rinsed with deionised ( distilled, pure ) water //
and previously rinsed with vinegar ( solution it will contain, sample ) //
pipette: read at eye-level / read bottom of meniscus / bottom of meniscus on the mark /
allow drainage time / last drop to remain ( not to be shaken out, blown out ) /
drain under gravity / touch ( tip, tap) pipette against wall of flask
burette: read at eye-level / jet ( part below tap ) full / vertical / read bottom of meniscus

ANY THREE: (3 x 3)

DILUTE: transfer to 250 cm³ volumetric flask //
previously rinsed with deionised ( distilled, pure ) water //
fill with deionised water until bottom of meniscus is on mark //
stopper and invert flask a number of times / stopper and mix contents thoroughly

ANY TWO: (2 x 3)

[ Award marks for reference to ‘ bottom of meniscus ’ once only in (a). ]

(b) NAME: phenolphthalein (3)

WHAT: from pink ( purple ) to colourless (3)
[ Colours reversed unacceptable. ] [ ‘ Clear ’ unacceptable for ‘ colourless ’. ]

(c) CALCULATE: (i) \( 0.0015 \times (1.5 \times 10^{-3}) \) moles (6)

\[
M = \frac{1.20 \times 2}{40^*} = 0.06\, \text{M} \quad (3)
\]

\[
\frac{25 \times 0.06}{1000} = 0.0015 \, \text{moles/25 cm}^3 \quad (3)
\]

\[
\frac{1.20}{20} = 0.06\, \text{g in 25 cm}^3 \quad (3)
\]

\[
\frac{0.06}{40^*} = 0.0015 \, \text{moles/25 cm}^3 \quad (3)
\]

\[
\frac{1.20}{40^*} = 0.03 \, \text{moles/500 cm}^3 \quad (3)
\]

\[
\frac{0.03}{20} = 0.0015 \, \text{moles/25 cm}^3 \quad (3)
\]

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

(ii) \( 0.0008 \times (8 \times 10^{-5}) \) moles per cm³ (6)

\[
0.0015 \, \text{moles CH}_3\text{COOH} \quad (3)
\]

\[
0.0015 \div 18.75 = 0.0008 \times (8 \times 10^{-5}) \, \text{moles per cm}^3 \quad (3)
\]

\[
M = \frac{18.75 \times M}{1} = \frac{25 \times 0.06}{1} \quad (3)
\]

\[
M = 0.08\, \text{M} \quad (3)
\]

\[
\frac{0.08}{1000} = 0.0008 \times (8 \times 10^{-5}) \, \text{moles per cm}^3 \quad (3)
\]

(d) FIND: (i) \( 0.8 \, \text{M} \quad (3) \)

\[
0.0008 \times 1000 \times 10 = 0.8 \, \text{moles/L} \quad (3)
\]

(ii) \( 4.8 \, \% \, (\text{w/v}) \quad (6) \)

\[
0.8 \times 60^* = 48\, \text{g/L} \quad (3)
\]

\[
\frac{48}{10} = 4.8\, \text{g/100 cm}^3 = 4.8\, \% \, (\text{w/v}) \quad (3)
\]

\[
0.8 \div 10 = 0.08 \, \text{moles/100 cm}^3 \quad (3)
\]

\[
0.08 \times 60^* = 4.8\, \text{g/100 cm}^3 = 4.8\, \% \, (\text{w/v}) \quad (3)
\]

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

(e) WHAT: anhydrous sodium carbonate titrated with a strong acid { hydrochloric acid (HCl),
sulfuric acid (H₂SO₄), nitric acid (HNO₃) } //
acid titrated with sodium hydroxide (NaOH) solution

[ Award (3) for correct titrations in reverse order. ]

\( 0.0015 \, \text{mol CH}_3\text{COOH} \)

\[
0.0015 \div 18.75 = 0.00008 \times (8 \times 10^{-5}) \, \text{moles per cm}^3 \quad (3)
\]

\[
M = 1.20 \times 240^* = 0.06\, \text{M} \quad (3)
\]

\[
\frac{1.20}{20} = 0.06\, \text{g in 25 cm}^3 \quad (3)
\]

\[
\frac{0.06}{40^*} = 0.0015 \, \text{moles/25 cm}^3 \quad (3)
\]

\[
\frac{1.20}{40^*} = 0.03 \, \text{moles/500 cm}^3 \quad (3)
\]

\[
\frac{0.03}{20} = 0.0015 \, \text{moles/25 cm}^3 \quad (3)
\]

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M = \frac{18.75 \times M}{1} = \frac{25 \times 0.06}{1} \quad (3)
\]

\[
M = 0.08\, \text{M} \quad (3)
\]

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\frac{0.08}{1000} = 0.0008 \times (8 \times 10^{-5}) \, \text{moles per cm}^3 \quad (3)
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\frac{18.75 \times M}{1} = \frac{25 \times 0.06}{1} \quad (3)
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M = 0.08\, \text{M} \quad (3)
\]

\[
\frac{0.08}{1000} = 0.0008 \times (8 \times 10^{-5}) \, \text{moles per cm}^3 \quad (3)
\]
QUESTION 2

(a) DESCRIBE: bromine ($Br_2$) solution (water) / acidified potassium manganate(VII) {permanganate} / ($KMnO_4/H^+$) / ($MnO_4^-/H^+$)

(decolourises (changes to colourless, colour disappears) //
if unsaturated

or

no change in colour //
if saturated

[’Clear’ unacceptable for ‘colourless’.]  

