



Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2024

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
	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%

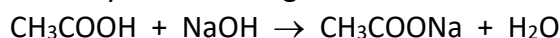
Bain úsáid as an tábla seo i gcás na n-ábhar a bhfuil 400 marc san iomlán ag gabháil leo agus inarb é 10% gnáthráta an bhónais.

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

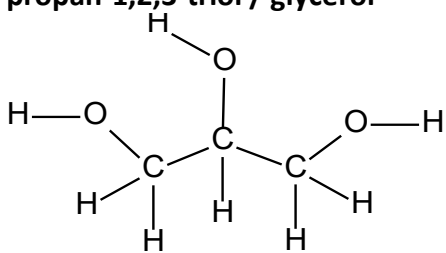
Bunmharc	Marc Bónais
351 - 353	14
354 - 356	13
357 - 360	12
361 - 363	11
364 - 366	10
367 - 370	9
371 - 373	8
374 - 376	7
377 - 380	6
381 - 383	5
384 - 386	4
387 - 390	3
391 - 393	2
394 - 396	1
397 - 400	0

1. A student carried out an experiment to determine the concentration of ethanoic acid in vinegar. A 10.0 cm³ portion of the vinegar was first diluted to exactly 50.0 cm³. The diluted vinegar solution was titrated against a 0.09 M sodium hydroxide solution in a conical flask. On average, 12.4 cm³ of the *diluted* vinegar were required to neutralise 25.0 cm³ of the NaOH solution. The titration reaction is described by the following balanced chemical equation:



- (a) (i) Name the piece of apparatus used to measure accurately the 10.0 cm³ portion of the original vinegar.
pipette / burette [accept graduated cylinder / syringe] (3)
- (ii) Describe how this piece of apparatus was rinsed before use.
with deionised water (3)
with vinegar (3)
- (iii) Describe a suitable method to dilute the 10.0 cm³ portion of the original vinegar to exactly 50.0 cm³.
add (10.0 cm³ of original) vinegar to (50 cm³) volumetric flask (3)
to mark with deionised water / (add water to) bring bottom of meniscus to mark (3)
- (b) (i) Calculate the volume of *undiluted* vinegar which would be required to neutralise 25.0 cm³ of the 0.09 M NaOH solution.
reference to a factor of 5 [state/imply] (3)
12.4 ÷ 5 = 2.48 (cm³) [accept 2.5 (cm³)] (3)
- (ii) Outline an advantage of diluting the vinegar before carrying out the titration.
smaller (%) error / more accurate (volume) / less (concentrated) NaOH (3)
- (c) (i) Name a suitable indicator for this titration.
phenolphthalein (3)
- (ii) State the colour change observed at the end point.
pink [do not accept purple] (3)
to colourless [do not accept clear] (3)
[award 3 marks for both correct colours reversed]
- (d) (i) Calculate the number of moles of sodium hydroxide in each 25.0 cm³ portion.
 $\frac{0.09 \times 25.0}{1000} = 0.00225$ (moles) (4)
- (ii) Calculate the number of moles of ethanoic acid in each cm³ of the *diluted* vinegar.
0.00225 ÷ 12.4 = 0.00018 (moles) (4)
- (iii) Calculate the concentration of ethanoic acid in the original vinegar in moles per litre.
0.00018 × 1000 (2)
× 5 = 0.91 (M) (2)
- (iv) Calculate the concentration of ethanoic acid in the original vinegar in % (w/v).
M_r = 60 (2)
 $\frac{0.91 \times 60}{10} = 5.44$ (%) (3)

2. (a) A student carried out an experiment to purify benzoic acid by recrystallisation, using water as the solvent.
- (i) Explain why water is a suitable solvent for carrying out this recrystallisation.
**(benzoic acid has) low solubility in cold water /
 (benzoic acid has) high solubility in hot water** (4)
- (ii) Explain the purpose of the first (hot) filtration.
to remove insoluble impurities (4)
- (iii) Fluted filter paper in a warm funnel, as shown on the right, is used in the hot filtration. Explain why this arrangement is suitable for hot filtration.
**increased surface area / faster filtration / keeps solution warm /
 avoids benzoic acid coming out of solution / increases yield** (4)
- (iv) Explain why the second filtration is only carried out after a sufficient period of cooling.
to maximise the yield / to allow crystallisation (3)
- (v) What observation would the student make that shows that the recrystallised benzoic acid was pure?
melting point (3)
over a narrow range / sharp / close to correct value (2)
- (b) A second student carried out a test to show that ethanal is easily oxidised.
- (i) Identify the reagent(s) which the student could have used.
acidified KMnO_4 (solution) // Fehling's (A and B) // Tollen's (reagent) (3)
- (ii) State the colour change observed for the reagent(s) you have identified.
pink/purple // blue // colourless (3)
to colourless // to red // to silver (3)
[award 3 marks for both correct colours reversed]
- (iii) Identify the organic substance produced in this test.
ethanoic acid (3)
- (iv) Write a half equation for the reduction of the inorganic reagent used in this test.
 $\text{Mn}^{7+} \rightarrow \text{Mn}^{2+}$ // $\text{Cu}^{2+} \rightarrow \text{Cu}^+$ // $\text{Ag}^+ \rightarrow \text{Ag}$ (3)
- (c) A third student prepared soap in the laboratory.
- (i) Identify the reactants used in the preparation of soap.
fat / lard / oil / triglyceride / e.g. glyceryl tristearate / stearin / tristearin (3)
sodium hydroxide / potassium hydroxide (3)
- (ii) Identify the solvent used in the preparation of soap.
ethanol (3)
- (iii) Name the co-product formed when soap is prepared in this way.
 Draw the molecular structure of this co-product, including all atoms and bonds.
propan-1,2,3-triol / glycerol **[accept glycerin/glycerine]** (3)



