Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate 2019

Marking Scheme

Chemistry

Higher Level

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

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

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

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

Future Marking Schemes

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

Introduction

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

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

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

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

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

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

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

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

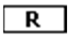
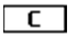
Candidates are required to answer eight questions in all.

These must include at least two questions from Section A.

All questions carry equal marks (50).

Annotations used in marking

Fully correct or fully incorrect responses may not be annotated.

Annotation	Meaning
	correct
	incorrect
	mathematical slip
	reverse order
	surplus answer or part of answer
	blank page or part of page
	cancellation /contradiction
	part of answer of significance
	incorrect charge, subscript, etc
	key word, phrase omitted

QUESTION 1

(*a*) (*i*) IDENTIFY: **$MnSO_4$**.$2H_2O$ **(manganese**(II) **sulfate) / $MnCl_2$**.$4H_2O$ **(manganese**(II) **chloride)**
[Incorrect oxidation number cancels.]

(*ii*) EXPLAIN: **ensures all O_2 (oxygen, Mn^{x+}, Mn^{3+}, Mn^{4+}) detected (analysed, reacts) /**
ensures O_2 (oxygen, Mn^{x+}, Mn^{3+}, Mn^{4+}) limiting /
if insufficient added not all O_2 (oxygen, Mn^{x+}, Mn^{3+}, Mn^{4+}) detected (analysed, reacts) /
provides enough for all O_2 (oxygen, Mn^{x+}, Mn^{3+}, Mn^{4+}) /
to ensure all Mn^{x+} (Mn^{3+}, Mn^{4+}) reduced /
ensures iodine (I_2) kept in solution / dissolves iodine (I_2) /
forms soluble KI_3 / forms soluble I_3^-

(*iii*) WHAT: changes to **brown (red, orange, golden, yellow, iodine) /**
brown (red, orange, golden, yellow, iodine) solution formed **/**
precipitate (solid) dissolves (disappears)

(4 + 4 + 4)

(*b*) (*i*) DESCRIBE: (9)

rinsed with deionised (distilled, pure) water / use clean (dry) flask //

swirl to mix contents **/**
wash down walls (sides, neck) with deionised (distilled, pure) water /
stand on white tile (paper)

[Rinse with iodine solution unacceptable;
add (200 cm^3) iodine unacceptable but does not cancel.]
Prepation and one use: (6 + 3)

(*ii*) GIVE: use (move) **clamp (stand)** to move burette until level of liquid is at eye-level **/**
place burette **on lower (higher) surface** to bring level of liquid to eye-level **/**
suspend (hang) burette **over edge of bench** to move level of liquid to eye-level **/**
use foot**stool** to bring eye-level to liquid-level **/**
bend (crouch, kneel) until eye at level of liquid **/**
etc (3)

(*c*) WHAT: (*i*) **brown (red, orange, golden, yellow)** fades **to pale (light) yellow /**
brown (red, orange, golden, yellow) fades **to straw** colour **/**
fades to pale (light) yellow / fades to straw colour (3)
[*Starting* with other colours at earlier stages and *ending* with blue (black, blue-black) acceptable.]

(*ii*) **blue (black, blue-black) to colourless** (3)
[*Ending* with 'blue (black, blue-black) to colourless' essential if other colours mentioned.]
[Allow answers to (*i*) and (*ii*) in correct order but not labelled (*i*) and (*ii*).]

(*d*) CALCULATE: (*i*) **0.000075** (**7.5 × 10^{-5}, 3/40000**) moles thiosulfate (9)

M_r of $Na_2S_2O_3.5H_2O$ = **248*** (2)
$M = \frac{3.1}{248}$ = 0**.0125 (1/80)** M (6)

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

$\frac{6.0 \times 0.0125}{1000}$ = 0**.000075** (**7.5 × 10^{-5}, 3/40000**) moles thiosulfate (1)

(*ii*) 0**.00001875** (**1.875 × 10^{-5}, 3/160000**) moles of O_2 (3)

thiosulfate : O_2 = 4 : 1 ⇒ 0.000075 (7.5 × 10^{-5}, 3/40000) ÷ 4 [Divide by 4 essential.] = **0.00001875** (**1.875 × 10^{-5}, 3/160000**) moles O_2 in 200.0 cm^3 (3)