(b) (i) DEDUCE: D: ethanal / $CH_3CHO$

DESCRIBE: add Fehling’s (Benedict’s) solution (reagent) / add ammoniacal silver nitrate (Tollens’ reagent) //

heat gently / blue (Cu$^{2+}$) solution reacts (changes, is reduced) /

colourless (Ag(I), silver(I) oxide, Ag$_2$O, Ag$^+$) reacts (changes, is reduced) //

(giving brick red precipitate / giving silver mirror (metal)
[DESCRIBE marks only available if DEDUCE marks awarded.]  
[Reagent and observations must match.]

(ii) IDENTIFY: C: eugenol //  
          E: ethanoic acid ($CH_3COOH$) /  

WHAT: two layers / organic (cyclohexane) layer and aqueous layer  
[Marks available from a diagram.]

(iii) WRITE: $2CH_3COOH + Mg \rightarrow (CH_3COO)_2Mg + H_2$

FORMULAE: (3) BALANCING: (3)

(c) (i) DESCRIBE: sample (crystals) in melting point (m.p.) capillary tube in melting point block (apparatus, in Thiele tube) shown in diagram / sample (crystals) on aluminium (melting) block shown in diagram //

heat slowly while observing crystals / heat source shown or labelled in diagram //

record (note) temperature range at which melting occurs / record (note) the melting point temperature

[’Record melting point’ insufficient even where thermometer shown or mentioned.]  
[Maximum (6) if no diagram or no labels.]

(ii) WHICH: G / F is less pure

(iii) NAME: recrystallisation
QUESTION 3

(a) DRAW: both reactants in flask (reaction vessel), e.g. A, B or C below, and one reactant labelled with name or formula [hydrogen peroxide added from dropping funnel not acceptable] // flask connected to graduated container, e.g. X or Y below, for oxygen collection / [graduations marked or collecting graduated container labelled]

(b) PLOT: both axes correctly labelled (\( V / volume / cm^3 / oxygen / O_2 / time / t / minutes / min \))(3)
appropriate, correct numeric scales on both axes (3)
careful plotting to give smooth curve of correct shape through origin for run A // careful plotting to give smooth curve of correct shape through origin for run B (6 + 3)
same volume of oxygen produced by run A and run B
[Time versus volume acceptable.]
[(6) marks deducted if graph not on graph paper or not on same set of axes.]
[Deduct (3) for any one of the following: kink in curve due to inaccurate plotting of one or more points; points connected with straight lines; curve not through origin.
Apply once to each curve.]
(c) **CALCULATE:** 8.2 – 9.5 cm$^3$ oxygen per minute (6)

\[
\text{any two points from a tangent drawn at 4 minutes on curve A}
\text{e.g. (6.0, 82) and (1.0, 39)}
\]

\[
\frac{82 - 39}{6.0 - 1.0} = \frac{43}{5.0} = 8.6 \text{ cm}^3 \text{ oxygen per minute}
\]

[Deduct 1 mark if tangent correctly drawn at 4 minutes on curve B.]

(d) **WHICH:**

(i) A //

(ii) B  

(2 × 3)

**WHAT:**  

surface adsorption / heterogeneous [Accept ‘surface adsorption’]  

(3)

**SUGGEST:**

greater surface area (more finely divided, smaller particle size) / more active / purer / B has less surface area (less finely divided, greater particle size) / B less pure / B less active / B poisoned  

(3)

[SUGGEST marks available only if (6) awarded for WHICH.]

(e) **WHAT:**

(i) oxidiser / oxidising reagent / oxidises / causes other substances to burn readily  

[‘Health problems’ and ‘dangerous’, are unacceptable but do not cancel.]
[‘Burns’, ‘corrosive’ and ‘flammable’ are unacceptable and cancellation applies.]

(ii) harmful / irritating / irritant  

[‘Health problems’, ‘dangerous’, ‘toxic’, ‘poisonous’ are acceptable.]

[Allow ‘corrosive’.]
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) WHAT:

(i) 27 //
(ii) 59

(b) DESCRIBE:  electrons (negative particles, negative charges, –‘s) in // positive (+) sphere (ball, mass, material, matter)
[Marks may be obtained from a clear diagram with correct charges indicated.] (2 × 3)

(c) EXPLAIN: nitrogen is relatively stable // has a half-filled 2p (outer) sublevel (subshell) /
has three half-filled 2p (outer) orbitals
[2p allowed for an electron configuration but other points in bold, e.g. ‘half-filled’, must be stated.]

or

oxygen is relatively unstable (less stable) //
doesn’t have half-filled 2p (outer) sublevel (subshell) / doesn’t have three half-filled 2p (outer) orbitals / has only one full outer 2p orbital /
loss of electron gives half-filled 2p (outer) sublevel (subshell) /
loss of electron gives three half-filled 2p (outer) orbitals
[2p allowed for an electron configuration but other points in bold, e.g. ‘half-filled’, must be stated.]