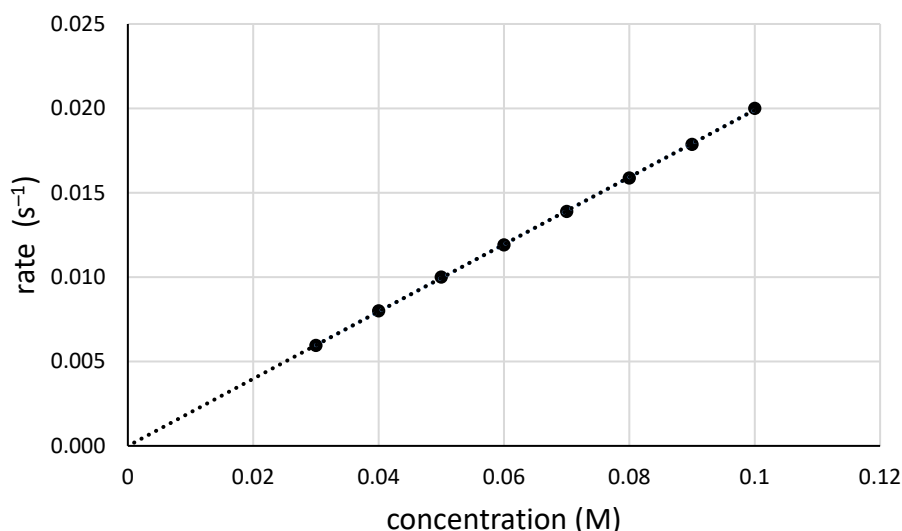
(3)

3. The reaction of sodium thiosulfate with hydrochloric acid is described by the following balanced chemical equation: $\text{Na}_2\text{S}_2\text{O}_3 + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{SO}_2 + \text{S} + \text{H}_2\text{O}$
- To investigate the effect of *concentration* on the rate of this reaction, the experiment was carried out for a number of different concentrations of sodium thiosulfate solution. For each run, a stopwatch was started when 100 cm^3 of $\text{Na}_2\text{S}_2\text{O}_3$ were mixed with 10 cm^3 of 3 M HCl. For each run, the reaction was carried out at room temperature and the time taken for the same mass of sulfur to precipitate was measured. The inverse of that time was taken as a measure of the initial rate of reaction.

The results are shown in the table below.

Concentration of $\text{Na}_2\text{S}_2\text{O}_3$ (M)	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.03
Time (s)	50	56	63	72	84	100	125	168
Rate = $\frac{1}{\text{Time}}$ (s^{-1})	0.020	0.018						

- (a) (i) Describe a method that could be used to know when the same mass of sulfur had been precipitated in each run.
X placed under flask // light-meter (3)
(time measured until) X not visible // (time measured until) same value (3)
- (ii) Describe how a 0.10 M solution of $\text{Na}_2\text{S}_2\text{O}_3$ could be used to prepare a 100 cm^3 portion of 0.09 M $\text{Na}_2\text{S}_2\text{O}_3$ solution.
 90 cm^3 of (0.10 M) solution (3)
made up (to 100 cm^3) with water (3)
- (b) (i) Copy and complete the third row of the table into your answerbook by filling in the missing rate values, correct to three decimal places.
0.016, 0.014, 0.012, 0.010, 0.008, 0.006 (6 × 1)
- (ii) Draw a graph on graph paper to show how the rate of the reaction varies with the concentration of sodium thiosulfate solution.



- axes labelled (3)**
points plotted [-1 for each incorrectly plotted point] (6)
[maximum of 3 marks for points plotted on paper other than graph paper]
line of best fit (2)

- (iii) What can be concluded from your graph?
rate proportional to concentration / time inversely proportional to concentration (3)

- (c) (i) Use your graph to estimate the rate of reaction if 100 cm³ of 0.015 M Na₂S₂O₃ solution had been used.

≈ 0.003 (s⁻¹) (4)

- (ii) Calculate the time taken for the sulfur to precipitate in this case.

$\frac{1}{0.003} = 333$ (s) (4)

- (d) To investigate the effect of *temperature* on the rate of this reaction, the time taken for the same mass of sulfur to precipitate was measured at three different temperatures, using fixed volumes and concentrations of the reactants.

The results are shown in the table below.

Temperature (°C)	T ₁	T ₂	T ₃
Time (s)	40	10	25

- (i) Describe a suitable method for heating the reactants and measuring the reaction temperature. A labelled diagram may help your answer.

heat source / water bath / hotplate / Bunsen burner (3)

thermometer (3)

- (ii) Which temperature (T₁, T₂ or T₃) was the highest? Justify your answer.

