Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2026

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.

In considering this marking scheme for the written examination, the following points should be noted.

1. In many instances only key words are given – words that must appear in the correct context in the candidate's answer in order to merit the assigned marks.
Where incorrect terminology is used or where part of the candidate's answer contradicts another part, the marks may not be awarded. Cancellation may apply when a candidate gives more than the required number of responses, or a list of correct and incorrect answers.

2. Words, expressions or statements separated by a solidus, /, are alternatives which are equally acceptable.

3. A double solidus, //, separates answers which are mutually exclusive. A partial answer from one side of the // may not be taken in conjunction with a partial answer from the other side.

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

5. The detail required in any answer is determined by the context and manner in which the question is asked, and also by the number of marks assigned to the answer in the examination paper. Therefore, in any instance, it may vary from year to year.
Material that is bracketed is not required in that year.

6. When a candidate is asked to identify a chemical substance, either the name or formula is accepted, unless otherwise indicated. For *deionised water*, the term *distilled water* or *pure water* should also be accepted, unless otherwise indicated. For organic compounds the IUPAC name or traditional scientific name is acceptable, unless otherwise indicated. Inorganic compounds may be named using oxidation state or traditional naming convention – e.g. potassium manganate(VII) or potassium permanganate for $KMnO_4$.

7. Each time an arithmetical error occurs in a calculation, one mark is deducted; this also applies to inappropriate or incorrect rounding of numerical answers. 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 arithmetical one. If the addition of atomic masses is not shown, the candidate loses the marks for an incorrect M_r.

8. For drawing the molecular structure of an organic compound, one mark is deducted if the H atoms are omitted in a systematic way and one mark is deducted if bonds to H atoms are omitted in a systematic way.

9. For omission of appropriate units (or for incorrect units) in final answers, one mark is deducted, unless otherwise indicated.

10. A zero should only be recorded when the candidate has attempted the question item but does not merit marks. If a candidate does not attempt a question item examiners should record NR.

11. Examiners are expected to annotate each part of the candidate's response as directed at the marking conference.

For a fully correct response, examiners may award one total mark (e.g. 6 marks) or a number of partial marks (e.g. 2 marks, 2 marks, 2 marks) that add to the same total.

For an incorrect or partially incorrect response examiners should place the appropriate annotations near the correct/incorrect elements of the response such that a total mark is generated for the response (e.g. 2 marks, 0 marks, 2 marks).

Symbol	Name	Use
	Cross	Incorrect element
	Tick	Correct element (0 marks)
	Tick_n	Correct element (n marks)
	Horizontal wavy line	To be noticed
	Vertical wavy line	Additional page
	Ellipse	Incorrect material
-1	−1	−1
0	0	0
^	^	Missing element
C	C	Cancellation
[	Square bracket	Surplus element

12. 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 75% or less of the total mark available (i.e. 300 marks or less). 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. See below for when a candidate is awarded more than 300 marks.

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

1. A student carried out an experiment to determine the amount of water of crystallisation in a sample of hydrated sodium carbonate (washing soda). 5.02 g of hydrated sodium carbonate ($Na_2CO_3.xH_2O$) was placed in a small beaker. The solid was then transferred to a 250 cm^3 volumetric flask and made up to the mark using deionised water. 20.0 cm^3 portions of this solution were transferred to a conical flask and titrated against a previously standardised 0.10 M hydrochloric acid (HCl) solution. On average, 28.35 cm^3 of 0.10 M hydrochloric acid solution were required to neutralise the 20.0 cm^3 of the sodium carbonate (Na_2CO_3) solution. The titration reaction is described by the following balanced chemical equation:

$$2HCl + Na_2CO_3 \rightarrow 2NaCl + H_2O + CO_2$$

(*a*) (*i*) Describe a suitable method to accurately transfer all the hydrated sodium carbonate from the beaker to the volumetric flask.

reference to use of deionised water //

use funnel to transfer substance //

addition of rinsing's (from beaker and funnel to volumetric flask) [*any two*] [5+2]

(*ii*) Explain why hydrated sodium carbonate ($Na_2CO_3.xH_2O$) is not considered a primary standard.

undergoes efflorescence / value of x changes [2]

(*b*) (*i*) Describe how the burette was rinsed before use.

with deionised water

with HCl / solution it will contain

(*ii*) State two precautions that should be taken as the end point of the titration is approached to ensure an accurate titration result.

add drop by drop // rinse inside of flask with deionised water // swirl solution [*any two*] [6+2+2+2]

(*c*) (*i*) Identify a suitable indicator for use in this titration.

e.g. methyl orange [3]

(*ii*) State the colour change that would be observed at the endpoint in this titration.

e.g. from yellow / orange [3]

to pink / red [3]

[suitable indicator identified in part (i) allow 3 marks for both correct colours reversed]

(*d*) (*i*) Calculate the number of moles of HCl present in 28.35 cm^3 of the 0.10 M HCl solution.

