Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2025

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 organic compounds the IUPAC name is required, unless otherwise indicated. Inorganic compounds may be named using oxidation state or traditional naming convention – e.g. sodium sulfate(IV) or sodium sulfite for Na_2SO_3.

7. Each time an arithmetical error occurs in a calculation, one mark is deducted. 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)
✓ n	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 iron(II) content of an iron supplement tablet. Six iron tablets with a total mass of 2.496 g were dissolved in dilute sulfuric acid. The solution and the washings were transferred to a 250 cm^3 volumetric flask and made up to the mark using deionised water. A 25.0 cm^3 portion of this solution was transferred into a conical flask and some sulfuric acid was added. The solution was then titrated against a previously standardised solution of potassium manganate(VII) ($KMnO_4$). A number of titrations were carried out. The titration reaction is described by the following balanced equation:

$$MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$$

(*a*) Identify a primary standard that the student could have used to standardise the solution of potassium manganate(VII).

ammonium iron(II) sulfate / $(NH_4)_2SO_4.FeSO_4.6H_2O$ **(5)**

(*b*) (*i*) Outline the correct procedure for bringing the solution in the volumetric flask precisely to the 250 cm^3 mark.

add (deionised water) drop by drop / slowly **(3)**
bottom of meniscus on the mark **(3)**

(*ii*) Explain why using more than one iron tablet in the 250 cm^3 of solution increases the accuracy of the analysis.

smaller % error / large volume of potassium manganate(VII) / high concentration of iron solution / one tablet error **(3)**

(*c*) (*i*) Name the piece of apparatus used to accurately measure and transfer the 25.0 cm^3 portion of iron(II) solution into the conical flask.

pipette / burette **(3)**

(*ii*) Describe how this piece of apparatus was rinsed before use.

with deionised water **(3)**
with iron(II) solution / solution it will contain **(3)**

(*d*) (*i*) Explain why the addition of an indicator into the conical flask was not required.

potassium manganate(VII) acts as the indicator **(3)**

(*ii*) Describe what the student observed at the end point.

(pale) pink **(3)**

(*iii*) Describe what would be observed in the conical flask if insufficient acid was present during the titration. Explain your answer.

brown / precipitate **(3)**
MnO_2 / Mn^{4+} **(3)**

(*e*) On average, 22.5 cm^3 of 0.010 M potassium manganate(VII) solution were required for complete reaction with 25.0 cm^3 of the solution of the iron(II) in excess acid.

(*i*) Calculate the number of moles of manganate(VII) ions present in 22.5 cm^3 of 0.010 M potassium manganate(VII) solution.

$\frac{0.010}{1000} \times 22.5 = 0.000225 / 2.25 \times 10^{-4}$ (moles per 22.5 cm^3) **(3)**

(*ii*) Calculate the number of moles of iron(II) present in the 250 cm^3 solution in the volumetric flask.

$0.000225 \times 5 = 0.001125$ (moles per 25 cm^3) **(2)**
$0.001125 \times 10 = 0.01125$ (moles per 250 cm^3) **(2)**

(*iii*) Calculate the average mass of iron(II) in one tablet.

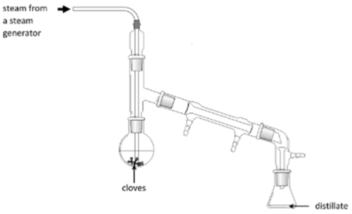
$0.01125 \div 6 = 0.001875$ (moles per tablet) **(2)**
$\times 56 = 0.105$ (g per tablet) **(2)**

(*iv*) Calculate the percentage by mass of iron(II) in one tablet.

$\frac{0.105}{0.416} = 0.2524$, $\times 100 = 25.24$ (%) // $\frac{0.630}{2.496} = 0.2524$, $\times 100 = 25.24$ (%) **(4)**

[*Allow 3 marks for 0.2524*]

2. Clove oil is an essential oil with a wide number of uses. Clove oil can be extracted from dried clove buds by steam distillation using apparatus like that shown below.



(*a*) The distillate produced consists of clove oil and another substance A.

(*i*) Identify substance A.

water / H_2O **(3)**

(*ii*) State and explain the appearance of the distillate collected.

milky **(3)**

emulsion / oil droplets dispersed in water **(3)**

(*iii*) State one advantage of extracting clove oil using steam distillation.

minimise decomposition / maximise yield / prevent decomposition (of clove oil) /remove (clove oil) at a lower boiling point **(3)**

(*b*) Eugenol may be extracted from the distillate by liquid-liquid extraction using the solvent cyclohexane.