(*iii*) 0**.00009375** (**9.375 × 10^{-5}, 3/32000**)) moles /l (M) of O_2 (3)

0.00001875 (1.875 × 10^{-5}, 3/160000) × 5 = 0**.00009375** (**9.375 × 10^{-5}, 3/32000**) moles /l (M) of O_2 (3) [Multiply by 5 essential.]

or

$\frac{200 \times M}{1} = \frac{6 \times 0.0125}{4}$ ⇒ M = 0**.00009375** (**9.375 × 10^{-5}, 3/32000**) moles /l (M) of O_2 (3)

(*iv*) **3**.0 p.p.m. (5)

0.000009375 (9.375 × 10^{-5}, 3/32000) × 32 = 0**.003** g/l [Multiply by 32 essential.] 0.003 × 1000 = **3**.0 p.p.m. [Multiply by 1000 essential.] (4 + 1)

[*1 mark to be deducted for incorrect or inappropriate rounding off resulting in candidate's final answer lying outside given value but deduction to be made once only in (d).*]

QUESTION 2

(*a*) (*i*) WHAT: **bubbling (fizzing, effervescence, foaming, gas evolves) /**
solid (magnesium, Mg) dissolves (disappears) / solution forms /
white powder (solid, precipitate) formed (7)
['Mg reacts' unacceptable.][Allow any gas evolves.]

(*ii*) WRITE: **H_2 //**
$(CH_3COO)_2Mg$ / $(C_2H_3O_2)_2Mg$ / $C_4H_6O_4Mg$ / $(CH_3COO^-)_2Mg^{2+}$ (2 × 2)
[Allow (3) for both products correctly named {hydrogen and magnesium ethanoate (magnesium acetate)} if no other marks awarded.]

(*b*) DESCRIBE: add (mix) **Tollens' (**ammoniacal **silver nitrate, Ag(I), Ag^+)** reagent to (with) ethanal **//**
heat gently **/** use **water bath /**
silver (Ag, mirror, precipitate, solid) is positive test for aldehyde

or

add (mix) **Fehling's (Benedict's, Cu(II), Cu^{2+})** reagent to (with) ethanal **//**
heat gently **/** use **water bath /**
brick **red (precipitate, solid, Cu(I), Cu^+)** is positive test for aldehyde (6 + 3)

or allow

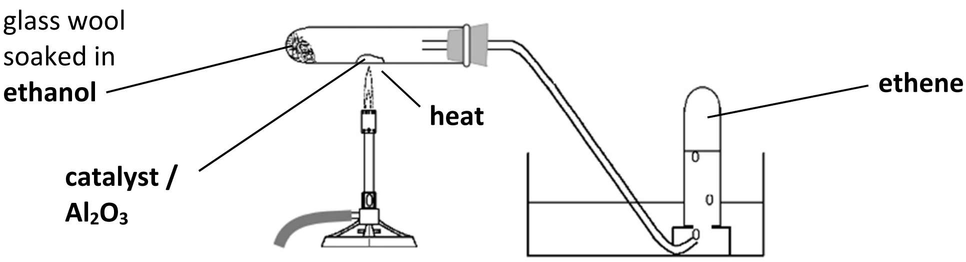
add (mix) **acidified (H⁺** and**, H_2SO_4** and**)** dilute potassium **permanganate (manganate(VII), $KMnO_4$, MnO_4^-)** to (with) ethanal **//**
decolorising is positive test for aldehyde **/** pale purple (pink) **to colourless** is positive test for aldehyde

or allow

add (mix) **acidified** (**H^+** and**, H_2SO_4** and**)** dilute **chromate**(VI) **(dichromate**(VI)**, $Cr_2O_7^{2-}$, CrO_4^{2-})** to (with) ethanal **//**
orange (yellow) to **green** is positive test for aldehyde
(6 + 3)

(*c*) (*i*) DRAW:
horizontal (slanting) **test tube with delivery tube** shown //
collection over water shown
(2 × 3)

LABEL:



[Locations of ethanol, ethene, catalyst (Al_2O_3) must be labelled;
location of heat source labelled or Bunsen shown.]
FOUR CORRECT LOCATIONS: (4 × 1)

(*ii*) IDENTIFY: **alumina / aluminium oxide / Al_2O_3** (3)
[Allow from diagram.]