T₂ (2)

greatest rate / least time (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) neutrons, are there in a nucleus of helium-3?
 (i) **2** (ii) **1** (4 + 2)
- (b) Identify two reagents needed to test for the presence of phosphate ions in aqueous solution.
ammonium molybdate, nitric acid (4 + 2)
- (c) State two reasons why real gases deviate from ideal behaviour.
particles have volume / intermolecular forces / collisions not elastic [any two] (4 + 2)
[accept a named intermolecular force as an alternative to "intermolecular forces"]
- (d) The diagram on the right shows two identical flasks, one filled with helium gas and the other filled with oxygen gas. The flasks are kept at the same temperature and pressure. There are 2.4 g of gas in the flask of oxygen. Calculate the mass of helium present.
reference to masses of 4 and 32 / ratio of 1:8

$$\frac{2.4 \times 4}{32} = 0.3 \text{ (g)}$$
 (4 + 2)
- (e) State the standard units of (i) first ionisation energy, (ii) biochemical oxygen demand (BOD).
 (i) **kJ mol⁻¹ / J mol⁻¹** (ii) **parts per million / ppm / mg L⁻¹ / g m⁻³** (4 + 2)
- (f) Name three homologous series of organic compounds that contain a carbonyl group.
aldehyde / ketone / carboxylic acid / ester [any three] (3 + 2 + 1)
- (g) Oxygenates are often added to petrol.
 (i) Explain why oxygenates are often added to petrol.
increase octane number / reduce auto-ignition / smoother combustion
 (ii) Identify an oxygenate suitable for this purpose.
alcohol / any named alcohol, e.g. ethanol / ether / any named ether e.g. MTBE (4 + 2)
- (h) What is the specific purpose of adding aluminium sulfate:
 (i) during water treatment,
 (ii) during the tertiary stage of sewage treatment?
 (i) **flocculation** (ii) **to remove phosphates** (4 + 2)
- (i) Write a balanced chemical half equation for the reaction that occurs at the cathode when an electric current is passed through an aqueous solution of sodium sulfate.

$$2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$$
 /
$$\text{H}_2\text{O} + \text{e}^- \rightarrow \frac{1}{2}\text{H}_2 + \text{OH}^-$$
 (4 × 1 + 2)
- (j) Explain the fundamental principle of chromatography.
mobile phase and stationary phase
(substances have) selective adsorption / different affinities for either phase (4 + 2)
- (k) The structure of the painkiller benzocaine is shown on the right. Calculate the percentage yield of a reaction in which 2412.3 g of pure benzocaine was obtained when the theoretical yield was 21.5 moles.
M_r = 165

$$\frac{2412.3}{21.5 \times 165} = 0.68, \text{ i.e. } 68 \text{ (\%)}$$
 (4 + 2)
- (l) A Identify three chemical species formed when carbon dioxide gas dissolves in pure water.
H₂CO₃ / HCO₃⁻ / CO₃²⁻ / H⁺ [any three] (3 + 2 + 1)
- B Outline the contributions of each of the following to crystallography:
 (i) Lawrence Bragg
developed X-ray (crystallography) technique
 (ii) Dorothy Hodgkin
the structure of (bio)molecules (4 + 2)

5. In 1885 the Swiss mathematician Johann Balmer wrote a mathematical formula to describe the wavelengths of the visible line spectrum of atomic hydrogen, which is now named after him. However there was no explanation for the existence of these lines until 1913. In 1913 Bohr's model of the hydrogen atom was shown to be consistent with the Balmer series. Bohr's model was therefore supported by experimental evidence.
- (a) (i) Bohr proposed that the electrons in an atom occupy energy levels.
Explain what is meant by the term energy level.
fixed energy / quantised energy / energy in an orbit / energy in a shell of an electron (in an atom) (3)
- (ii) Distinguish between the ground state and the excited states of the electron in a hydrogen atom.
ground state: lowest energy / $n = 1$ / stable / in 1s // excited states: greater energy / $n > 1$ / unstable / not in 1s (6)
- (iii) Explain what happens when an electron moves from an excited state to its ground state.
energy is released as a photon / as light / as em radiation / at a specific frequency / $E_m - E_n = hf$ (3)
- (iv) Name the instrument used to examine the line spectrum of an element.
spectrometer / spectroscope [do not accept mass spectrometer] (3)

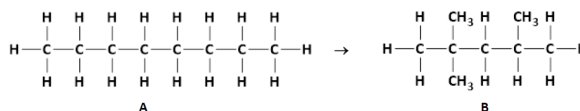
In time, Bohr's model was shown to be an over-simplification of the structure of multi-electron atoms. Furthermore, modern atomic theory takes into account the wave nature of the electron and the Heisenberg uncertainty principle, which were not understood in 1913.