(*i*) Describe, with the aid of a labelled diagram, a suitable procedure for the extraction and collection of eugenol from the distillate.

separating funnel //organic layer over an aqueous layer // reference to safe mixing or collection in separate vessels [*any two*] **(6 + 3)**

[maximum of 6 marks awarded if diagram not included]

(*ii*) State two properties of cyclohexane that make it a solvent suitable for use in the liquid-liquid extraction of eugenol.

non-polar // low solubility in water // low boiling point // low reactivity // lower density than water [*any two*] **(2 × 3)**

(*iii*) State one precaution that could be taken during the liquid-liquid extraction to maximise the yield of eugenol.

repeat extraction / washing (of aqueous layer) / avoid spillage / venting **(3)**

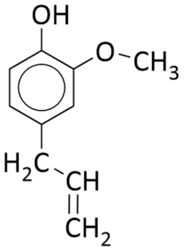
(*iv*) Describe how eugenol can be isolated from the dried eugenol-cyclohexane mixture.

by evaporation of solvent **(3)**

(*c*) (*i*) Suggest one use of eugenol.

flavouring / antiseptic / fragrance *etc.* **(3)**

(*ii*) Draw the structure of a molecule of eugenol.



(6)

(*iii*) Name a spectroscopic technique that could be used to confirm the identity of a sample of eugenol.

infra-red / IR / mass spectroscopy / ultra-violet / UV **(3)**

(*iv*) Calculate the volume of dry eugenol (density 1.06 g cm^{-3}) obtained from 18.0 g of cloves, given that the percentage yield was 7%.

18 × 0.07 = 1.26

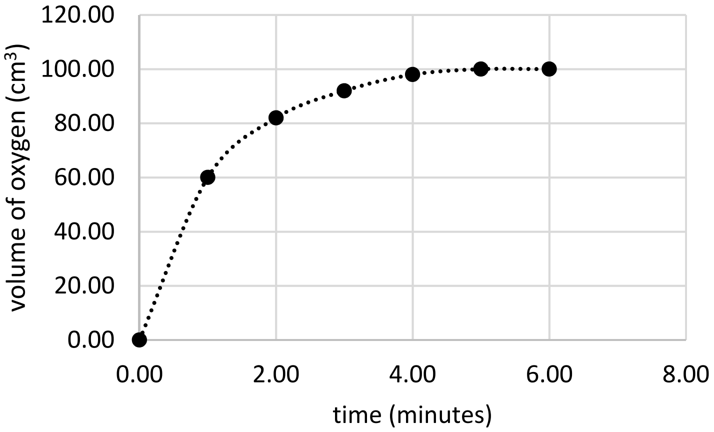
1.26 ÷ 1.06 = 1.2 cm^3 **(3 + 2)**

3. A student monitored the rate of production of oxygen gas (O_2) from hydrogen peroxide (H_2O_2), using manganese(IV) oxide (MnO_2) as a catalyst. A 5.0 cm^3 portion of hydrogen peroxide solution was diluted to exactly 20 cm^3 with deionised water and then transferred into a reaction flask. 0.5 g of finely-powdered manganese(IV) oxide was added. The volume of oxygen produced was recorded at intervals over six minutes. The reaction is described by the following balanced chemical equation: $2H_2O_2 \rightarrow O_2 + 2H_2O$

The results are given in the table below.

Time (minutes)	0.0	1.0	2.0	3.0	4.0	5.0	6.0
Volume of oxygen (cm^3)	0.0	60.0	82.0	92.0	98.0	100.0	100.0

(*a*) (*i*) Plot a graph on graph paper to show the volume of oxygen produced versus time.



axes labelled **(3)**

points plotted **(7 × 1)**

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

curve with good fit **(2)**

(*ii*) Use your graph to find the instantaneous rate of production of oxygen at 2.5 minutes.

good tangent drawn at 2.5 minutes **(3)**

≈ 9.8 cm^3 min^{-1} **(3)**

(*b*) (*i*) Use your graph to find the average rate of production of oxygen in cm^3 per minute over the first 2.5 minutes.

≈ 34.8 (cm^3 min^{-1}) **(3)**

(*ii*) Would you expect the average rate over the first 2.5 minutes to increase, decrease or stay the same if 0.5 g of granular manganese(IV) oxide was used instead of the fine powder? Justify your answer.

decrease

smaller surface area / fewer collisions **(4 + 2)**

(*iii*) Would you expect the average rate over the first 2.5 minutes to increase, decrease or stay the same if a more concentrated hydrogen peroxide solution was used? Justify your answer.

increase

more particles (per unit volume) / more collisions **(4 + 2)**

(*c*) (*i*) Use the data given to determine the average rate of production of oxygen in cm^3 per minute over the first minute.
60 (cm^3 min^{-1}) **(3)**

(*ii*) Use the data given to determine the average rate of production of oxygen in cm^3 per minute over the second minute (from t = 1 to t = 2 minutes).
22 (cm^3 min^{-1}) **(3)**

(*iii*) Account for the difference between the average rate of production of oxygen over the first and the second minutes of the reaction.
as the reaction proceeds concentration of reactants decreases **(3)**

(*d*) (*i*) Explain how a catalyst alters the rate of a chemical reaction.
provides alternative pathway with a lower activation energy

(*ii*) Identify the type of catalysis involved in the production of oxygen from hydrogen peroxide using manganese(IV) oxide as the catalyst. Justify your answer.
surface adsorption / heterogeneous
reactant and catalyst in different phases **(4 + 2 + 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*) Describe the arrangement of the elements in Mendeleev's 1869 periodic table of the elements.

by atomic mass **(3)**
similar properties **(3)**

(*b*) How many (*i*) protons and (*ii*) electrons are there in a $^{52}_{24}Cr^{3+}$ ion?