DESCRIBE: **white / powder / solid** (3)
[Allow if labelled clearly on diagram.][Wrong colour does not cancel].

(*iii*) EXPLAIN: **suck-back** possible / **cold water enters** hot **test-tube (apparatus, glassware)**

HOW: **remove** delivery **tube (apparatus)** from water (trough) before reducing (removing) heat /
loosen stopper before reducing (removing) heat **/**
remove delivery **tube (apparatus)** from water (trough) to avoid pressure drop (partial vacuum creation, gas compression, gas volume decrease) **/**
loosen stopper to avoid pressure drop (partial vacuum creation, gas compression, gas volume decrease)

(3 + 3)

(*iv*) CALCULATE: **300 to 315** cm^3 / **0.3**00 **to 0.315** litres (8)

density = $\frac{\text{mass}}{\text{volume}} \Rightarrow 0.8 = \frac{\text{mass}}{2.9} \Rightarrow$ *m* = 0.80 × 2.9 = **2.32** g (✓)

$\frac{2.32}{46^*}$ = **0.05**04 moles ethanol used (✓)

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

$\Rightarrow 0.0504 \times \frac{26}{100}$ = **0.013**104 actual mol ethene (✓)

0.013104 × 24,000 = **300 - 315** cm^3 ethene /
0.013104 × 24.0 = **0.300 - 0.315** litres ethene (✓)

/

0.0504 × 24, 000 = **1200** - **1210** cm^3 ethene in theory /
0.0504 × 24.0 = **1.21** litres ethene in theory (✓)
$\Rightarrow 1200 \times \frac{26}{100}$ = **300 - 315** cm^3 ethene /
$\Rightarrow 1.21 \times \frac{26}{100}$ = 0.**300 - 0.315** litres ethene (✓)

[*1 mark to be deducted for incorrect rounding off resulting in candidate's final answer lying outside given range but deduction to be made once only in (c) (iv).*]

Four ticks: mass, moles, percentage, volume *or* mass, moles, volume, percentage
Award 3 marks for each of the first two correct ticks and 1 mark for each remaining correct tick.
(3 + 3 + 1 + 1)

or

$2.9 \times \frac{26}{100}$ = **0.754** cm^3 ethanol (✓)
density = $\frac{\text{mass}}{\text{volume}} \Rightarrow 0.8 = \frac{\text{mass}}{0.754}$
$\Rightarrow$ *m* = 0.80 × 0.754 = **0.6032** g (✓)
$\frac{0.6032}{46^*}$ = **0.013**104 moles ethanol used (✓)

/

density = $\frac{\text{mass}}{\text{volume}} \Rightarrow 0.8 = \frac{\text{mass}}{2.9}$
$\Rightarrow$ *m* = 0.80 × 2.9 = **2.32** g (✓)
$2.32 \times \frac{26}{100}$ **= 0.6032** g (✓)
$\frac{0.6032}{46^*}$ = **0.013**104 moles ethanol used (✓)

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

0.013104 × 24,000 = **300 - 315** cm^3 ethene /
0.013104 × 24.0 = **0.300 - 0.315** litres ethene (✓)

Do not penalise if volume of 22.4 litres or 22 400 cm^3 used.
[*1 mark to be deducted for incorrect rounding off resulting in candidate's final answer lying outside given range but deduction to be made once only in (c) (iv).*]