(d) DISTG: sigma (σ) bond is formed by head (end) on overlap of atomic orbitals //
pi (π) bond is formed by sideways overlap of atomic orbitals
[Orbitals need not be mentioned twice.] [Allow ‘collision’ of orbitals.]

or

sigma (σ) bond symmetrical with respect to rotation about bond axis //
pi (π) bond asymmetrical (unsymmetrical) with respect to rotation about bond axis

or

sigma (σ) bond allows rotation about the bond axis //
pi (π) bond does not allow rotation about the bond axis

or

sigma (σ) bond has one region of overlap //
pi (π) bond has two regions of overlap

or

in a multiple (double, triple) covalent bond //
sigma (σ) bond is strongest bond / sigma (σ) bond is formed first / pi (π) bond is weaker
bond / pi (π) bond is formed only after a sigma (σ) bond has already been formed

[Marks may be obtained from good clear diagrams with orbitals labelled if present.] (2 × 3)

(e) WRITE:

(i) H₃PO₄ // (2 × 3)
(ii) HPO₄²⁻
(f) **WHAT:** there is a *simple (small) whole number ratio of volumes* of reactants and products // at the same (constant) conditions of *temperature and pressure* // ['*Amounts’ not acceptable for ‘volumes’.]

['*At all conditions of temperature and pressure’ and ‘at s.t.p.’ are not acceptable.]

(g) **HOW MANY:** \(0.0125 / 0.013\) moles \(\text{(6)}\)

\[
Mr = 132^* \\
= \frac{1.65}{132} = 0.0125 / 0.013 \text{ moles} \quad \text{(3)}
\]

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

(h) **HOW:** add barium chloride {barium nitrate, \(\text{BaCl}_2, \text{Ba(NO}_3\text{)}_2\)} solution // add barium ions (\(\text{Ba}^{2+}\)) solution // white precipitate dissolves (disappears, clears) in (on addition of) dilute hydrochloric acid (\(\text{HCl}\)) \(\text{(2 × 3)}\)

(i) **WHAT:** minimum combined energy of colliding particles (molecules, atoms, ions) // for reaction to take place between them

or

minimum combined energy of particles (molecules, atoms, ions) // for effective collisions

[Mention of collisions essential but only once.]

(j) **GIVE:** molecules (compounds, substances, bonds, groups of atoms, functional groups) absorb infrared radiation // of different (characteristic, certain) frequencies (wavelengths, energies) \(\text{(2 × 3)}\)

(k) **A** **DESCRIBE:** scrubbing (reaction) // with limestone (calcium carbonate, \(\text{CaCO}_3\), \(\text{CaO}\), hydroxide compounds, amines, zeolites, etc) \(\text{(2 × 3)}\)

[Equations acceptable, e.g. \(\text{CaO} + \text{SO}_2 \rightarrow \text{CaSO}_3(6)\) or \(\text{CaCO}_3 + \text{SO}_2 \rightarrow \text{CaSO}_3 + \text{CO}_2(6)\)]

**B** **NAME:** x-ray // crystallography \(\text{(2 × 3)}\)
QUESTION 5

(a)  (i) DISTING: ground state: \[ n = 1 / \text{lowest (first, nearest nucleus) energy level} / 1s / \text{minimum amount of energy} / \text{stable state} \]

excited states: \[ n > 1 / n = 2, 3, \text{etc} / n = 2, \text{etc} / 2s, 2p, 3s, \text{etc} / n = 2 \text{and higher} / \text{energies (energy levels) other than } n = 1 / \text{higher energies} / \text{higher energy (unstable) levels} \]

[For excited states accept ‘any (a, some) higher energy level’ but not ‘the higher energy level’.

[Allow a diagram with three concentric circles around a nucleus, with the innermost circle labelled ground state for (6).]

(ii) HOW: add heat \{energy, electricity, light, electromagnetic radiation\}

(iii) EXPLAIN: [Information must be given verbally.]
excited electron falls back from \( n = 3, 4, \text{etc} \) / excited electron falls back from \( n = 3, \text{etc} \) / excited electron falls from higher energy levels /

to second shell (energy level) / to \( n = 2 \) / to \( E_2 \) /

the energy lost is emitted as light \{electromagnetic radiation (energy)\} of different frequencies (colours, wavelengths) / the energy lost is emitted as different (discrete) \( hf \) \{\( h\nu \), photon(s)\} / different electron transitions correspond to different lines (colours, frequencies)

[Allow two correct examples of Balmer series electron energy changes, e.g. \( E_3 - E_2 \) and \( E_6 - E_2 \), for the first two points.]

WHAT: Balmer series

(iv) EXPLAIN: no corresponding electron transition (energy loss) / no corresponding excited state / electron cannot exist (be) between energy levels / electron cannot exist (be) between \( n = 3 \) and \( n = 4 \) / electron transition cannot originate from (terminate) between energy levels / electron transition cannot originate from between \( n = 3 \) and \( n = 4 \) / electron transition cannot terminate between \( n = 3 \) and \( n = 2 \) /

\[ E_n - E_2 \neq hf \{h\nu\} \text{ for yellow} / \text{no whole (natural, integer) number solution for } n \text{ in } E_n - E_2 = hf \{h\nu\} \text{ for yellow} \]
(b) **DESCRIBE:**