- (b) (i) Explain how the Heisenberg uncertainty principle applies to an electron in an atom.
not possible to (accurately) measure certain pairs of physical properties (e.g. position and momentum/velocity) at the same time (3)
- (ii) Write the full s, p electron configuration for an atom of neon (Ne) in its ground state, including the number of electrons in each atomic orbital.
 $1s^2 2s^2$ (3)
 $2p_x^2 2p_y^2 2p_z^2$ (3)
- (iii) By reference to the electron configuration for neon, distinguish between an energy sublevel and an atomic orbital.
sublevel: 2p // (Ne has) 3 // can be $> 2 e^-$ (3)
orbital: e.g. $2p_x$ // (Ne has) 5 // = $2 e^-$ (3)
- (iv) Neon is chemically unreactive. Explain this property by reference to its electron configuration.
full outer energy level / full p sublevel / satisfies octet rule (3)
- (v) Explain how the successive ionisation energy values of neon provide evidence supporting the existence of energy levels.
ninth (ionisation energy) significantly greater (than the eighth) (2)
- (vi) Draw the shape of a p orbital.
correct dumb-bell shape (6)
[award 3 marks for drawing that shows overlapping dumb-bell shapes]



6. Hydrocarbon A may be converted to hydrocarbon B, as shown below.

- (a) Hydrocarbon A is obtained in the naphtha fraction when crude oil is fractionally distilled during oil refining.



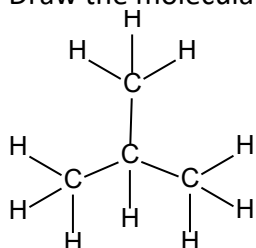
- (i) Describe one property which hydrocarbon A has in common with the other hydrocarbons in the naphtha fraction.
boiling point (range) / mass / size / number of atoms (3)
- (ii) State the systematic IUPAC names of compounds A and B.
A: octane **B: 2, 2, 4-trimethylpentane** (3 + 3)
- (iii) Explain why compounds A and B are referred to as saturated alkanes.
only single bonds / no addition reactions possible / maximum H present (3)

- (b) The conversion of compound A to compound B occurs in a process that takes place in some oil refineries after fractional distillation.

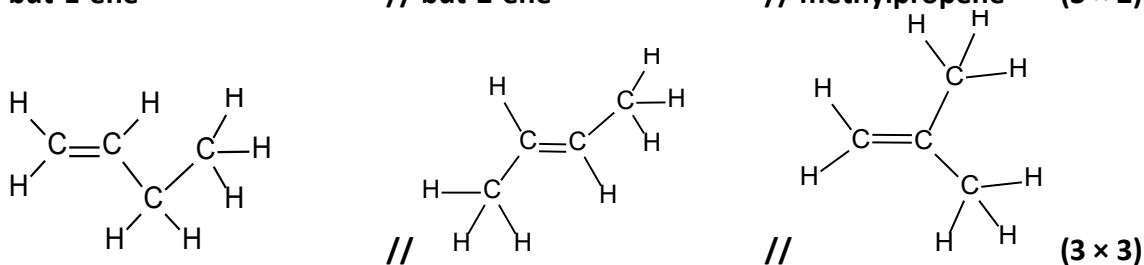
- (i) Name the process that can convert compound A to compound B.
isomerisation (3)
- (ii) Why is this conversion carried out?
increase octane number / reduce auto-ignition / smoother combustion / increase branching (3)

- (c) A molecule of compound A can undergo catalytic cracking to produce a molecule of methylpropane and a molecule of compound C.

- (i) Draw the molecular structure of methylpropane, including all atoms and bonds.



- (ii) State the systematic IUPAC name of three of the possible isomers of compound C. In each case, draw the molecular structure of the isomer, including all atoms and bonds.
but-1-ene // **but-2-ene** // **methylpropene** (3 × 2)



[accept cis & trans but-2-ene; accept cyclobutane & methylcyclopropane]

- (d) The complete combustion of compound A may be described by the following balanced chemical equation: $\text{CH}_3(\text{CH}_2)_6\text{CH}_3(l) + 12\frac{1}{2}\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 9\text{H}_2\text{O}(l)$

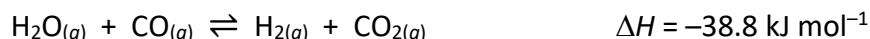
- (i) The heat of formation of compound A is $-250.3 \text{ kJ mol}^{-1}$. The heats of formation of carbon dioxide and water are $-393.5 \text{ kJ mol}^{-1}$ and $-285.8 \text{ kJ mol}^{-1}$ respectively. Calculate the heat of combustion of compound A.

$$\begin{array}{rcl} 8(-393.5) & [= -3148] & (2 \text{ [multiplicative factor]} + 1 \text{ [sign]}) \\ + 9(-285.8) & [= -2572.2] & (2 \text{ [multiplicative factor]} + 1 \text{ [sign]}) \\ - (-250.3) & [= +250.3] & (2 \text{ [multiplicative factor]} + 1 \text{ [sign]}) \\ = -5469.9 \text{ (kJ mol}^{-1}\text{)} & & (2) \end{array}$$

- (ii) The heat of formation of compound B is $-260.5 \text{ kJ mol}^{-1}$. Calculate the heat of reaction for the conversion of compound A to compound B.

$$-260.5 - (-250.3) = -10.2 \text{ (kJ mol}^{-1}\text{)} \quad (3)$$

7. When 4.0 moles of steam and 1.0 moles of carbon monoxide were mixed together at temperature T in a container of fixed volume V , they reacted to produce hydrogen and carbon dioxide. An equilibrium was established which is described by the following balanced chemical equation:



- (a) (i) Explain what is meant by chemical equilibrium.
forward and reverse reactions // concentrations (3)
have equal rates // are constant (2)
- (ii) Write an expression for the equilibrium constant K_c for this reaction.

$$\frac{[\text{H}_2][\text{CO}_2]}{[\text{H}_2\text{O}][\text{CO}]}$$
 (6)
[award 3 marks if round brackets are used]
- (iii) At equilibrium at temperature T , there were 0.8 moles of hydrogen gas in the container. Calculate the value of K_c for the equilibrium at this temperature.

$$[\text{H}_2\text{O}] = \frac{3.2}{V} \quad // \quad [\text{CO}] = \frac{0.2}{V} \quad // \quad [\text{CO}_2] = \frac{0.8}{V} \quad (3 \times 2)$$

[accept expressions for concentrations with or without reference to V]

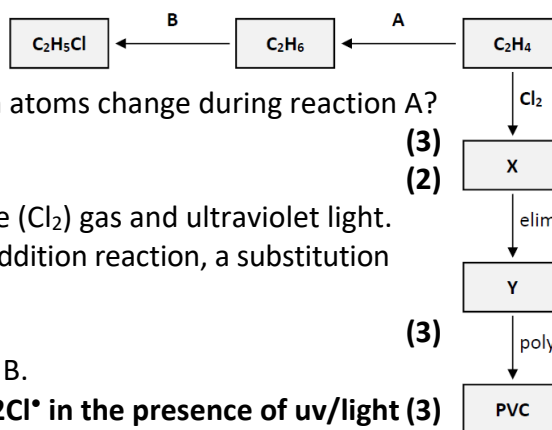
$$\frac{0.8 \times 0.8}{3.2 \times 0.2} = 1$$
 (3)
- (b) (i) If the same reaction had been carried out at the same temperature T in the same container, but with an initial mixture of 2.5 moles of steam and 2.5 moles of carbon monoxide, the value of K_c would not change from the value calculated in (a)(iii) above. Explain why the value of K_c would not change.
no change in temperature / K_c is only affected by temperature (3)
- (ii) Calculate the mass of carbon dioxide present in the container at equilibrium in the case described in (b)(i).

	$\text{H}_2\text{O}_{(g)}$	+	$\text{CO}_{(g)}$	\rightleftharpoons	$\text{H}_{2(g)}$	+	$\text{CO}_{2(g)}$	
initially	2.5		2.5		0		0	
equilibrium	$2.5 - x$		$2.5 - x$		x		x	(3)

[accept expressions for concentrations with or without reference to V]

$$\frac{x^2}{(2.5 - x)^2} = 1$$
 (3)
 $x = 1.25$ (moles) (2)
 $M_r = 44$ (2)
mass = 55 g (2)
- (c) (i) State the effect, if any, of decreasing the pressure in the container on the percentage conversion of steam to hydrogen. Justify your answer.
no effect (3)
equal number of moles/molecules (of gas) on both sides (2)
- (ii) How could the value of K_c be increased for this equilibrium reaction? Justify your answer.
reduce temperature (3)
exothermic reaction favoured / (forward) reaction is exothermic (2)
- (iii) In an industrial context, a catalyst is usually used to ensure that equilibrium is established as quickly as possible for this reaction. State the effect of using a catalyst on the value of K_c at temperature T . Justify your answer.
no effect (3)
(rate of) forward and reverse reactions affected equally / only rate affected / catalyst only affects time taken to reach equilibrium / K_c is only affected by T (2)

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



(a) How does the geometry around the carbon atoms change during reaction A?

planar / trigonal / triangular / 120°

(3)

to tetrahedral / 109°

(2)

Reaction B takes place in the presence of chlorine (Cl_2) gas and ultraviolet light.

(b) (i) Should reaction B be classified as an addition reaction, a substitution reaction or an elimination reaction?

substitution

(3)

(ii) Describe the mechanism for reaction B.

(initiation/homolysis): $\text{Cl}_2 \rightarrow 2\text{Cl}^\bullet$ in the presence of uv/light (3)

(propagation): $\text{C}_2\text{H}_6 + \text{Cl}^\bullet \rightarrow \bullet\text{C}_2\text{H}_5 + \text{HCl}$ (3)

(propagation): $\bullet\text{C}_2\text{H}_5 + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_5\text{Cl} + \text{Cl}^\bullet$ (3)

(termination): e.g. $\bullet\text{C}_2\text{H}_5 + \text{Cl}^\bullet \rightarrow \text{C}_2\text{H}_5\text{Cl}$ (3)

[Note: \bullet is not needed on Cl but is needed on $\bullet\text{C}_2\text{H}_5$]

(iii) A trace quantity of C_4H_{10} is formed during reaction B. Explain how the formation of C_4H_{10} is evidence for the mechanism described.

shows existence of ethyl free radical / $2\bullet\text{C}_2\text{H}_5 \rightarrow \text{C}_4\text{H}_{10}$

(3)

(iv) Apart from the formation of C_4H_{10} , state one other piece of evidence for this mechanism.

reaction needs uv/light (to start) / multiple product molecules for each photon /

free radical source increases reaction rate / $\text{Cl}_2 \rightarrow 2\text{Cl}^\bullet$ in the presence of uv/light (3)

(c) Polyvinylchloride (PVC) is synthesised in three steps from C_2H_4 . These steps are an addition reaction to form compound X, then an elimination reaction to form compound Y and finally the polymerisation of Y to form PVC, as outlined in the reaction scheme above.