(i) 24 **(3)**
(ii) 21 **(3)**

(*c*) Write the chemical formulae for: (*i*) calcium hydroxide, (*ii*) aluminium sulfate.

(i) $Ca(OH)_2$ **(3)**
(ii) $Al_2(SO_4)_3$ **(3)**

(*d*) Write the full *s*, *p*, *d* electron configuration for an atom of vanadium (V) in its ground state.

$1s^2\ 2s^2\ 2p^6$ **(3)**
$3s^2\ 3p^6\ 4s^2\ 3d^3$ **(3)**

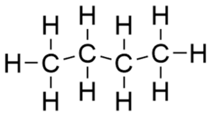
(*e*) A synthetic aromatic molecule is composed of 57.84% carbon, 3.61% hydrogen and 38.55% oxygen by mass. Find by calculation the empirical formula of this molecule.

$\frac{57.84}{12} : \frac{3.61}{1} : \frac{38.55}{16}$ **(3)**
$C_4H_3O_2$ **(3)**

(*f*) State Avogadro's law.

at the same temperature and pressure **(3)**
equal volumes of gases have equal numbers of particles **(3)**

(*g*) Draw the molecular structure of two isomers of C_4H_{10}, including all atoms and bonds.



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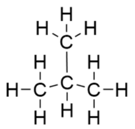


(2 × 3)

(*h*) A dog of mass 8.3 kg is to be given 140 mg per kg of body mass of a 5.0% (w/v) solution of a certain dog medicine. Calculate the volume of solution which should be given to the dog.

140 × 8.3 = 1162 (mg) **(3)**
1162 (mg) ÷ 50 = 23.24 cm^3 **(3)**

(*i*) Explain the term biochemical oxygen demand (BOD).

quantity of dissolved oxygen consumed by biological action **(3)**
over 5 days in the dark at 20 °C **(3)**

(*j*) State two ways in which you would expect the melting point of impure benzoic acid to differ from that of pure benzoic acid.

lower (melting point) **(3)**
broader range / less sharp **(3)**

(*k*) Assign oxidation numbers and determine which element is reduced in the reaction described by the following balanced equation:

$$3Cu + 2NO_3^- + 8H^+ \rightarrow 3Cu^{2+} + 2NO + 4H_2O$$

N (+5) →N (+2) / Cu(0) → Cu (+2) **(3)**
Nitrogen / N **(3)**

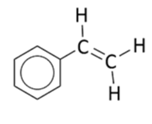
(*l*) Answer part A *or* part B.

A Explain how oxygen gas is separated industrially from air.

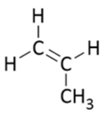
fractional distillation **(3)**
liquefaction of air **(3)**

B Monomers for two addition polymers are shown on the right.
Identify each of the corresponding addition polymers.

X = polyphenylethene / polystyrene **(3)**
Y = polypropylene / polypropene **(3)**



X



Y

5. (*a*) A naturally-occurring sample of bromine (Br) analysed by a forensic scientist was found to contain two isotopes, 50.69% with mass number 79 and 49.31% with mass number 81.

(*i*) Name the analytical instrument used to determine the percentage abundance of isotopes of given mass number of an element.

mass spectrometer **(2)**

(*ii*) Compare the composition of the nucleus of a bromine–79 atom with the nucleus of a bromine–81 atom.

35 protons **(3)**

44 neutrons (Br-79) and 46 neutrons (Br-81) **(3)**

(*iii*) Explain what is meant by the relative atomic mass of an element.

average mass of an atom **(3)**

compared to one twelfth the carbon–12 isotope **(3)**

(*iv*) Use the data above to calculate the relative atomic mass of bromine, correct to two decimal places.

$50.69 \times 79 = 4004.5$ and $49.31 \times 81 = 3994.11$ **(2)**

$4004.5 + 3994.11 = 7998.61$ **(2)**

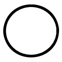
$7998.61 \div 100 = 79.99$ **(2)**

(*b*) An atomic orbital diagram for a bromine atom in its ground state is shown on the right.