<table>
<thead>
<tr>
<th>Method 1</th>
<th>Method 2</th>
<th>Method 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>clean a platinum (nichrome) wire</strong> (rod, probe) in concentrated hydrochloric acid (HCl)</td>
<td><strong>soak wood (splint, stick) overnight in water / use damp (wet) wood (splint, stick)</strong></td>
<td><strong>prepare a solution of the given salt in water and ethanol (propanol)</strong></td>
</tr>
<tr>
<td><strong>red (crimson) colour is a positive result for lithium</strong></td>
<td><strong>red (crimson) colour is a positive result for lithium</strong></td>
<td><strong>red (crimson) colour is a positive result for lithium</strong></td>
</tr>
</tbody>
</table>

*[Allow ‘inoculating loop’, or ‘spatula’ for ‘platinum wire’.] [Clear labelled diagram for some or all points acceptable.]*

(c) **DEFINE:**

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

or

approximate solution //

**to a Schrödinger wave equation**

DISTINGUISH: 

2\(p\) sublevel consists (is made up) of three 2\(p\) orbitals of equal energy / 2\(p\) sublevel accommodates (has, holds) no more than 6 electrons but each of the 2\(p\) orbitals accommodates {has, holds} no more than 2 of these electrons

WRITE:

1\(s^2\) 2\(s^2\) 2\(p^6\) 3\(s^2\) 3\(p^6\) 4\(s^2\) [Allow subscripts instead of superscripts.]

EXPLAIN:

4\(s\) sublevel lower in energy than the 3\(d\) / electrons fill the 4\(s\) sublevel before the 3\(d\)
QUESTION 6

(a) NAME: fractionation / fractional distillation (5)

IDENTIFY: boiling (condensing) point (temperature) (6)

(b) GIVE: 
(i) aviation (airplane, jet) fuel / home heating (cooking, lighting) oil (3)
(ii) roofing / road making / waterproofing (3)

(c) NAME: isomerisation (3)
NAME: dehydrocyclisation / reforming (3)

EXPLAIN: improves (increases) octane rating (number) / reduces tendency of fuel to cause knocking / by making molecules (compounds, hydrocarbons) that are branched (cyclic, shorter chained) (3)

CALCULATE: 237.6 kJ (9)

\[
\begin{align*}
\text{C}_8\text{H}_{18} & \rightarrow 8\text{C} + 9\text{H}_2 & \Delta H &= 250.1 \text{ kJ} \\
8\text{C} + 5\text{H}_2 & \rightarrow \text{C}_8\text{H}_{10} & \Delta H &= -12.5 \text{ kJ} \\
\text{C}_8\text{H}_{18} & \rightarrow \text{C}_8\text{H}_{10} + 4\text{H}_2 & \Delta H &= 237.6 \text{ kJ}
\end{align*}
\]

or

\[
\Delta H_{\text{reaction}} = \Sigma \Delta H_{f(\text{products})} - \Sigma \Delta H_{f(\text{reactants})}
\]

\[
\Delta H_{\text{reaction}} = -12.5 \text{ (3)} - [-250.1] \text{ (3)}
\]

\[
= 237.6 \text{ kJ mol}^{-1} \text{ (3)}
\]

(d) DEDUCE: \text{C}_7\text{H}_{14} (6)

[Accept structure.]

(e) DRAW:

(i) octane

(ii) 2,2,4-trimethylpentane

(iii) ethylbenzene

\[
\text{[Accept correct condensed structures, e.g. CH}_3\text{(CH}_2\text{)}_3\text{CH}_3, (\text{CH}_3)_2\text{CCH}_2\text{CH(}\text{CH}_3)_2, \text{C}_6\text{H}_5\text{C}_2\text{H}_5.] \\
\text{[Allow Hs to be omitted in fully expanded structures or fully expanded parts of structures.]}\]
QUESTION 7

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

PREDICT:  
(i) low temperature //  
[Allow ‘decrease in temperature’.]
EXPLAIN: favours (results in, produces more) exothermic (heat producing) reaction / high temperature would favour (result in, produce more) endothermic (heat absorbing) reaction / favours forward reaction which is exothermic / does not favour reverse reaction which is endothermic  
(2 × 3)

(ii) high pressure //  
[Allow ‘increase in pressure’.
EXPLAIN: favours (results in, produces) fewer moles (molecules) / favours smaller volume / low pressure would favour (result in, produce) more moles (molecules) / favours greater volume / favours fewer moles (molecules) on right / favours smaller volume on right / does not favour more moles (molecules) on left / does not favour greater volume on left /  
(2 × 3)

EXPLAIN: reaction (rate) too slow (uneconomical, costly) at low temperatures  
(3)

(b) STATE: no effect / none  
(3)
EXPLAIN: in presence of catalyst sulfur trioxide (SO₃) produced and used up at same rate / catalyst alters (speeds up) rate of forward and reverse reactions equally  
(3)
[EXPLAIN marks linked to STATE marks.][‘Equilibrium reached faster’ insufficient on its own.]
(c) WRITE: \[ K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]} \] (6)

CALCULATE: \[ 196000 / 1.96 \times 10^5 \] (18)

Initially: moles \( \text{SO}_2 = \frac{96}{64} = \frac{3}{2} (1.5) \) and moles \( \text{O}_2 = \frac{24}{32} = \frac{3}{4} (0.75) \) (3)