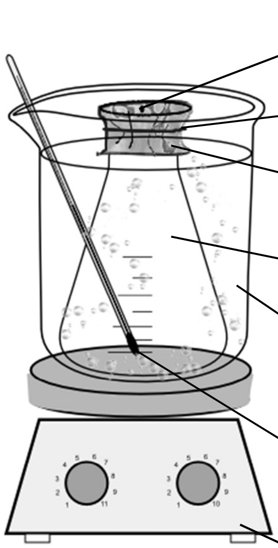
Award 3 marks for each of the first two correct ticks and 1 mark for each remaining correct tick.
(3 + 3 + 1 + 1)

QUESTION 3

(*a*) DRAW: (5)

conical **flask** approximately ¾ immersed (up to neck) **in beaker of water //**
foil (tinfoil, aluminium, Al) lid **/ bung //**
pin**hole** and rubber band **/** small **hole** in bung
Three items: (2 + 2 + 1)
[Any one correct label on drawing essential for these marks to be awarded.]

SHOW: (*i*) **hotplate (Bunsen burner, heating mantle, heat source)** under beaker (4)
(*ii*) **thermometer (temperature probe, temperature sensor) in water (beaker, flask)** (2)
[Labels not essential on heat source or thermometer provided one other label present.]

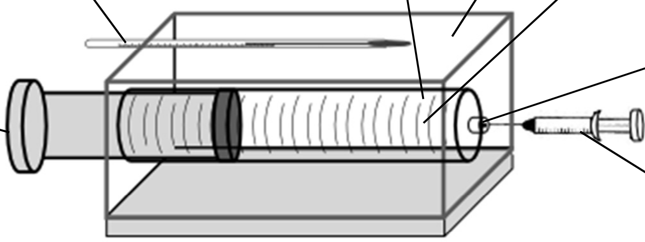


or

DRAW: (5)

gas (large) syringe //
rubber seal (septum, self-sealing cap) //
injected by hypodermic (small) syringe
Three items: (2 + 2 + 1)
[*Syringes should be recognisable; injection shown or mentioned.*]
[Any one correct label on drawing essential for these marks to be awarded.]

SHOW: (*i*) **oven (furnace in box, bulb in box)** heats gas syringe **/ steam** flow **through box** heats gas syringe **/ water bath** heats gas syringe (4)
(*ii*) **thermometer (temperature probe, temperature sensor) in oven (box, steam jacket, water bath)** (2)
[Labels not essential on heat source or thermometer provided one other label present.]



(*b*) EXPLAIN

WHY: (*i*) *flask in beaker method:*
some **vapour (gas, air) escaped** / because of pin**hole**

or

gas syringe method:
plunger of gas (large) syringe **moved /**
plunger of gas (large) syringe **free to move**
[EXPLAIN (*i*) linked to part (*a*).]

HOW: (*ii*) *flask in beaker method:*
flask filled with water **using (with) graduated cylinder /**
full **flask** of water **emptied into graduated cylinder**

or

gas syringe method:
compare (subtract) initial and final **readings** of vapour (gas) **in (of, on) gas (large) syringe** scale / **scale** of (on) **gas (large) syringe**
[EXPLAIN (*ii*) linked to part (*a*).]

(6 + 3)

(*c*) DESCRIBE: *flask in beaker method:*
subtract (take) mass of flask (at start, initially, empty), rubber band and foil (lid) from **mass of flask,** rubber band, foil (lid) **and contents (**condensed **vapour, X, liquid) /**
subtract (take) mass of flask (at start, initially, empty), rubber band and foil (lid) from **mass of flask,** rubber band, foil (lid) **at end (final, after cooling)**

[DESCRIBE linked to part (*a*).][Allow weight for mass.]
[Allow 'minus' and '–' for subtraction.]
[Allow answers where order of subtraction is unclear.]

or

gas syringe method:
subtract (take) mass of hypodermic (small) syringe after injection from **mass of hypodermic (small) syringe** and **liquid (contents, X)** before injection

(6)

[DESCRIBE linked to part (*a*).] [Allow weight for mass.]
[Allow 'minus' and '–' for subtraction.]
[Allow answers where order of subtraction is unclear.]