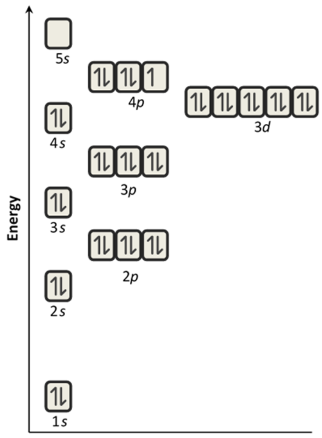
(*i*) What is an atomic orbital?

where the probability of finding an electron is high **(3)**

(*ii*) Draw the shape of the atomic orbital of lowest energy in a bromine atom in its ground state.



(3)



(*iii*) State the maximum number of electrons that can be accommodated in a *p*-orbital.

2 **(3)**

(*iv*) Describe how two or more atomic orbitals of equal energy are filled with electrons.

occupy singly **(3)**

then in pairs **(3)**

(*v*) Under what circumstance might an electron in a bromine atom temporarily occupy a higher energy orbital?

absorbs (a fixed amount of) energy **(3)**

(*c*) (*i*) Explain what is meant by atomic (covalent) radius.

half the distance between the nuclei of two atoms of the same element joined by a single covalent bond

(*ii*) Explain why the atomic (covalent) radius of bromine is greater than that of chlorine.

(bromine has) more energy levels

(*iii*) Explain why the atomic (covalent) radius of bromine is smaller than that of selenium.

(bromine has) greater effective nuclear charge / greater atomic number

(4 + 4 + 2 + 2)

6. (*a*) Crude oil is a complex mixture of mostly saturated hydrocarbon molecules. In an oil refinery this mixture is separated into different fractions such as refinery gas and gasoline by a process called fractional distillation.

(*i*) State what is meant by saturated, as applied to hydrocarbons.

only single bonds **(3)**

(*ii*) Describe, with the aid of a labelled diagram, how refinery gas may be obtained by the fractional distillation of crude oil in an oil refinery.

column with outlet pipes (trays) at various levels **(3)**
temperature decreasing from bottom to top of column **(3)**
heated crude oil near the base and refinery gas removed at the top **(3)**
[*maximum of 6 marks awarded if diagram not included*]

(*iii*) Identify the two major hydrocarbon components of liquid petroleum gas (LPG), a fuel obtained from refinery gas.

propane / C_3H_8 **(3)**
butane / C_4H_{10} **(3)**

Some fractions undergo further chemical processing in order to make them more useful.

(*iv*) Name the chemical process that can convert octane into 2,2,4-trimethylpentane.

isomerisation **(3)**

(*v*) Identify the inorganic co-product of the chemical process in which hexane is converted into cyclohexane.

hydrogen (gas) / H_2 **(3)**

(*b*) The high heat of combustion of hydrogen gas makes it a potentially suitable alternative to hydrocarbon fuels.

(*i*) What is meant by the heat of combustion of a fuel?

heat released when one mole reacts completely with excess oxygen

(*ii*) Name an instrument that can be used to accurately measure the heat of combustion of a fuel.

bomb calorimeter

(*iii*) State two methods used to produce hydrogen gas industrially.

steam reforming
electrolysis of water **(4 + 4 + 2 + 2)**

(*c*) Hydrazine (N_2H_4), another fuel, is formed in a reaction between ammonia and hydrogen peroxide. This reaction may be described by the following balanced chemical equation:

$$2NH_3 + H_2O_2 \rightarrow N_2H_4 + 2H_2O$$

Calculate the heat change for this reaction given that the heats of formation of ammonia, hydrogen peroxide, hydrazine, and water are —45.9 kJ mol^{-1}, —187.8 kJ mol^{-1}, 50.6 kJ mol^{-1} and —285.8 kJ mol^{-1}, respectively.

+ (+50.6)	**[= +50.6]**	**(2 [*multiplicative factor*] + 1 [*sign*])**	**(3)**
+ 2 (–285.8)	**[= –571.6]**	**(2 [*multiplicative factor*] + 1 [*sign*])**	**(3)**
– 2(–45.9)	**[= +91.8]**	**(2 [*multiplicative factor*] + 1 [*sign*])**	**(3)**
– (– 187.8)	**[= +187.8]**	**(2 [*multiplicative factor*] + 1 [*sign*])**	**(3)**
	= –241.4 (kJ)		**(2)**

7. (*a*) (*i*) Explain how an acid differs from a base according to the Brønsted-Lowry theory.

proton donor **(2)**

proton acceptor **(2)**

(*ii*) Explain how a strong acid differs from a weak acid according to the Brønsted-Lowry theory.

good proton donor **(2)**

poor proton donor **(2)**

(*iii*) What is a conjugate acid-base pair?

two species that differ by a H^+ **(2)**

(*iv*) Identify the conjugate acid-base pairs in the following reaction:

$$HCO_3^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3(aq)} + OH^-{}_{(aq)}$$

HCO_3^- and H_2CO_3, H_2O and OH^- **(3)**

(*b*) (*i*) Explain what is meant by pH.