At equilibrium: moles \( \text{SO}_3 = \frac{112}{80} = \frac{7}{5} (1.4) \) (3)

\[
\begin{align*}
2\text{SO}_2 + \text{O}_2 & \rightleftharpoons 2\text{SO}_3 \\
\text{Equil mol:} & \quad 0.1 (3) \quad 0.05 (3) \quad 1.4 \\
\text{Equil M:} & \quad 0.002 \quad 0.001 \quad 0.028 \\
\end{align*}
\]

Divide by 50. (3)

\[
K_c = \frac{(0.028)^2}{(0.002)^2(0.001)} = 196000 / 1.96 \times 10^5 \] (3)

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

[Where \( K_c \) incorrect, e.g. inverted, allow consequential marks for calculation – up to a maximum of 15 marks.]

\[
\begin{align*}
\text{Start (moles):} & \quad \frac{96}{64} = \frac{3}{2} (1.5) \quad \frac{24}{32} = \frac{3}{4} (0.75) \\
\text{Equil (moles):} & \quad \frac{112}{80} = \frac{7}{5} (1.4) \\
\text{Equil (moles):} & \quad (1.5 - 2x) \quad (0.75 - x) \quad 2x = 1.4 \quad x = 0.7 \\
\text{Equil (moles):} & \quad 0.1 \quad 0.05 \quad 1.4 \quad (2 \times 3) \\
\text{Equil (mol/L):} & \quad 0.002 \quad 0.05 + 0.05 = 0.10 \quad 1.4 + 50 = 1.45 \quad (0.001 + 0.028 = 0.03) \\
\end{align*}
\]

\[
K_c = \frac{(0.028)^2}{(0.002)^2(0.001)} = 196000 / 1.96 \times 10^5 \] (3)
QUESTION 8

(a) NAME: A = ethanol / ethyl alcohol //
B = poly(ethene) / polyethene / polythene / polyethylene (2 × 3)

(b) IDENTIFY:
aluminium oxide / alumina / Al₂O₃ / concentrated sulfuric acid / H₂SO₄ (3)
elimination / dehydration (3)
tetrahedral to planar (3)

(c) WHAT: substitution (3)

DESCRIBE:
initiation:
homolysis (splitting, fission) of chlorine molecule (Cl₂) into free radicals (atoms, Cl*, Cl) by ultraviolet (uv) light /
\[
\text{Cl}_2 \xrightarrow{\text{uv}} 2\text{Cl}^* / \text{Cl}_2 \xrightarrow{\text{uv}} 2\text{Cl}
\] (3)

propagation (1):
chlorine radical (atom, Cl*, Cl) reacts with ethane molecule (C₂H₆) giving hydrogen chloride (HCl) and an ethyl radical (C₂H₅*) /
\[
\text{Cl}^* + \text{C}_2\text{H}_6 \rightarrow \text{HCl} + \text{C}_2\text{H}_5^* / \text{Cl} + \text{C}_2\text{H}_6 \rightarrow \text{HCl} + \text{C}_2\text{H}_5^*
\] (3)
[Hydrochloric acid not acceptable for HCl and cancellation applies.]
[Where C₂H₅ used instead of C₂H₅* deduct 3 marks but only once in (c).]

propagation (2):
ethyl radical (C₂H₅*) reacts with chlorine molecule (Cl₂) giving monochloroethane (C₂H₅Cl) and a chlorine radical (atom, Cl*, Cl) /
\[
\text{C}_2\text{H}_5^* + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_5\text{Cl} + \text{Cl}^* / \text{C}_2\text{H}_5^* + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_5\text{Cl} + \text{Cl}
\] (3)

chain reaction occurs / propagation steps repeat until one reactant used up / propagation steps repeat until termination reached [Accept ‘chain reaction occurs’ anywhere in (c).] (3)

termination:
combination of remaining radicals to form molecules (chlorine, chloroethane, butane) /
\[
2\text{Cl}^* \rightarrow \text{Cl}_2 / 2\text{Cl} \rightarrow \text{Cl}_2 / \text{Cl}^* + \text{C}_2\text{H}_5^* \rightarrow \text{C}_2\text{H}_5\text{Cl} / \text{Cl} + \text{C}_2\text{H}_5^* \rightarrow \text{C}_2\text{H}_5\text{Cl} / 2\text{C}_2\text{H}_5^* \rightarrow \text{C}_4\text{H}_{10}
\] (3)

EXPLAIN:
tetraethyllead increases the rate (speeds up reaction) by providing (producing, breaking into) ethyl free radicals /
tetraethyllead increases initiates (promotes) reaction by providing (producing, breaking into) ethyl free radicals ['Radical promoter’ insufficient on its own.] (3)
(d) **NAME:** ethyl methanoate / ethyl formate

**DRAW:**

![Images of molecular structures with labels for ethyl methanoate/ethyl formate]

Note some or all of the hydrogens and carbons need not be shown explicitly; -C₂H₅ need not be expanded; allow -Et instead of -C₂H₅; accept HCOOC₂H₅ [NAME and DRAW not linked.]

**CIRCLE:** only the carbonyl group circled

[Allow carbonyl identified in incorrect ester.]

**WHAT:** base hydrolysis / saponification
QUESTION 9

(a) (i) UNDER: 20 °C // in the dark [Allow 19-21 °C.]