$\frac{0.10}{1000}$ × 28.35 = 0.002835 (moles of HCl per 28.35 cm^3) [4]

(*ii*) Calculate the number of moles of Na_2CO_3 in the 250 cm^3 solution.

0.002835 ÷ 2 = 0.0014175 (moles of Na_2CO_3 per 20 cm^3) [2]

0.0014175 × 12.5 = 0.01772 (moles of Na_2CO_3 per 250 cm^3) [2]

(*iii*) Calculate the mass of Na_2CO_3 in the 250 cm^3 solution.

Mr = 106 [2]

0.01772 × 106 = 1.88 (g per 250 cm^3) [2]

(*iv*) Calculate number of moles of water of crystallisation in the sample of $Na_2CO_3.xH_2O$.

5.02 – 1.88 = 3.14 (g) [2]

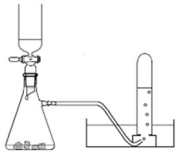
3.14 ÷ 18 = 0.174 (moles) [2]

(*v*) Determine the value of x, the average number of water molecules in the formula $Na_2CO_3.xH_2O$.

0.01772 moles : 0.174 moles [2]

x = 9.8 / 10 [2]

2. (*a*) Ethyne gas (C_2H_2) was prepared in a school laboratory and collected by displacement of water as shown.



(*i*) Identify the two reactants used in the preparation of ethyne gas.
calcium carbide / CaC_2 **[2]**
water / H_2O **[2]**

(*ii*) Explain the principle that allows ethyne to be collected by displacement of water.
ethyne is insoluble in water /
water is polar / ethyne non-polar **[6]**

(*iii*) State one precaution that should be taken to ensure a pure sample of ethyne gas is collected.
discard the first test tube of gas collected /
bubble through acidified copper sulfate **[3]**

(*iv*) Identify a reagent that could be used to show ethyne is unsaturated
acidified potassium permanganate / bromine (water) **[3]**

(*v*) State the colour change observed for the reagent you have identified.
from purple / pink // yellow / orange / brown **[3]**
to colourless [*do not accept clear*] **[3]**
[*colour change must match reagent in iv*]

(*b*) A sample of soap was prepared by a student by refluxing vegetable fat with excess sodium hydroxide in the presence of a suitable solvent.

(*i*) Name the type of reaction that occurred during reflux.
saponification / base hydrolysis / substitution

(*ii*) Identify a suitable solvent for use in the preparation of soap.
ethanol / alcohol

The solvent was removed by distillation.

(*iii*) Why was it desirable to remove the solvent after the reflux?
soap is soluble in the solvent / maximise yield of soap

(*iv*) How was the soap isolated from the other substances left in the reaction mixture?
reference to using brine //
reference to filtration **[6+3+2+2+2]**

(*c*) Ethanoic acid reacts with excess magnesium metal according to the following equation:

$$2CH_3COOH + Mg \rightarrow X + H_2$$

(*i*) Identify X, that is produced during the above reaction.
$(CH_3COO)_2Mg$ / magnesium ethanoate **[3]**

(*ii*) 15 cm^3 of a 5% (w/v) solution of ethanoic acid was reacted with excess magnesium metal. Calculate the volume of hydrogen gas (**H_2**) produced at room temperature and pressure.
5 g per 100 cm^3 / 0.75 g per 15 cm^3 **[2]**
Mr = 60 **[2]**
$\frac{0.75}{60}$ = 0.0125 (moles CH_3COOH per 15 cm^3) **[2]**
0.0125 ÷ 2 = 0.00625 (moles H_2 per 15 cm^3) **[2]**
0.00625 × 24 = 0.15 L **[2]**

3. (*a*) A colorimeter or comparator can be used to measure the concentration of free chlorine in swimming pool water.

(*i*) What is the general principle of all colorimetric experiments?

absorbance (of light) // transmission (of light)

directly proportional to concentration // inversely proportional to concentration **[4+2]**

(*ii*) Why is chlorine added to swimming pool water?

kill (harmful) microorganisms **[3]**

(*iii*) Identify the free chlorine species present in swimming pool water.