$-\log_{10}$ **(2)**

$[H^+]$ / moles per litre of H^+ ions **(2)**

(*ii*) Calculate the H_3O^+ ion concentration, in moles per litre, of a solution of a strong acid with pH = 1.4.

$[H^+] = 10^{-1.4}$ **(2)**

0.0398 (mol L^{-1}) **(2)**

(*iii*) Calculate the pH of a 0.015 M solution of a weak monobasic acid with $K_a = 3.2 \times 10^{-4}$ at 25 °C.

$\sqrt{K_aM_{acid}} = [H^+]$ / $-\log_{10}\sqrt{K_aM_{acid}}$ **(2)**

$K_aM_{acid} = 0.0000048$ / $\sqrt{K_aM_{acid}} = 0.00219$ **(2)**

pH = 2.66 / 2.7 **(3)**

(*c*) (*i*) Write an expression for the ionic product of water (K_w).

$K_w = [H^+][OH^-]$ **(6)**

The ionic product of water (K_w) at 60 °C is 9.61×10^{-14} mol^2 l^{-2}.

(*ii*) Calculate the pH of pure water at 60 °C.

$[H^+] = \sqrt{9.61 \times 10^{-14}}$ / $[H^+] = 3.1 \times 10^{-7}$ **(3)**

pH = $-\log_{10}(3.1 \times 10^{-7})$ = 6.5 **(3)**

(*d*) A certain water-soluble acid-base indicator, represented by HA, is a weak acid which dissociates in water as described by the following balanced equation:

$$\underset{\text{yellow}}{HA} + H_2O \rightleftharpoons H_3O^+ + \underset{\text{blue}}{A^-}$$

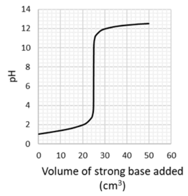
(*i*) State the colour you would expect to observe when a few drops of HA are added to a solution of a strong base. Justify your answer.

blue **(3)**

H_3O^+ concentration decreases / (equilibrium position) moves to the right / system opposes stress **(3)**

The pH curve on the right shows the change of pH as 50 cm^3 of a solution of a strong base were added to 25 cm^3 of a solution of a strong monobasic acid.

The indicator HA changes colour in the pH range of 4.2 to 5.4.



(*ii*) Would the indicator HA be a suitable choice of indicator for the titration? Justify your answer.

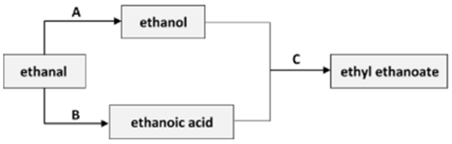
yes **(2)**

(pH range of indicator) coincides with vertical portion of the curve **(2)**

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

(*a*) Identify a reaction (**A** to **C**) in the scheme above that is:

(*i*) a substitution reaction
(*ii*) an oxidation reaction
(*iii*) a reduction reaction



(*i*) C **(2)**
(*ii*) B **(2)**
(*iii*) A **(2)**

(*b*) (*i*) Name the homologous series to which ethanal belongs.

aldehyde **(3)**

(*ii*) State the colour change observed when ethanal is warmed gently with Fehling's reagent.

(from) blue **(3)**
to red **(3)**

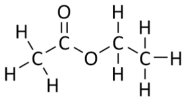
(*iii*) Identify the reagent and transition metal catalyst used to convert ethanal to ethanol.

hydrogen (gas) / H_2 **(3)**
nickel / Ni **(3)**

(*c*) Ethanol containing the radioactive isotope oxygen-18, represented by O*, reacts with non-radioactive ethanoic acid to form ethyl ethanoate. No radioactive water is formed in the process and all the ethyl ethanoate formed contains the oxygen-18 isotope.
The reaction is described by the following balanced chemical equation:

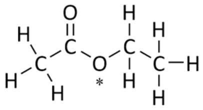
$$\mathbf{C_2H_5O^*H + CH_3COOH \rightleftharpoons CH_3COO^*C_2H_5 + H_2O}$$

(*i*) Draw the structure of a molecule of ethyl ethanoate, showing all atoms and bonds.



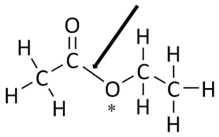
(5)

(*ii*) Indicate clearly on your diagram the position of the O* atom in ethyl ethanoate



(3)

(*iii*) Indicate clearly on your diagram the bond that was formed during the formation of ethyl ethanoate.



(3)

In a single molecule of ethyl ethanoate:

(*iv*) State the number of electrons involved in sigma bonds.

26 **(3)**

(*v*) State the number of electrons involved in pi bonds.

2 **(3)**

(*vi*) State the number of lone pairs of electrons present.

4 **(3)**

(*d*) Both ethanol and ethanoic acid demonstrate acidic properties.