(ii) AFTER: five (5) days

(iii) DEFINE: over enrichment of water with nutrients (nitrates, phosphates) / excessive nutrients (nitrates, phosphates) in water

STATE: excessive (abundant, dense) plant growth / algal bloom (growth) / decreases water transparency / oxygen depletion (hypoxia) / fish kill / shellfish poisoning / water colour (taste, smell, aesthetic value, value as source of drinking water supply, value for leisure activities) impaired, etc

(iv) SUGGEST: fertilizer run-off / silage run-off / slurry (wastewater, septic-tank) run-off / leakage from mines / addition of sewage / addition of nitrates (phosphates, detergents) / industrial pollution (waste) / milk (other named organic pollutant) added / acid rain, etc

(b) WHY: lead is toxic (harmful to health, poisonous)

NAME: atomic absorption spectroscopy (AAS) / mass spectroscopy / gas (ionic) chromatography (GC) / x-ray fluorescence (diffraction, absorption) / colorimetry / infra-red (ultraviolet, visible, IR, UV, nmr) spectroscopy / immunoassay, etc

HOW: precipitation (ion exchange, displacement reaction) / distillation / reverse osmosis / addition of hydrochloric acid (HCl, lime, calcium hydroxide, CaCO3) / addition of soluble chloride (sulfate, sulfide, phosphate, hydroxide, carbonate, Cl–, SO42–, S2–, PO43–, OH–, CO32–, etc) / activated charcoal / reed bed, etc

(c) HOW: rain (water) acidic due to dissolved carbon dioxide (CO2) / carbonic acid (H2CO3) in rain (water) / H2O + CO2 → H2CO3 // rain (water) reacts with limestone to form soluble (dissolved) calcium hydrogen carbonate {calcium ions, Ca2+, Ca(HCO3)2}

or

\[ \text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{Ca(HCO}_3)_2 / \text{H}_2\text{CO}_3 + \text{CaCO}_3 \rightarrow \text{Ca(HCO}_3)_2 \]

(i) WRITE: Ca(HCO3)2 → CaCO3 + H2O + CO2 / Ca(HCO3)2 → CaCO3 + H2CO3

FORMULAE: (3) BALANCING: (3)

(ii) EXPLAIN: two hydrogen ions (2H+) from the cation-exchange resin (RH) replace a Ca2+ (cations, positive ions) in the water /

\[ 2\text{RH} + \text{Ca}^{2+} \rightarrow \text{R}_2\text{Ca} + 2\text{H}^+ // \]

a hydroxide (hydroxyl) ion (OH–) from the anion-exchange resin (R*OH) replaces a HCO3– (anions, negative ions) in the water /

\[ \text{R}^*\text{OH} + \text{HCO}_3^- \rightarrow \text{R}^*\text{HCO}_3^- + \text{OH}^- (2\text{R}^*\text{OH} + 2\text{HCO}_3^- \rightarrow 2\text{R}^*\text{HCO}_3^- + 2\text{OH}^-) // \]

hydrogen ion(s) (H+) and hydroxide (hydroxyl) ion(s) (OH–) combine to form water /

\[ 2\text{H}^+ + 2\text{OH}^- \rightarrow 2\text{H}_2\text{O} / \text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} \]

(3 + 3 + 2)
QUESTION 10

(a) (i) DISTNG: strong acid: good proton donor / readily donates protons / almost fully dissociated // weak acid: poor proton donor / slightly (poorly, weakly) dissociated (2 × 3) [Allow ‘Partly (partially, not fully) dissociated’ and ‘does not readily donate protons’ for weak acid description.]

(ii) CALCULATE: 0.005 M

\[
\text{pH} = -\log [H^+] \Rightarrow [H^+] = \text{inverse log} (-2) = 0.01
\]

\[
0.01 + 2 \text{ (dibasic)} = 0.005 \text{ M}
\]

CALCULATE: 5/9 (0.556) M [0.55 – 0.56 M]

\[
\Rightarrow K_a (1.8 \times 10^{-4}) = \frac{[H^+]\cdot[A^-]}{[HA]} = \frac{(0.01)^2}{1.8 \times 10^{-4}} \quad \Rightarrow \frac{[HA]}{[H^+]} = \frac{(0.01)^2}{K_a (1.8 \times 10^{-4})}
\]

\[
[H^+] = \sqrt{K_a [HA]} / 0.01 = \sqrt{1.8 \times 10^{-4}[HA]} \quad \Rightarrow [H^+] = K_a [HA] / (0.01)^2 = 1.8 \times 10^{-4}[HA]
\]

\[
[H^+] = 5/9 (0.55555) \text{ M} \quad [0.5556 – 0.56 \text{ M}]
\]

[iii] DEFINE: \( K_w = [H^+][OH^-] / K_w = [H_2O^+][OH^-] / \text{product of molar concentrations of hydrogen (hydronium) ions (H^+, H_3O^+) and hydroxide (hydroxyl) ions (OH^-) in water} \)

WHAT: 3.0 × 10^{-7} M

\[
K_w (9.0 \times 10^{-14}) = [H^+][OH^-] = \sqrt{K_w} (\sqrt{9.0 \times 10^{-14}}) / [H^+] = [OH^-]
\]

\[
[H^+] = 3.0 \times 10^{-7} \text{ M}
\]
(b) DEFINE: 

(i) **gain of (increase in)** electrons  

(ii) **reduction (decrease)** in oxidation number  

ASSIGN: 

\[ \text{ClO}^- + \text{S}_2\text{O}_3^{2-} + \text{OH}^- \rightarrow \text{Cl}^- + \text{SO}_4^{2-} + \text{H}^+ \]

\[ +1 \quad +2 \quad -1 \quad +6 \]