HOCl / hypochlorous acid / $^{-}$OCl / hypochlorite ions **[3]**

(*iv*) Identify a suitable reagent(s) to test for free chlorine in swimming pool water.

potassium iodide / KI and ethanoic acid / CH_3COOH // DPD **[3]**

(*v*) State the colour change that occurs when the reagents identified in (*iv*) react with free chlorine.

from colourless

to red / brown // pink / red **[3+2]**

[*colour change must match reagent in iv*]

(*b*) The total mass of *suspended* and *dissolved* solids in a 1250 cm^3 sample of swimming pool water was 1.750 g. The concentration of total *suspended* solids was 520 p.p.m.

(*i*) Describe a suitable method that could be used to measure the concentration of total *suspended* solids in the water sample.

pour solution through pre-weighed filter paper //

allow to dry //

(reweigh and) calculate difference in mass **[5+2+2]**

(*ii*) Calculate the concentration of *dissolved* solids in p.p.m.

1.750 × 1000 = 1750 (mg) **[3]**

1750 × $\frac{1000}{1250}$ = 1400 (p.p.m.) **[3]**

1400 – 520 = 880 (p.p.m.) **[3]**

(c) The type and quantities of *dissolved* solids found in swimming pool water can vary depending on the treatment chemicals used and the source of the water. Examples include sodium chloride, sodium sulfate and sodium nitrate.

(*i*) Describe a chemical test to confirm the presence of nitrate ions in the water sample.

add $FeSO_4$ / iron(II) sulfate //

add H_2SO_4 / concentrated sulfuric acid //

brown ring **[4+2+2]**

(*ii*) Which of the two remaining salts can be identified by the addition of a solution of silver nitrate ($AgNO_3$)? What observation indicates a positive test result?

NaCl / sodium chloride / chloride **[2]**

white precipitate **[2]**

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 attempted.***

(*a*) How many (*i*) protons, (*ii*) electrons are present in the ion Co^{2+}?

(i) 27 **[3]**

(ii) 25 **[3]**

(*b*) Name the scientist who determined (*i*) the *e*/*m* of the electron,
(*ii*) the magnitude of charge on an electron.

(i) Thomson **[3]**

(ii) Millikan **[3]**

(*c*) Write a balanced equation for the beta decay of a carbon–14 nucleus.

$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$ / $^{0}_{-1}\beta$ **[3×2]**

(*d*) Account for the difference in bond angle between $BeCl_2$ (180°) and H_2O (104.5°).

presence of lone pairs on water **[6]**

(*e*) Calculate the relative atomic mass, correct to two decimal places, of a sample of chlorine containing 75.76% of the chlorine–35 isotope and 24.24% of the chlorine–37 isotope.

(75.76 × 35) + (24.24 × 37) / 2651.6 + 896.88 = 3548.48 **[3]**

3548.48 ÷ 100 = 35.48 **[3]**

(*f*) Identify (*i*) the conjugate acid, (*ii*) conjugate base of HPO_4^{2-}.

(i) $H_2PO_4^-$ **[3]**

(ii) PO_4^{3-} **[3]**

(*g*) State the principle of the separation of the components in a mixture using chromatography.

mobile phase and stationary phase **[3]**

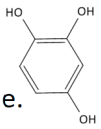
substances have selective adsorption / different affinities for either phase **[3]**

(*h*) Identify a substance (*i*) used in water treatment to increase the pH of water,
(*ii*) used to fluoridate drinking water.

(i) $Ca(OH)_2$ / calcium hydroxide / (slaked) lime **[3]**

(ii) NaF / sodium fluoride **[3]**

(*i*) Calculate the number of molecules of hydroxyhydroquinone, whose structure is shown on the right, in a cup of espresso coffee which contains 0.0017 g of hydroxyhydroquinone.



Mr = 126 **[2]**

$\frac{0.0017}{126}$ **= 1.349×10^{-5} (moles of $C_6H_6O_3$)** **[2]**

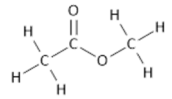
$1.349 \times 10^{-5} \times 6 \times 10^{23} = 8.1 \times 10^{18}$ **[2]**

(*j*) Identify the elements produced at (*i*) the anode, (*ii*) the cathode during the electrolysis of potassium iodide.

(i) I_2 / iodine **[3]**

(ii) H_2 / hydrogen / K / potassium **[3]**

(*k*) Draw the structure, including all atoms and all bonds, of the organic compound formed when methanol and ethanoic acid are reacted together in the presence of an acid catalyst.



[6]

(*l*) (A) Describe how atmospheric nitrogen gas is fixed by lightning.

energy (from lightning) **[3]**

causes nitrogen to react with oxygen / $N_2 + O_2 \rightarrow 2NO$ **[3]**

(B) State an example of (*i*) a molecular crystal, (*ii*) a covalent macromolecular crystal.