(*d*) CALCULATE: **88 [88 or 89]** (15)

$\boldsymbol{n = \frac{pV}{RT}}$ ***/ pV = nRT*** (5)

$n = \frac{1.011 \times 10^5 \times 76 \times 10^{-6}}{8.3 \times 372.15}$ / $\mathbf{1.011 \times 10^5 \times 76 \times 10^{-6}}$ ***= n*** $\times \mathbf{8.3 \times 372}.15$ (3)

[Use of Kelvin essential here]

[Apply slip error once to pressure not in Pa and/or volume not in m^3.]

n = **2.49** $\times$ $\mathbf{10^{-3}}$ moles [**2.48** $\times$ $\mathbf{10^{-3}}$ **– 2.49** $\times$ $\mathbf{10^{-3}}$ moles] (3)

or

$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$ / $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (5)

$\frac{101.1 \times 76}{372.15} = \frac{101.325 \times V_2}{273.15}$ / $v_2 = \frac{101.1 \times 76 \times 273.15}{101.325 \times 372.15}$ / $v_2 = \frac{76 \times 273.15}{372.15}$ /

V_2 = **55.65 – 55.7** cm^3 (3)

[Use of Kelvin essential here]

n = $\frac{55.66}{22400}$ = **2.48** $\times$ $\mathbf{10^{-3}}$ moles [**2.48** $\times$ $\mathbf{10^{-3}}$ **– 2.49** $\times$ $\mathbf{10^{-3}}$ moles] (3)

[Treat a mathematical slip incorrect power of ten in answer.]

and

$\boldsymbol{n = \frac{m}{M_r}}$ / $\boldsymbol{M_r = \frac{m}{n}}$ / $\boldsymbol{M_r = \frac{0.22}{2.49 \times 10^{-3}}}$ (2)

M_r = 88.4 = **88** **[88 or 89]*** (2)

Allow relative molecular mass of X not rounded to whole number.
Do not penalise where relative molecular mass of X is labelled g.

(*e*) ACCOUNT: **hydrogen (H) bonds in water /**
dipole-dipole forces (bonds, interactions) in water (H_2O) /
van der Waals (London, dispersion, temporary intermolecular, induced dipole) forces (bonds, interactions) in bromine (Br_2) /

intermolecular forces (bonds, interactions) in water (H_2O) stronger **/**
intermolecular forces (bonds, interactions) in bromine (Br_2) weaker **/**

bromine (Br_2) non-polar (pure covalent) /
water (H_2O) is polar (9)

QUESTION 4

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

(*a*) WHAT: beams of **electron**s / (6)
[Allow (3) for **negative particle**s

(*b*) WHAT: **calcium-40** / **Ca-40 / $^{40}_{20}$Ca / $^{20}_{40}$Ca** (6)

(*c*) STATE: **equal volumes of gases at the same temperature and pressure //**
have equal (the same) number(s) of particles (atoms, molecules, moles) (2 × 3)
[Do not allow s.t.p for 'same temperature and pressure'.]

(*d*) WHAT: SO_2: **4 / +4 //**
SO_4^{2-} : **6 / +6** (2 × 3)
[Order of question unless responses clearly identified.]

(*e*) GIVE:

sigma (σ):	**pi (π):**
formed from **end-on (head-on) overlap* of orbitals**	formed from **sideways (lateral) overlap*** of orbitals
overlap parallel to (along) the bond-axis	**overlap perpendicular to (on either side of, above and below)** bond axis
involves any type of orbital / **involves *s* or *p***, etc **orbitals /** ***can involve s orbitals***	**involves *p*** or *d* etc orbitals **/** **involves *p*** or *d* etc orbitals **/** ***cannot involve s orbitals***
symmetrical with regard to rotation around bond axis / ***allows rotation around bond axis***	***not symmetrical with regard to rotation around bond axis /*** ***restricts rotation around bond axis***
involves good (more) of overlap* of orbitals	***involves poor (less) overlap* of orbitals***
strong**er **/ not easily broken	***weak**er **/ easily broken***
formed first / ***formed alone /*** ***formed alone***	*only* ***formed after sigma*** *formed /* ***pi cannot exist on its own /*** ***always involve (accompany) sigma bond***
associated with ***single (all covalent) bonds***	*associated with* ***multiple (double, triple)*** *covalent* ***bonds***
determine shape of molecule	***do not determine shape of molecule***

ANY TWO LINES: (2 × 3)

[Where statements are in italics, one statement on either side can be taken to infer the other; otherwise two statements one from each side and on same line of table is required.]
[Accept 'collision' for *overlap.]