IDENTIFY: 

(iii) Reducing agent: \( \text{S}_2\text{O}_3^{2-} / \text{S}^{2+} / \text{S}(+2) / \text{S}(2) / \text{S}(\text{II}) / \) 

sulfur (S) in \(+2\) oxidation state / sulfur (S) in \(\text{S}_2\text{O}_3^{2-}\)  

(iv) Oxidising reagent: \( \text{ClO}^- / \text{Cl}^+ / \text{Cl}(+1) / \text{Cl}(1) / \text{Cl}(\text{I}) / \) 

chlorine (Cl) in \(+1\) oxidation state / chlorine (Cl) in \(\text{ClO}^-\)  

BALANCE: 

\[ 4\text{ClO}^- + \text{S}_2\text{O}_3^{2-} + \text{OH}^- \rightarrow 4\text{Cl}^- + 2\text{SO}_4^{2-} + \text{H}^+ \]

[Charges essential throughout.]  

Where 10 marks not awarded for the balanced equation 

\[ 4\text{ClO}^- + \text{S}_2\text{O}_3^{2-} + \text{OH}^- \rightarrow 4\text{Cl}^- + 2\text{SO}_4^{2-} + \text{H}^+ \]

award 3 marks for sulfur balanced and 3 marks for chlorine balanced. 
[Charges essential throughout.]  

or 

\[ \text{ClO}_3^- + 6\text{Br}^- + 6\text{H}^+ \rightarrow \text{Cl}^- + 3\text{Br}_2 + 3\text{H}_2\text{O} \]

[Charges essential throughout.]  

Where 10 marks not awarded for the balanced equation 

\[ \text{ClO}_3^- + 6\text{Br}^- + 6\text{H}^+ \rightarrow \text{Cl}^- + 3\text{Br}_2 + 3\text{H}_2\text{O} \]

award 3 marks for bromine balanced and 3 marks chlorine balanced.  
[Charges essential throughout.]  

*Award marks for one equation only.*
(c) (i) WHAT: atoms with same atomic number (Z) / atoms with same number of protons / atoms of same (an) element // having different mass numbers (A) / having different numbers of neutrons  

WHAT: isotope (atom) with unstable nucleus / nucleus (isotope) spontaneously decays (decomposes, emits radiation, emits alpha, beta and gamma rays) / radioactive isotope  

DEFINE: time taken // for half the sample to decay (decompose) / for activity to reduce by (to) a half  

(ii) COMPLETE: \[ \frac{\text{222}}{\text{86}} \text{Rn} \] // \[ \frac{\text{4}}{\text{2}} \text{He} \]  

(iii) HOW MANY: \[ 7.5 \times 10^{18} \text{ atoms of radium–223} \]  

\[ \frac{1 \times 10^{-4} \times 12.5}{100} = 1.25 \times 10^{-5} \text{ moles radium–223 left} \] \[ 1.25 \times 10^{-5} \times 6.0 \times 10^{23} = 7.5 \times 10^{18} \text{ atoms of radium–223} \] 

or 

\[ 1.0 \times 10^{-4} \times 6.0 \times 10^{23} = 6.0 \times 10^{19} \text{ atoms of radium–223 initially} \] \[ \frac{6 \times 10^{19} \times 12.5}{100} = 7.5 \times 10^{18} \text{ atoms radium–223 left} \] 

or 

\[ \frac{1 \times 10^{-4} \times 87.5}{100} = 8.75 \times 10^{-5} \text{ moles radium–223 decayed} \] \[ 1.0 \times 10^{-4} - 8.75 \times 10^{-5} = 1.25 \times 10^{-5} \text{ moles radium–223 left} \] \[ 1.25 \times 10^{-5} \times 6.0 \times 10^{23} = 7.5 \times 10^{18} \text{ atoms of radium–223} \] 

or 

\[ 1.0 \times 10^{-4} \times 6.0 \times 10^{23} = 6.0 \times 10^{19} \text{ atoms of radium–223 initially} \] \[ \frac{6 \times 10^{19} \times 87.5}{100} = 5.25 \times 10^{19} \text{ atoms radium–223 decayed} \] \[ 6.0 \times 10^{19} - 5.25 \times 10^{19} = 7.5 \times 10^{18} \text{ atoms radium–223 left} \]
QUESTION 11

(a) (i) WHICH: sulfur (S) (1)