(i) iodine (I_2) / carbon dioxide (dry ice, CO_2) *etc.* **[3]**

(ii) diamond / graphite / graphene *etc.* **[3]**

5. The arrangement of elements in the modern periodic table helps to predict patterns and trends in the properties of elements. Refer to the data on page 80 and 81 of the *Formulae and Tables* booklet when answering the following questions.

(*a*) (*i*) Explain what is meant by the first ionisation energy of an element.

the minimum (amount of) energy //
required to remove an electron from an isolated atom / atom in the gaseous state
$X_{(g)} \rightarrow X^+_{(g)} + e^-$ **[4+2]**

(*ii*) State two reasons why oxygen (O) has a higher first ionisation energy value than sulfur (S).

oxygen: shorter atomic radius // less shielding / screening
// greater effective nuclear charge [*any two*] **[4+2]**

(*iii*) Explain why boron (B) has a lower first ionisation energy than beryllium (Be).

boron: one electron in 2p subshell has lower stability /
beryllium: full 2s subshell has extra stability **[3]**

(*iv*) Which element would you expect to have the higher second ionisation energy sodium (Na) or magnesium (Mg)? Justify your answer.

sodium
removing an electron from a stable / noble gas electron configuration **[4+2]**

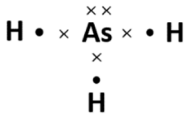
(*b*) (*i*) Explain what is meant by the term electronegativity.

relative attraction of atom
for a shared pair of electrons **[4+2]**

(*ii*) Use electronegativity values to predict the type of bonding in a molecule of AsH_3.

2.20 – 2.18 = 0.02 / reference to small difference in electronegativity
non-polar (covalent) / slightly polar (covalent) **[3+2]**

(*iii*) Draw a dot and cross diagram to show the arrangement of electrons in a molecule of AsH_3.



[5]

[maximum 3 marks if lone pair is omitted from As]

(*iv*) Would you expect an AsH_3 molecule to be polar or non-polar? Justify your answer.

polar
lone pair of electrons / not symmetrical / pyramidal **[4+2]**

(*c*) An element, X, has a low first ionisation energy and a low electronegativity value. Predict whether element X would make a suitable oxidising agent or reducing agent. Justify your answer.

reducing agent
readily donates / loses electrons **[5+2]**

6. Crude oil is a complex mixture of hydrocarbon molecules. In an oil refinery these molecules are separated into different fractions. Some of these fractions are useful but others need further chemical processing. For example, the unprocessed gasoline fraction cannot be used as petrol as it has a very low octane number.

(*a*) (*i*) Explain what is meant by the octane number of a fuel.
measure of (resistance to) knocking / auto-ignition

(*ii*) Identify the two reference hydrocarbons used to establish the octane number of a fuel.
heptane
2,2,4-trimethylpentane

(*iii*) State two structural features of molecule that would contribute to it having a high octane number.
branched // cyclic // short chain **[*any two*]** **[6+3+2+2+2]**

(*b*) Several processes are used in oil refining to increase the octane number of a fuel.

A $C_6H_{14} \rightarrow X + 4H_2$

B $C_{18}H_{38} \rightarrow C_6H_{14} + C_4H_8 + C_2H_4 + 2Y$

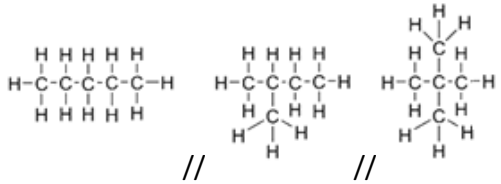
C $C_5H_{12} \rightarrow C_5H_{12}$

(*i*) Name molecule X which is formed as part of process A.
benzene **[3]**

(*ii*) Deduce the molecular formula for Y.
C_3H_6 **[3]**

(*iii*) Name the homologous series to which Y belongs.
alkene **[3]**

(*iv*) Draw the three possible isomers of the molecule C_5H_{12} including all atoms and bonds.



// // **[3×3]**

(*c*) (*i*) Explain what is meant by the term heat of formation.
heat change when one mole of a compound is formed **[2]**
from its elements in their standard states. **[2]**

The Claus process is used in oil refining to convert hydrogen sulfide (H_2S), a toxic gas, to sulfur (S) and steam (H_2O). The reaction can be described by the following balanced chemical equation: $SO_{2(g)} + 2H_2S_{(g)} \rightarrow 3S_{(s)} + 2H_2O_{(g)}$ $\Delta H = -145.6$ kJ mol^{-1}
The heats of formation of sulfur dioxide (SO_2) and steam (H_2O) are –296.8 kJ mol^{-1} and –241.8 kJ mol^{-1} respectively.

(*ii*) Use the information above to calculate the heat of formation (ΔH) of hydrogen sulfide (H_2S).