(*f*) WRITE: **$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ / $H_2O + e^- \rightarrow \frac{1}{2}H_2 + OH^-$ /**
$2H_2O \rightarrow H_2 + 2OH^- - 2e^-$ / $H_2O \rightarrow \frac{1}{2}H_2 + OH^- - e^-$ FORMULAE: (3) BALANCING: (3)
[***e*** for ***e***$^-$ acceptable.]

(*g*) DEFINE: average amount of **energy** involved **to break (form) bonds (a bond) /**
average amount of **energy** involved **to break (form) 1 mole of bonds**
average amount of **energy** stored **in** a mole of **a bond (bonds) //**
of a particular (same) type in a chemical species **in the gaseous state (phase) /**
of a particular (same) type in a chemical species **into separate (single) atoms /**
of a particular (same) type in a chemical species **into gaseous atoms**
or
average amount **of bond dissociation energies for all bonds //**
of the same type in a chemical species **in the gaseous state (phase)** (2 × 3)

(*h*) WHAT: components have **different attractions (affinities, interactions, solubilities)** for (in) / components **differentially partitioned (dissolved) between //** **stationary** and **mobile phase**s (2 × 3)

or

mobile phase carrying the mixture through (in contact with) **stationary** phase **//** components **selectively (differently) adsorbed (retained)** by stationary phase **/** components **pass (move, elute) through (on, along)** stationary phase **at different speeds (rates)** (2 × 3)

(*i*) HOW MANY: **100** mg (6)

M_r = **206***
$n = \frac{m}{M_r}$ ⇒ 4.86 × 10^{-4} × 206 = 0.100 g ⇒ **100.**116 mg (2 × 3)

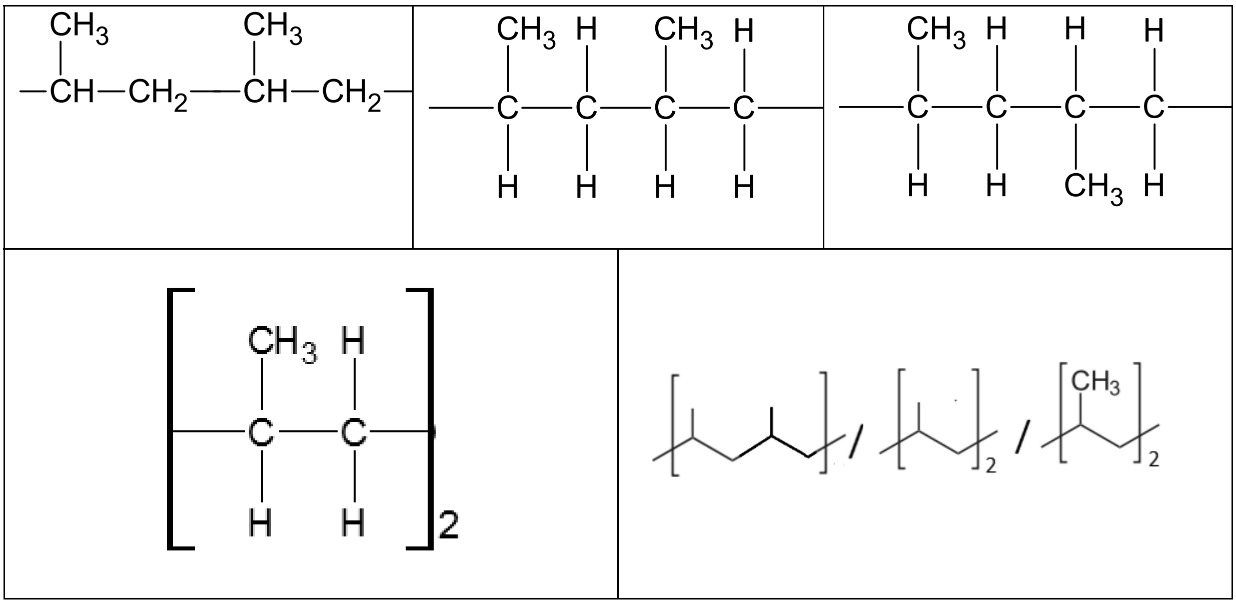
[**Addition must be shown for error to be treated as slip.*]
[*Treat answer 0.1 g as a slip error.*]