WHAT: 16 g S (12)

\[
\frac{20.2}{101} \times 0.2 = 0.2 \text{ moles KNO}_3 \quad (3)
\]

\[
\frac{24.0}{32} = 0.75 \text{ moles S} \quad (3)
\]

and

\[
\frac{0.2 \times 5}{4} = 0.25 \text{ moles S required to react with 0.2 moles KNO}_3 \quad (2)
\]

\[
0.75 - 0.25 = 0.5(0) \text{ moles S unused (in excess)} \quad (2)
\]

\[
0.5 \times 32 = 16 \text{ g S unused} \quad (2)
\]

or

\[
\frac{0.75 \times 4}{5} = 0.6(0) \text{ moles KNO}_3 \text{ required to react with 0.75 moles S} \Rightarrow 0.2 \text{ moles KNO}_3 \text{ limiting} \quad (6)
\]

\[
\frac{0.2 \times 5}{4} = 0.25 \text{ moles S required to react with 0.2 moles KNO}_3 \quad (2)
\]

\[
0.75 - 0.25 = 0.5(0) \text{ moles S unused (in excess)} \quad (2)
\]

\[
0.5 \times 32 = 16 \text{ g S unused} \quad (2)
\]

or

\[
\frac{0.2}{4} < \frac{0.75}{5} \quad / \quad 0.05 < 0.15 \quad \Rightarrow 0.2 \text{ moles KNO}_3 \text{ limiting} \quad (6)
\]

\[
\frac{0.2 \times 5}{4} = 0.25 \text{ moles S required to react with 0.2 moles KNO}_3 \quad (2)
\]

\[
0.75 - 0.25 = 0.5(0) \text{ moles S unused (in excess)} \quad (2)
\]

\[
0.5 \times 32 = 16 \text{ g S unused} \quad (2)
\]

(ii) CALCULATE: 7.84 litres (6)

\[
\frac{0.2 \times 7}{4} / \frac{0.2 \times 2}{4} + \frac{0.2 \times 5}{4} = 0.35 \text{ moles gas} \quad (3)
\]

\[
0.35 \times 22.4 = 7.84 \text{ litres} \quad (3)
\]

[Award final answer of 2.24 litres and 5.60 litres (5)]
[Use of 24 L as molar volume not acceptable here.]

WHAT: 9.4 g K₂O (6)

\[
\frac{0.2 \times 2}{4} = 0.1 \text{ moles K₂O} \quad (3)
\]

\[
94* \times 0.1 = 9.4 \text{ g K₂O} \quad (3)
\]

[*Addition must be shown for error to be treated as slip.]
(b) DETERMINE: pure covalent / non-polar covalent  
[Accept slightly polar covalent.]

DRAW:

PREDICT: pyramidal (trigonal pyramidal)  
[No marks for ‘trigonal’ on its own.]

WHICH: azane / ammonia / NH₃
JUSTIFY: nitrogen (N) small and strongly electronegative / hydrogen bonds occur when hydrogen is bonded to nitrogen, oxygen, fluorine (N, O, F)  
[JUSTIFY marks only available if WHICH marks awarded.]

SUGGEST: (i) hydrogen bonding in azane (ammonia, NH₃) stronger than the other intermolecular forces (dipole-dipole, van der Waals) in phosphane or arsane / hydrogen bonding strongest type of intermolecular force //
(ii) phosphine (PH₃) molecules smaller (lighter, smallest of the two) / phosphine (PH₃) molecules have smaller (smallest of the two) molecular mass / phosphine (PH₃) has fewer (fewest of the two) electrons / phosphine (PH₃) has a smaller (smallest of the two) degree of intermolecular (van der Waals) forces  
[Accept equivalent phrases with respect to arsine (AsH₃)]
(c) A

(i) WHAT: absorbs [shields earth (us) from] ultraviolet (uv) radiation (4)

(ii) HOW: high energy {frequency (short wavelength)} radiation / ultraviolet (uv) radiation / UVC // breaks oxygen molecules (O₂) into separate atoms (radicals) / O₂ → 2O / O₂ → 2O* // these oxygen atoms (O, O*, radicals) react with oxygen molecules (O₂) to form ozone (O₃) / O + O₂ → O₃ / O* + O₂ → O₃ (3 × 3)

(iii) DESCRIBE: Cl + O₃ → ClO + O₂ / Cl* + O₃ → ClO* + O₂ // ClO + O → Cl + O₂ / ClO* + O* → Cl* + O₂ // chain reaction / process repeats (continues) / Cl (Cl*) attacks another O₃ (ozone molecule) / repeat line 1 (3 × 3)

[Radical dots not essential here.]

(iv) WHY: broken down before they reach stratosphere / broken down more easily than CFCs / broken down in troposphere / shorter atmospheric residence times / more reactive than CFCs / less stable than CFCs / CH bonds break before CF or CCl bonds in free radical reactions (3)

B

(i) GIVE: sodium (Na) used in street lighting (lasers, fireworks, desiccant, drying agent, coolant in nuclear reactors // chlorine used to disinfect (kill microorganisms) / chlorine used in water treatment (purification) / chlorine used as oxidising reagent (agent) / chlorine used in making plastics (PVC, polyvinylchloride, polychloroethene) (2 × 3)

(ii) WHY: molten sodium chloride conducts electricity / solid sodium chloride cannot (does not) conduct electricity (3)

HOW: lowers melting point (melting temperature) of electrolyte / lowers the electrolysis temperature / fluxing agent (3)

(iii) WHAT: to prevent recombination of the products / to keep products separate / to keep sodium (Na) and chlorine (Cl₂) separate (3)

(iv) WRITE: Na⁺ + Cl⁻ → Na + ½Cl₂ / 2Na⁺ + 2Cl⁻ → 2Na + Cl₂ / NaCl → Na + ½Cl₂ / 2NaCl → 2Na + Cl₂

FORMULAE: (3) BALANCING: (3)

(v) WHY: aluminium also electropositive / aluminium high up (in) electrochemical series / chemical reducing agents not strong enough to reduce aluminium ore / aluminium ore not easily reduced (4)