– (–145.6) **= [+145.6] // [+72.8]** **(2 [multiplicative factor] +1 [sign])**

– (–296.8) **= [+296.8] // [+148.4]** **(2 [multiplicative factor] +1 [sign])**

+ (–241.8) **= [–483.6] // [–241.8]** **(2 [multiplicative factor] +1 [sign])**

ΔH_f = –20.6 kJ mol^{-1} **[*allow 2 marks for answer –41.2 (kJ)*]** **[4]**

7. Steam reforming is a common industrial method used for the production of hydrogen gas. A mixture of 7.6 moles of methane (CH_4) and 10.4 moles of steam (H_2O) were heated over a nickel catalyst in a sealed 4 litre container at temperature T_1. They reacted to form hydrogen gas (H_2) and carbon monoxide (CO). An equilibrium was established which is described by the following balanced chemical equation:

$$CH_{4(g)} + H_2O_{(g)} \rightleftharpoons CO_{(g)} + 3H_{2(g)} \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

(*a*) (*i*) Explain what is meant by the term chemical equilibrium.

rate of the forward and reverse reactions are equal / the concentration of the reactants and products are constant in a reversible reaction

(*ii*) What effect does the use of a catalyst have on the position of the equilibrium? Explain your answer.

no effect

catalyst affects the rate of the forward and reverse reactions to the same extent / does not change the final concentration of reactants or products **[6+3+2]**

(*b*) At equilibrium, at temperature T_1, there were 6.8 moles of carbon monoxide in the container.

(*i*) Calculate the number of moles of **CH_4** present in the equilibrium mixture.

7.6 – 6.8 = 0.8 (moles of CH_4) **[3]**

(*ii*) Calculate the number of moles of **H_2O** present in the equilibrium mixture.

10.4 – 6.8 = 3.6 (moles of H_2O) **[3]**

(*iii*) Calculate the number of moles of **H_2** present in the equilibrium mixture.

6.8 × 3 = 20.4 (moles of H_2) **[3]**

(*iv*) Write an expression for the equilibrium constant K_c for this reaction.

$$\frac{[CO][H_2]^3}{[CH_4][H_2O]}$$ ***[award 3 marks if round brackets are used]*** **[6]**

(*v*) Calculate the value of K_c for the equilibrium correct to one decimal place at temperature T_1.

convert to moles per litre (÷4) **[3]**

i.e. $\frac{0.8}{4}$ **= 0.2 (mol L^{-1} of CH_4),** $\frac{3.6}{4}$ **= 0.9 (mol L^{-1} of H_2O),**

$\frac{6.8}{4}$ **= 1.7 (mol L^{-1} CO),** $\frac{20.4}{4}$ **= 5.1 (mol L^{-1} H_2)**

$K_c = \frac{[1.7][5.1]^3}{[0.2][0.9]}$ **= 1252.8 (mol^2 L^{-2})** **[3]**

(*c*) (*i*) State Le Châtelier's principle.

systems at equilibrium

oppose an applied stress **[4+2]**

(*ii*) Predict the effect on K_c if the same reaction is carried out at the same temperature T_1 but the initial concentrations of reactants are halved. Explain your answer.

no effect

ratio of reactants to product does not change / only temperature affects K_c **[4+2]**

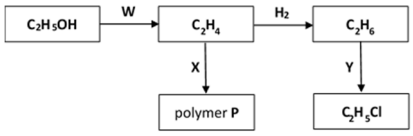
When the mixture was allowed to come to equilibrium at temperature T_2 in the same 4 litre container it was observed that the value of K_c increased.

(*iii*) Which is the higher temperature, T_1 or T_2? Justify your answer.

T_2

forward reaction is endothermic / forward reaction favoured **[4+2]**

8. Study the reaction scheme below and answer the questions that follow.



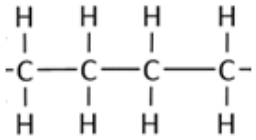
(*a*) (*i*) Name the homologous series to which C_2H_5OH belongs]
alcohols **[2]**

(*ii*) Identify the catalyst and conditions required for conversion W to take place.
Al_2O_3 / aluminium oxide **[2]**
heat **[2]**

(*iii*) Conversion W is an elimination reaction. State two features of conversion W that show it is an elimination reaction.
double bond formed / reference to correct change in geometry **[3]**
smaller molecule / H_2O formed **[3]**

(*b*) C_2H_4 can undergo addition and polymerisation reactions.

(*i*) Draw two repeating units of the polymer formed when C_2H_4 undergoes addition polymerisation, showing all atoms and all bonds.