(*i*) Write a balanced chemical equation for the reaction of ethanol with sodium.

$\mathbf{C_2H_5OH + Na \rightarrow C_2H_5ONa + \frac{1}{2}H_2}$
/ $\mathbf{2C_2H_5OH + 2Na \rightarrow 2C_2H_5ONa + H_2}$ **(4 × 1 + 2)**

(*ii*) Explain why the ethanoate ion (CH_3COO^-) is a weaker conjugate base than the ethoxide ion ($C_2H_5O^-$).

ethanoate ion is more stable / ethanoic acid is a stronger acid **(3)**

9. Nitrosyl bromide (NOBr) decomposes to form nitrogen monoxide (NO) and bromine gas in a reversible reaction which is described by the following balanced chemical equation:

$$2NOBr_{(g)} \rightleftharpoons 2NO_{(g)} + Br_{2(g)}$$

(*a*) (*i*) Explain what is meant by a reversible reaction.

reactants can be formed from products **(4)**

(*ii*) Explain why the concentrations of reactants and products remain constant when dynamic equilibrium is established in a reversible reaction.

rates of the forward and reverse reactions are equal **(4)**

(*b*) When 55 g of nitrosyl bromide were sealed into a 2 litre closed container, 78% of the nitrosyl bromide had decomposed at equilibrium at temperature *T*.

(*i*) Calculate the number of moles of nitrosyl bromide sealed into the container, initially.

M_r = 110 **(2)**

$\frac{55}{110}$ = 0.5 (moles of NOBr) **(2)**

(*ii*) Calculate the number of moles of nitrosyl bromide present in the container at equilibrium.

0.5 × 78% = 0.390 (moles decomposed) **(2)**

0.5 – 0.39 = 0.110 (moles of NOBr at equilibrium) **(2)**

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

$\frac{[NO]^2[Br_2]}{[NOBr]^2}$

[award 3 marks if round brackets are used] **(6)**

(*iv*) Calculate the value of K_c for the equilibrium at temperature *T*.

0.390 (moles of NO) **(2)**

0.195 (moles of Br_2) **(2)**

convert moles to moles per litre (÷ 2) i.e. 0.055 of NOBr, 0.195 of NO, 0.0975 of Br_2 **(3)**

$K_c = \frac{(0.195)^2\,(0.0975)}{(0.055)^2}$ = 1.2 (mol L^{-1}) **(3)**

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

system at equilibrium
opposes an applied stress **(4+2)**

(*ii*) State the effect, if any, on the number of moles of bromine gas present at equilibrium if the pressure was increased while keeping the temperature *T* constant. Justify your answer.

decreases
(equilibrium position) moves to side with fewer moles **(4+2)**

The value of K_c for the reaction increases with an increase in temperature.

(*iii*) State whether the decomposition of nitrosyl bromide is an endothermic or an exothermic reaction. Justify your answer.

endothermic
(equilibrium position) moves in direction that absorbs heat **(4+2)**

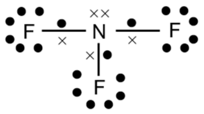
10. (*a*) Nitrogen trifluoride (NF_3) is a synthetic gas used in the manufacturing of smartphones.

(*i*) Use electronegativity values to predict the type of bonding in NF_3.

3.98(F) - 3.04(N) = 0.94 **(3)**

polar covalent **(3)**

(*ii*) Draw a dot and cross diagram to show the arrangement of all the valence electrons in a molecule of NF_3.



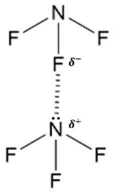
(3)

(*iii*) Name and account for the shape of the NF_3 molecule.

pyramidal **(3)**

one lone pair and three bonding pairs (of electrons around central atom) **(3)**

(*iv*) Draw a diagram to show how intermolecular forces arise between two molecules of NF_3 in the liquid state.



(3)

(*v*) Name the type of intermolecular forces you would expect to find in NF_3.

dipole-dipole ["Van der Waals" do not cancel] **(3)**

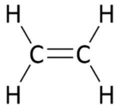
Both BF_3 and NF_3 molecules contain a central atom bonded to three fluorine atoms.

(*vi*) Explain why BF_3 is a non-polar molecule while NF_3 is a polar molecule.

BF_3 is symmetrical / centres of positive and negative charge coincide **(4)**

(*b*) Ethene can react with chlorine by ionic addition to form 1,2-dichloroethane.

(*i*) Draw the structure of a molecule of ethene, showing all atoms and bonds.



(4)

(*ii*) Indicate clearly on your diagram which of the bonds in ethene are broken during the addition reaction.

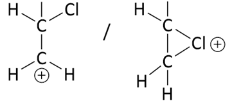
either one of the C—C bonds clearly labelled **(3)**

(*iii*) Identify the two chlorine species formed following the polarisation and the breaking of the Cl–Cl bond.