(i) State the systematic IUPAC name for compound X.

1,2-dichloroethane

(3)

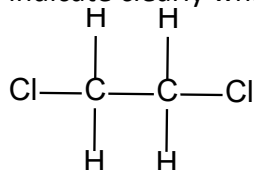
(ii) Name the inorganic compound that is eliminated when X is converted to Y.

hydrogen chloride

[do not accept HCl or hydrochloric acid]

(3)

(iii) Draw the structure of a molecule of X showing all of its atoms and all of its bonds and indicate clearly which of its bonds are broken during the elimination reaction.

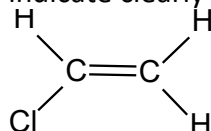


(3)

one C-Cl bond indicated and one C-H bond on the other carbon indicated

(3)

(iv) Draw the structure of a molecule of Y showing all of its atoms and all of its bonds and indicate clearly which of its bonds are formed during the elimination reaction.

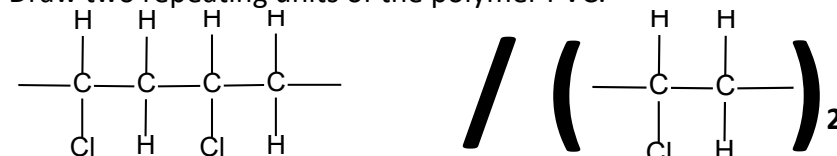


(3)

(one bond of the) C=C double bond indicated

(3)

(v) Draw two repeating units of the polymer PVC.

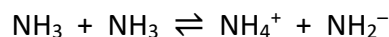


(6)

[award 3 marks two repeating units consistent with answer in part (iv)]

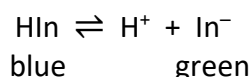
9. (a) (i) Explain why ammonia (NH₃) is considered to be a base according to the Brønsted-Lowry theory but is not considered to be a base according to the Arrhenius theory.
- it is a proton acceptor (3)**
it does not dissociate in water to produce OH⁻ (3)

The self-ionisation of liquid ammonia is described by the following balanced chemical equation:



- (ii) Identify the conjugate acid of NH₃ in this equilibrium.
NH₄⁺ (3)
- (iii) Identify the conjugate base of NH₃ in this equilibrium.
NH₂⁻ (3)
- (b) (i) Define pH.
-log₁₀ [H⁺] (3)
- (ii) The pH of pure water is 7 at 25 °C. Explain why the pH of pure water is not 7 at 50 °C.
K_w changes with T / [H⁺] changes with T / degree of dissociation changes with T (3)
- (iii) A 10 cm³ sample of strong monobasic acid X was diluted by mixing it with deionised water until it had a new volume of 100 cm³. What is the change in the pH?
increases by 1 [accept changes by 1] (3)
- (iv) Weak monobasic acid Y has an acid dissociation constant K_a = 1.8 × 10⁻⁵. A sample of acid Y has a pH of 2.98. Calculate the concentration of the sample.
pH = -log₁₀(√K_aM_{acid}) / [H⁺] = √K_aM_{acid} / [H⁺] = 10^{-pH} / √K_aM_{acid} = 0.00105 (3)
K_aM_{acid} = 0.000011 (3)
[Y] = 0.061 mol L⁻¹ (3)

- (c) A certain water-soluble acid-base indicator can be represented as HIn. Its dissociation in water is described by the following balanced chemical equation:



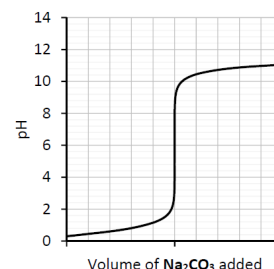
The undissociated HIn is blue. The In⁻ ion is green.

What colour change is observed when a few drops of a solution of HIn are added to 25 cm³ of a 0.1 M solution of potassium hydroxide (KOH)? Justify your answer.

blue to green / (turns) green (4)

[H⁺] decreases / reaction moves to the right / system reacts to oppose stress (4)

- (d) Acid Z is titrated against a solution of sodium carbonate (Na₂CO₃). The titration curve is shown in the diagram.
- (i) What evidence is there that acid Z is a strong acid?
pH is close to 0 (when pure) / weak base and long vertical [accept pH < 1 or pH is very low]



An indicator with pH range of 8 to 10 was used in this titration.