[*allow 3 marks for omission of C– at ends*] **[6]**

(*ii*) Name the polymer produced in reaction X.
polyethene **[3]**

(*iii*) How does the geometry around the carbon atoms change during reaction X?
from planar **[3]**
to tetrahedral **[3]**

(*iv*) Explain how the nature of the bonding in C_2H_4 enables it to undergo addition and polymerisation.
presence of double bond / pi electrons **[4]**

(*c*) Reaction Y occurs via free radical substitution.

(*i*) Identify the reagent and conditions necessary for the formation of free radicals during the initiation stage of this reaction.
Cl_2 **[2]**
uv **[2]**

(*ii*) Is the formation of free radicals during the initiation stage an endothermic or exothermic process? Justify your answer.
endothermic **[2]**
requires energy to break bonds **[2]**

(*iii*) Use balanced chemical equations to show the formation of free radicals during the two propagation reactions.
$C_2H_6 + Cl^{\bullet} \rightarrow C_2H_5^{\bullet} + HCl$ **[4]**
$C_2H_5^{\bullet} + Cl_2 \rightarrow C_2H_5Cl + Cl^{\bullet}$ **[4]**

(*iv*) Explain why the addition of tetraethyl lead greatly speeds up reaction Y.
source of radicals **[3]**

9. (*a*) Nitrogen dioxide (NO_2) decomposes in the presence of a metal catalyst according to the following balanced chemical equation: $2NO_{2(g)} \rightarrow N_{2(g)} + 2O_{2(g)}$

The following data were obtained at temperature *T* for the decomposition of NO_2 gas by a metal catalyst.

time (s)	0	50	100	300	400	600
concentration of NO_2 (mol L^{-1})	0.010	0.0079	0.0065	0.0038	0.0034	0.0030

(*i*) Plot a graph on graph paper of concentration versus time for the decomposition of NO_2 gas.

axes labelled **[3]**

points plotted **[6×1]**

[maximum of 3 marks for points plotted on paper other than graph paper]

curve of good fit **[2]**

(*ii*) Calculate the instantaneous rate of decomposition at 300 s.

tangent at 300 s **[2]**

data obtained from tangent **[2]**

data used to calculate answer **[2]**

(*iii*) What effect, if any, would you expect an increase in temperature to have on the rate of decomposition? Justify your answer.

increase **[2]**

more particles with required activation energy / increased kinetic energy / increased effective collisions **[2]**

(*iv*) Show clearly on your graph the result you would expect to obtain if the surface area of the catalyst was doubled.

steeper curve levelling off at 0.0030 **[2]**

(*b*) The reaction above is one of several that occur in the catalytic converters of cars and is an example of heterogeneous catalysis.

(*i*) Identify a metal that acts as catalyst in catalytic converters.

platinum / Pt / palladium / Pd / rhodium / Rh **[3]**

(*ii*) Use a balanced chemical equation to describe one other reaction that is catalysed by a catalytic converter.

$CO + ½O_2 \rightarrow CO_2$ / $2NO + 2CO \rightarrow 2CO_2 + N_2$ /

complete combustion of a hydrocarbon e.g. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ *etc.* **[4+2]**

(*iii*) Identify a substance which poisons the catalysts in a catalytic converter.

lead / sulfur etc. **[3]**

(*iv*) Explain how a catalytic poison reduces the efficiency of a catalyst.

prevents adsorption of reactants / blocks the active sites **[3]**

(*c*) The diagram shows the oxidation of methanol using platinum wire as catalyst.

(*i*) State one observation made during this experiment.

pop / flame / glowing wire / odour

(*ii*) Why can this reaction also be described as an example of heterogeneous catalysis?

the catalyst and reactant are in different phases

[*different states not acceptable*]

(*iii*) Describe the mechanism by which the catalyst increases the rate of this reaction.

adsorption (of reactants) //

reaction occurs at the surface / on catalyst //

desorption / release (of products) **[4+2+2+2+2]**

10. (*a*) In 1861, Robert Bunsen and Gustav Kirchhoff used flame tests to study the line emission spectra of elements. Their work resulted in the discovery of a new element, rubidium (Rb).