Cl^+ **(3)**

Cl^- **(3)**

(*iv*) Draw the structure of the intermediate ionic species formed during the above reaction. Your diagram should include all atoms, bonds and relevant charges.



(3)

(*v*) Describe how the intermediate ionic species is converted to 1,2-dichloroethane.

Cl^- attacks **(3)**

the carbocation / carbonium ion / bridged chloronium ion **(3)**

(*vi*) Identify the inorganic molecule that is eliminated when 1,2-dichloroethane is converted to the monomer used to produce the polymer PVC.

hydrogen chloride / HCl **(3)**

(*c*) Effervescent tablets typically contain a dry mixture of citric acid ($C_6H_8O_7$), tartaric acid ($C_4H_6O_6$) and sodium hydrogencarbonate ($NaHCO_3$). This mixture reacts when the tablet is placed in water, producing carbon dioxide gas, according to the following balanced chemical equations:

$$\mathbf{C_6H_8O_7 + 3NaHCO_3 \rightarrow Na_3C_6H_5O_7 + 3H_2O + 3CO_2}$$
$$\mathbf{C_4H_6O_6 + 2NaHCO_3 \rightarrow Na_2C_4H_4O_6 + 2H_2O + 2CO_2}$$

An effervescent tablet contains 0.096 g of citric acid and 0.15 g of tartaric acid.

(*i*) Calculate the total mass of $NaHCO_3$ required for complete reaction with the two acids in the effervescent tablet.

M_r ($C_6H_8O_7$) = 192 **(2)**
M_r ($C_4H_6O_6$) = 150 **(2)**
M_r ($NaHCO_3$) = 84 **(2)**

$\frac{0.096}{192}$ = 0.0005 (moles of $C_6H_8O_7$) **(2)**
0.0005 × 3 = 0.0015 (moles of $NaHCO_3$) **(2)**

$\frac{0.15}{150}$ = 0.001 (moles of $C_4H_6O_6$) **(2)**
0.001 × 2 = 0.002 (moles of $NaHCO_3$) **(2)**

0.0015 + 0.002 = 0.0035 (total moles of $NaHCO_3$) **(2)**
0.0035 × 84 = 0.294 (g $NaHCO_3$) **(2)**

(*ii*) Calculate the maximum volume of CO_2 produced from the tablet at room temperature and pressure.

0.0035 × 24 = 0.084 L **(2)**

(*iii*) Calculate the number of H_2O molecules produced from 0.096 g of citric acid.

0.0005 × 3 **(2)**
$0.0015 \times 6 \times 10^{23} = 9 \times 10^{20}$ (H_2O molecules) **(3)**

11. (*a*) The Environmental Protection Agency (EPA) recommend that household wells are checked for water quality. A water sample from a hard water area may be tested for total hardness.

(*i*) What is meant by total hardness?

temporary hardness and permanent hardness / all calcium ions and all magnesium ions **(3)**

(*ii*) Write the full name for edta, a reagent used to determine total hardness.

ethylenediaminetetraacetic acid **(3)**

(*iii*) Name a suitable method for removing total hardness from water for domestic use.

ion-exchange / use of deioniser **(3)**

A water sample from an agricultural area may contain nitrate ions.

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

add iron(II) sulfate solution / $FeSO_4$ **(2)**
add concentrated sulfuric acid / H_2SO_4 **(2)**
brown ring forms (at interface) **(2)**

Lead ions from the disposal of batteries may enter a water supply.

(*v*) Identify an instrumental method of analysis that could be used to detect and measure the concentration of lead ions in a water sample.

atomic absorption spectrometry / AAS **(2)**

(*vi*) Describe how lead ions can be removed from a water supply.

precipitation / reverse osmosis **(2)**

Chlorination may be carried out on a water supply from a household well using a solution of sodium hypochlorite (NaOCl). This solution is prepared by diluting 5.0 litres of a 1% (w/v) solution of sodium hypochlorite to 25 litres with water.

(*vii*) Calculate the final concentration in p.p.m. (mg per litre) of the sodium hypochlorite solution after dilution to 25 litres.

(1% =) 1 g per 100 cm^3/ 10 g per 1 litre/ 50 g per 5 litres **(2)**
1000 mg per 100 cm^3/ 10000 mg per 1 litre/ 50000 mg per 5 litres **(2)**
multiply by dilution factor = 2000 (p.p.m.) **(2)**

(*b*) In an experiment to measure the heat of reaction (ΔH) of hydrochloric acid with sodium hydroxide, 80 cm^3 of 1.0 M hydrochloric acid solution at room temperature were added to 80 cm^3 of 1.0 M sodium hydroxide solution, also at room temperature in a suitable container. The temperature of the mixture rose by 6.8 K and then began to fall. The reaction is described by the following balanced chemical equation:

$$HCl + NaOH \rightarrow NaCl + H_2O$$

(*i*) Why did the temperature rise when the solutions were mixed?

heat released / exothermic reaction **(3)**

(*ii*) Explain what is meant by the term heat of reaction.

heat change **(3)**
when the number of moles of reactants in a balanced equation react completely **(3)**

(*iii*) Calculate the number of moles of hydrochloric acid in 80 cm^3 of 1.0 M hydrochloric acid solution.