- (ii) Would you expect the indicator to change colour before the point of neutralisation, after the point of neutralisation, or coinciding with the point of neutralisation? Justify your answer.

after

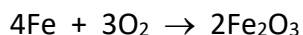
vertical part of the graph ends before 10

(5 + 2 + 2)

10. (a) (i) Define oxidation in terms of electron transfer.
loss (3)
- (ii) State the oxidation number of phosphorus in P_4 and PO_4^{3-} .
0, +5 (3 + 3)
- (iii) State the oxidation number of nitrogen in NO_3^- and NO .
+5, +2 (3 + 3)
- (iv) Hence or otherwise, balance the chemical equation:

$$P_4 + NO_3^- + H_2O \rightarrow PO_4^{3-} + NO + H^+$$
P: 5 [state/imply] [accept number consistent with (ii)] (3)
N: 3 [state/imply] [accept number consistent with (iii)] (3)
 $3P_4 + 20NO_3^- + 8H_2O \rightarrow 12PO_4^{3-} + 20NO + 16H^+$ (2)
- (v) Identify the reducing agent in the reaction above.
 P_4 (2)
10. (b) The elements radium (Ra) and polonium (Po) were discovered on the basis of their radioactivity through the work of Marie and Pierre Curie. In 1902 they obtained 0.1 g of pure $RaCl_2$ from a tonne of pitchblende, the material remaining after uranium is extracted from its ore. In 1910 Marie Curie isolated pure radium. However she never succeeded in isolating pure polonium, in part because of its short half-life.
- (i) What is meant by radioactivity?
(spontaneous) disintegration of a nucleus with the release of radiation
- (ii) What is meant by the half-life of a radioisotope?
time for half a sample to decay / time for activity to halve
- The nuclear equation below represents the alpha decay of polonium-210.
- $${}_{84}^{210}\text{Po} \rightarrow {}_Z^X + {}_2^4\alpha$$
- (iii) Identify the number X.
206
- (iv) Identify the number Y.
82
- (v) Identify the element represented by Z.
lead/Pb (6 + 3 + 2 + 2 + 2)
- (vi) Identify the two noble gas radioisotopes formed when a radium-226 nucleus undergoes alpha decay.
radon/Rn, helium/He (2 + 2)
- (vii) Calculate the maximum mass of radium that could be isolated from 0.1 g of $RaCl_2$.
 $M_r = 297$ (3)
 $\frac{226}{297} \times 0.1 = 0.076 \text{ (g)}$ (3)

10. (c) Rusting of iron involves several different reactions that take place in the presence of moist air. The mass of an iron object and its overall volume increase because of these rusting reactions occurring on the surface of the object. One of the reactions is described by the following balanced chemical equation:



The mass of an iron object increased by 1.92 g as a result of this reaction.

- (i) Calculate the volume of oxygen gas, measured at s.t.p., that reacted with the iron.

$$M_r = 32 \quad (2)$$

$$\frac{1.92}{32} = 0.06 \text{ (moles of O}_2\text{)} \quad (2)$$

$$0.06 \times 22.4 = 1.34 \text{ L} \quad // \frac{0.06 \times 8.3 \times 273}{101325} = 0.00134 \text{ m}^3 \quad (2)$$

- (ii) Calculate the mass of Fe₂O₃ produced.

$$M_r = 160 \quad // \frac{0.06}{3} \times 4 = 0.08 \text{ (moles of Fe)} \quad (2)$$

$$\frac{0.06}{3} \times 2 = 0.04 \text{ (moles of Fe}_2\text{O}_3\text{)} \quad // 0.08 \times 56 = 4.48 \text{ (g of Fe)} \quad (2)$$

$$0.04 \times 160 = 6.4 \text{ (g)} \quad // 4.48 + 1.92 = 6.4 \text{ (g)} \quad (2)$$

- (iii) Calculate the number of iron atoms that reacted.

$$0.08 \text{ (moles of Fe)} \quad (2)$$

$$0.08 \times 6.0 \times 10^{23} = 4.8 \times 10^{22} \text{ (atoms)} \quad (2)$$

- (iv) Calculate the increase in the volume of the iron object, taking the density of Fe to be 7.86 g cm⁻³ and the density of Fe₂O₃ to be 5.25 g cm⁻³.

$$\text{Fe:} \quad 0.08 \times 56 = 4.48 \text{ (g)} \quad (2)$$

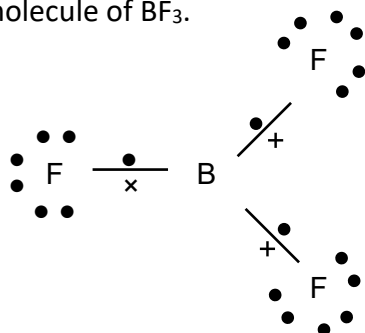
$$4.48 \div 7.86 = 0.57 \text{ (cm}^3\text{)} \quad (2)$$

$$\text{Fe}_2\text{O}_3: \quad 6.4 \div 5.25 = 1.22 \text{ (cm}^3\text{)} \quad (2)$$

$$\Delta = 1.22 - 0.57 = 0.65 \text{ (cm}^3\text{)} \quad (3)$$

11. (a) Boron trifluoride (BF₃) is a colourless gas with an unpleasant odour.

- (i) Draw a dot and cross diagram to show the arrangement of the valence electrons in a molecule of BF₃.



(4)

[award 2 marks if lone pair electrons are omitted from F(s)]

- (ii) Would you expect a B–F bond to be polar or non-polar? Justify your answer.

polar (3)

(large) electronegativity difference (3)

- (iii) Would you expect a BF₃ molecule to be polar or non-polar? Justify your answer.

non-polar (3)

symmetry / no net dipole / +ve and –ve centres coincide / B has no lone pair (3)

- (iv) Phosphane (PH₃) is a colourless, flammable, highly toxic gas used in the semiconductor industry. Predict the shape of a molecule of PH₃. Explain your prediction.

pyramidal / distorted tetrahedron / correct diagram drawn (3)

three bond pairs and one lone pair (on P) (3)

- (v) Neither BF₃ nor PH₃ is very soluble in water. Explain why.

non-polar / little hydrogen bonding / little intermolecular forces (3)

11. (b) The table below shows compounds A to E, where R represents a CH₃ group and R' represents a C₂H₅ group.