(*i*) What is a line emission spectrum?

discrete coloured lines (on a dark background) **[3]**

(*ii*) Describe a suitable method for distinguishing between metal salts using a flame test.

sample on pre-soaked (wooden) splint /nichrome wire / dissolved in alcohol //
exposed to (blue) Bunsen flame //
observe colour of flame **[*any two*]** **[2×3]**

(*iii*) Name the instrument used for viewing the line emission spectra of elements.

spectroscope / spectrometer **[2]**

(*iv*) Describe how line emission spectra occur.

atom / electron in ground state absorbs a fixed amount of energy **[2]**
electron jumps to an excited state / a higher energy level **[2]**
(excited) electron falls to a lower energy level **[2]**
(energy) emitted as photon **[2]**

(*v*) What evidence do line emission spectra provide for the existence of energy levels in atoms?

electrons restricted to certain energy values /
only fixed frequencies are emitted / E2–E1 = hf **[3]**

(*vi*) Explain why the line emission spectra of hydrogen and rubidium differ.

different distributions of energy levels / electron configurations / more electrons **[3]**

(*b*) (*i*) Explain what is meant by the term ideal gas.

obeys the gas laws / the kinetic theory of gases
under all conditions of temperature and pressure

(*ii*) State two conditions under which real gases come closest to ideal behaviour.

high temperature
low pressure

[6+5+2+2]

(*iii*) Assuming ideal behaviour, calculate the volume occupied by 0.06 moles of a gas at a pressure of 99 kPa and a temperature of 25 °C.

p = 99000 Pa **[2]**
T = 273 (.15) + 25 = 298 K **[2]**
pV=nRT / (99000)(V) = (0.06)(8.3)(298) **[2]**
V = 0.0015 m^3 **[*correct value for R required for final marks*]** **[2]**

At standard temperature and pressure the molar volume of ammonia (NH_3) may be 1.3% less than that of an ideal gas.

(*iv*) Explain why the molar volume of ammonia may be less than that of an ideal gas under these conditions.

presence of intermolecular forces **[2]**
[*accept a named intermolecular force as an alternative to "intermolecular forces"*]

(*c*) Benzoic acid can be synthesised by the reaction of phenylmethanol $C_6H_5CH_2OH$ with potassium permanganate $KMnO_4$ in alkaline conditions. 6.32 g of $KMnO_4$ were reacted with 2.70 cm^3 of $C_6H_5CH_2OH$ (density = 1.04 g cm^{-3}). 1.97 g of pure benzoic acid was isolated.
The reaction can be described by the following balanced chemical equation:

$$3C_6H_5CH_2OH + 4KMnO_4 \rightarrow 3C_6H_5COOH + 4MnO_2 + H_2O + 4KOH$$

(*i*) Calculate the number of moles of $C_6H_5CH_2OH$ present at the start of the reaction.

2.70 × 1.04 = 2.808 (g) **[2]**

Mr($C_6H_5CH_2OH$) = 108 **[2]**

$\frac{2.808}{108}$ **= 0.026 (moles of $C_6H_5CH_2OH$)** **[2]**

(*ii*) Show by calculation that $KMnO_4$ is in excess.

Mr($KMnO_4$) = 158 **[2]**

$\frac{6.32}{158}$ **= 0.040 (moles of $KMnO_4$) present** **[2]**

0.026 × $\frac{4}{3}$ **= 0.0347 (moles of $KMnO_4$) required** **[2]**

(*iii*) Calculate the mass of unreacted $KMnO_4$ remaining in the reaction mixture.

0.040 – 0.0347 = 0.0053 (moles) **[2]**

0.0053 × 158 = 0.837 (g of $KMnO_4$ unused) **[2]**

(iv) Calculate the theoretical yield of benzoic acid.

0.026 (moles of C_6H_5COOH) **[2]**

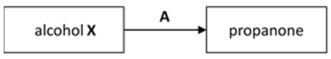
(v) Calculate the percentage yield of benzoic acid.

Mr = 122 **[2]**

$\frac{1.97\text{ g}}{3.17\text{ g}} / \frac{0.01615\text{ moles}}{0.026\text{ moles}}$ **[2]**

× 100 = 62.1 (%) **[3]**

11. (*a*) The reaction scheme below shows the synthesis of propanone from alcohol X.



(*i*) Classify conversion A as an addition, substitution or redox reaction.
redox

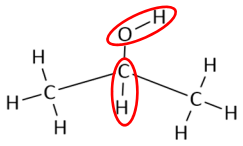
(*ii*) Identify a suitable reagent to bring about conversion A.
oxidising reagent e.g. acidified potassium permanganate

(*iii*) State the systematic IUPAC name for alcohol X.
propan-2-ol

[5+2+2]

(*iv*) Draw the structure of a molecule of alcohol X showing all of its atoms and all of its bonds. Clearly indicate on your diagram the bond(s) broken in alcohol X during conversion A.

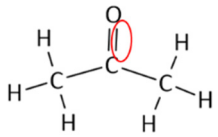
[3]



[2×2]

(v) Draw the structure of a molecule of propanone showing all of its atoms and all of its bonds. Clearly indicate on your diagram the bond(s) formed in propanone during conversion A.