$\frac{80}{1000}$ **= 0.08 (moles)** **(6)**

(*iv*) Calculate the heat energy produced in the reaction mixture, assuming the density of the resultant sodium chloride solution is 1.0 g cm^{-3} and the specific heat capacity of the solution is 4.2 kJ kg^{-1} K^{-1}.

mass = 0.160 (kg) **(2)**
$mc\Delta\theta$ / (0.160)(4.2)(6.8) **(2)**
4.5696 (kJ) / 4569.6 J **(2)**

(*v*) Calculate the value of ΔH, the heat of reaction.

4.5696 ÷ 0.08 = 57.12 **(2)**
$\Delta H = -57.12$ kJ mol^{-1} **(2)**

(*c*) Between 1908 and 1948 luminous paints containing compounds of radioactive radium–226 were used on the inside of watches and clocks so that they could be read in the dark.

Radium–226 emits alpha radiation. It has a half-life of 1600 years.

(*i*) Name one scientist credited with the discovery of the element radium.
(Marie / Pierre) Curie **(4)**

(*ii*) What is an alpha particle?
(particle consisting of) 2 protons and 2 neutrons / helium nucleus **(3)**

(*iii*) Identify the radioisotope produced when radium–226 emits an alpha particle.
Rn–222 / radon–222 **(3)**

(*iv*) Explain why a person wearing a watch containing this luminous paint is not at risk from the alpha radiation emitted by the radium–226.
low penetrating ability (of alpha radiation) **(3)**

(*v*) State a reason why a radium watch manufactured 100 years ago is still considered a source of ionising radiation.
long half-life / very little of sample will have decayed in 100 years **(3)**

The nuclear equation below represents the beta-particle decay of another isotope of radium, radium–225.

$$^{225}_{88}\mathrm{Ra} \rightarrow {}^{X}_{Y}\mathrm{Z} + {}^{0}_{-1}\mathrm{e}$$

(*vi*) Identify the number **X**.
225 **(3)**

(*vii*) Identify the number **Y**.
89 **(3)**

(*viii*) Identify the element **Z**.
actinium / Ac **(3)**

(*d*)A The nitrogen cycle on Earth is a biogeochemical process which transforms inert nitrogen gas in the atmosphere to a more usable form for living organisms.

(*i*) Explain why nitrogen gas in the atmosphere is chemically inert.

presence of the triple bond **(3)**

(*ii*) Write balanced chemical equations for the natural fixation by lightning of atmospheric nitrogen converting it first to NO and then to NO_2.

$N_2 + O_2 \rightarrow 2NO$ **(3 × 1 + 2)**

$2NO + O_2 \rightarrow 2NO_2$ **(3 × 1 + 2)**

(*iii*) Identify the two acids formed when nitrogen dioxide reacts with water.

HNO_2 / nitrous acid **(3)**

HNO_3 / nitric acid **(3)**

Nitrate ions found in soil are a usable form of nitrogen for plants.

(*iv*) Explain why plants need nitrogen.

make protein / formation of DNA / amino acids etc. **(2)**

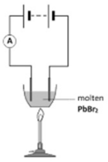
(*v*) Describe how nitrate ions in the soil are recycled to nitrogen gas in the atmosphere.

denitrification / denitrifying bacteria **(2)**

(*vi*) Describe one pathway by which nitrogen compounds in living organisms are recycled to nitrogen gas in the atmosphere.

decay / decomposition / excretion etc. **(2)**

(*d*)B The electrolysis of lead(II) bromide ($PbBr_2$) produces lead and bromine. The electrolysis can be carried out in an arrangement of apparatus as shown, using a pair of inert electrodes immersed in molten lead bromide.



(*i*) Explain what is meant by electrolysis.

breaking down of a chemical compound **(2)**

using electricity **(3)**

(*ii*) Identify a suitable material to use for the inert electrodes.

graphite (C) / platinum (Pt) **(3)**

(*iii*) Compare the electrical conductivity of solid lead(II) bromide to molten lead(II) bromide. Explain your answer.

molten form conducts **(3)**

ions free to move **(3)**

During the electrolysis, oxidation occurs at the anode.

(*iv*) Explain what is meant by oxidation in terms of electron transfer.

loss (of electrons) **(3)**

(*v*) Identify which element is formed at the anode.

bromine / Br_2 **(3)**

(*vi*) Write a balanced half-equation for the reaction that occurs at the anode.

$2Br^- \rightarrow Br_2 + 2e^-$ **(3 × 1 + 2)**