A	B	C	D	E
$\begin{array}{c} \text{Cl} \\ \\ \text{R}'-\text{C}-\text{R} \\ \\ \text{Cl} \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{R}-\text{C}-\text{R} \\ \\ \text{HO} \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{R}-\text{C}-\text{R}' \\ \\ \text{HO} \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{R}'-\text{C}-\text{O}-\text{H} \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{O}-\text{R} \end{array}$

- (i) State the systematic IUPAC names for compounds A, B, C, D and E.
A: 2,2-dichlorobutane
B: propan-2-ol
C: butan-2-ol
D: propanoic acid
E: methyl ethanoate (5 × 3)
- (ii) Classify compound B as a primary alcohol or a secondary alcohol. Justify your answer.
secondary (3)
OH is bonded to a carbon which is bonded to two other carbons (2)
- (iii) Are compounds D and E structural isomers? Justify your answer.
yes (3)
same number of atoms of each type / same molecular formula (2)

11. (c) Water hardness is caused by certain dissolved metal ions.

- (i) Write the chemical formulae for the two metal ions that most commonly cause hardness when dissolved in water.
Ca²⁺, Mg²⁺ [charges required] (3 + 3)
- (ii) Identify an anion which is commonly dissolved in water with these metal ions when temporary hardness is involved.
hydrogencarbonate / bicarbonate (3)
- (iii) Identify an anion which is commonly dissolved in water with these metal ions when permanent hardness is involved.
sulfate / chloride (3)

When hard water is boiled in a kettle, limescale deposits build up on the heating element.

- (iv) Write a balanced chemical equation to describe the formation of limescale when hard water is boiled.
Ca(HCO₃)₂ → CaCO₃ + CO₂ + H₂O (4 × 1 + 2)

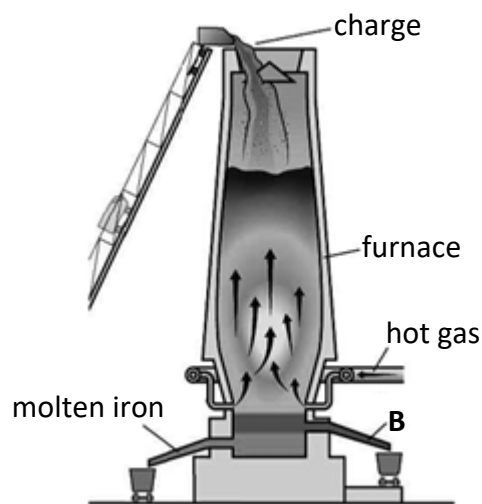
Hard water may be softened by deionising it.

- (v) Explain how water may be deionised using ion exchange resins.
ions exchanged for H⁺ and OH⁻ (3)
- (vi) Explain why deionised water is not as pure as distilled water.
may contain dissolved gases / may contain non-ionic material / may contain organic compounds / may contain suspended material (4)

11. (d)A Unlike many other environmental problems, stratospheric ozone depletion has been largely remedied by international agreement about the use of CFCs. The damaging effect of CFCs on the ozone layer was predicted by the Mexican chemist Mario Molina before the 'hole' in the ozone layer was observed.
- (i) What is ozone?
O₃ (4)
- (ii) Explain how ozone is formed in the stratosphere.
O₂ → 2O[•] (3)
O[•] + O₂ → O₃ (3)
[Note: • is not needed on O]
- (iii) What are CFCs?
chlorofluorocarbons (3)
- (iv) State one main use of CFCs.
refrigerant, aerosol/propellant, fire suppressant, blowing agent, solvent, chemical precursor (3)
- (v) Explain how CFCs in the stratosphere damage the ozone layer.
source of free radicals / source of Cl (atoms) (3)
which cause ozone to become O₂ (3)
- (vi) Identify one example of an ozone-friendly CFC replacement.
HCFCs / HFCs (3)

11. (d)B Iron metal is extracted from its ores by reduction in a blast furnace like that illustrated in the diagram on the right.

- (i) Identify the two solid materials that are continually added with the iron ore in the charge at the top of the furnace.
coke / carbon (3)
limestone / calcium carbonate (3)
- (ii) Identify the hot gas that is blown into the furnace above the hearth during production.
air / oxygen (3)
- (iii) Identify by-product B that is removed at the bottom of the furnace.
slag / CaSiO₃ / CaAl₂O₄ (4)



Carbon monoxide acts as a reducing agent in the blast furnace.

- (iv) Write a balanced chemical equation for the reaction of carbon monoxide with iron(III) oxide.
Fe₂O₃ + 3CO → 2Fe + 3CO₂ (4 × 1 + 2)

Steel is an alloy of iron.

- (v) Name the main stages in the manufacture of steel using the electric arc process.
charging, melting, refining, tapping, casting [any three] (3 × 2)