[3]



[2]

(*vi*) An isomer of propanone can be synthesised from a primary alcohol. Identify both the isomer of propanone and the primary alcohol.
propanal / C_2H_5CHO **[2]**
propan-1-ol / $CH_3CH_2CH_2OH$ / $C_2H_5CH_2OH$ **[2]**

(*b*) (*i*) Define oxidation in terms of electron transfer.
loss of electrons **[4]**

(*ii*) State the oxidation number of **Mn** in **MnO_4^-**.
+ 7 **[3]**

(*iii*) State the oxidation number of **C** in **$C_2O_4^{2-}$** and **CO_2**.
$C_2O_4^{2-}$ = + 3 **[3]**
CO_2 = + 4 **[3]**

(*iv*) Hence or otherwise, balance the following chemical equation:
$MnO_4^- + H^+ + C_2O_4^{2-} \rightarrow Mn^{2+} + H_2O + CO_2$

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

(*v*) Identify the reducing agent in the reaction above. Justify your answer.
$C_2O_4^{2-}$
undergoes oxidation / loses electrons **[4+2]**

(*c*)

acid	initial concentration	pH at 25 °C
HCl	0.1 M	1.0
CH_3COOH	0.1 M	2.8

(*i*) Explain what is meant by the term Brønsted-Lowry acid.

proton donor **[3]**

(*ii*) Write a balanced equation to show CH_3COOH acting as a Bronsted-Lowry acid in water.

$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$ **[4×1 +2]**

(*iii*) Use the information provided to calculate K_a, the acid dissociation constant, of CH_3COOH at 25 °C.

$pH = -\log_{10}[H_3O^+]$ / $[H^+] = \sqrt{K_a M_{acid}}$ / $[H^+] = 10^{-2.8}$ **[2]**

$[H^+] = 1.585 \times 10^{-3}$ **[2]**

$K_a = 2.51 \times 10^{-5}$ **[2]**

The solution of HCl is diluted by a factor of 100.

(*iv*) Calculate the pH of the diluted HCl solution.

$0.1 \div 100 = 0.001$ (moles l^{-1}) **[3]**

$-\log_{10}[0.001] = 3$ **[3]**

(*v*) Both acids have the same initial concentration. Explain, with reference to the hydrogen ion concentration, the difference in their pH values.

CH_3COOH is a weak acid / does not dissociate completely / less H^+ ions in solution **[4]**

(*d*) **(A)** Carbon dioxide is a greenhouse gas. According to Ireland's Central Statistics Office, in 2023 Ireland had the second highest emissions in the EU with an average of 10.4 tonnes of carbon dioxide emitted for every person in the country.

(*i*) Explain what is meant by the term greenhouse gas.

gas in (Earth's) atmosphere that traps heat **[3]**

(*ii*) State two major ways in which human activity contributes to the addition of carbon dioxide to the atmosphere.

burning fossil fuels // rotting vegetation // respiration etc. [any two] **[2×2]**

Carbon dioxide is an acidic oxide. Acidic oxides can be removed from waste gases using scrubbers in chimneys.

(*iii*) Explain what is meant by the term acidic oxide.

reacts with water to form an acid **[3]**

(*iv*) Describe how you would demonstrate, in a school laboratory, that carbon dioxide is an acidic oxide.

bubble through litmus /universal indicator **[3]**

turns red / pH less than 7 **[3]**

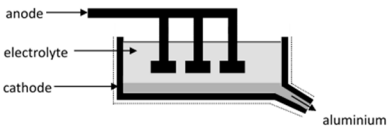
(*v*) Identify a reagent used in scrubbers to remove acidic oxides.

limestone **[3]**

(*vi*) Identify three chemical species formed as a result of carbon dioxide gas dissolving in water.

H_2CO_3 // HCO_3^- // CO_3^{2-} // H_3O^+ **[3×2]**

(B) Alumina (Al_2O_3) can be processed into pure aluminium by electrolysis in an electrochemical cell similar to that shown in the diagram below.



(*i*) Name the ore from which alumina can be obtained.

bauxite **[4]**

(*ii*) Why must the Al_2O_3 be molten or dissolved for the electrolysis stage?

to conduct electricity **[3]**

(*iii*) Identify a suitable material for use as the anode.

graphite **[3]**

(*iv*) Write a balanced chemical equation for the reaction that takes place at the anode.

$2O^{2-} \rightarrow O_2 + 4e^-$ **[3×1 + 3]**

(*v*) Identify a suitable material for use as the cathode.

graphite **[3]**

(*vi*) Write a balanced chemical equation for the reaction that takes place at the cathode.

$Al^{3+} + 3e^- \rightarrow Al$ **[3×1 + 3]**