(*j*) WRITE: $\mathbf{H_2CO_3 + CaCO_3 \rightarrow Ca(HCO_3)_2}$
Allow: $\mathbf{H_2O + CO_2 + CaCO_3 \rightarrow Ca(HCO_3)_2}$
LEFT SIDE FORMULAE: (3) RIGHT SIDE FORMULA IF EQUATION BALANCED: (3)

(*k*) **A** WHY: very strong (high energy) **triple bond / N≡N /** **non-polar /** high degree of **symmetry** perpendicular bond axis **/ no dipole moment /** **no unpaired electrons** ANY ONE: (6)

or

B DRAW: (6)



Correct carbon skeleton (6 carbons) with methyl groups on alternate carbons
[Hs need not be shown explicitly; end bonds need not be shown.]

QUESTION 5

(*a*) (*i*) WHAT: **elements** listed **according to** relative **atomic mass (weight)** and
chemical **properties repeat periodically (at** regular **intervals) /**
elements listed **according to** relative **atomic mass (weight)** and
in groups with similar properties

(*ii*) CMNT: **listed (positioned)** correctly **according to** chemical **properties /**
listing (positioning) these **by** relative **atomic mass (weight) would not group them with elements of similar** chemical **properties /**
chemical **properties matched (fitted) better when** order **reversed /**
it was thought relative **atomic mass**es **(weight**s**) had been incorrectly measured**

(*iii*) WHY: **undiscovered (unknown)** in 1869 **/ discovered after (later than)** 1869

(5 + 4 + 2)

(*b*) (*i*) DEFINE 1: *Atomic number:*
number of protons in the nucleus of an atom (3)

DEFINE 2: *Relative atomic mass:*
average mass of atom of the element **/**
average of mass of isotopes of the element **taking abundances into account (as they occur naturally) /**
average of mass numbers of isotopes of the element **taking abundances into account (as they occur naturally) //**
compared to (relative to, based on) 1/12th **carbon–12** isotope

(2 × 3)

(*ii*) GIVE: **more fundamental property** of element **/**
no need to reverse order to force elements into correct groups **/**
tellurium (Te) and iodine (I) positions on table **justified /**
tellurium (Te) and iodine (I) in correct groups / elements **in correct groups /**
elements **in groups with similar properties / properties repeat periodically /**
identifies gaps in periodic table / **indicates undiscovered elements** (3)

(*c*) (*i*) WHY: **stable arrangement of electrons / do not lose or gain electrons /**
2 or 6 electrons in outer subshell /
have **stable** outer **octet** (**n**s^2 **n**p^6) except He **/ satisfy octet rule** (3)
[Full outer shell unacceptable but does not cancel.]

(*ii*) HOW: **less reactive** down group **/ less likely to gain an electron** down group /
less easily reduced down group **/ more difficult to attract (gain) electron(s)** down group/
reduction more difficult down group

WHY: **increasing (greater) atomic radius (number of shells) / more shells /**
nucleus farther from outer electrons /
increasing (more) screening of nucleus by electrons in inner shells **/**
more difficult to achieve stable octet (ns^2np^6) /
more difficult to achieve full outer sub-level (subshell) /
decreasing (smaller) electron affinity /
decreasing (smaller) electronegativity
[HOW and WHY not linked.] (6 + 3)

(*d*) (*i*) HOW: **violently / vigorously / explosively / dangerously / rapidly / burns (goes on fire,** makes coloured **flame) / fizzes** (6)
[Allow ‘very reactive’.]

JUSTIFY: **reactivity increases down group / small ionisation energy / easily loses one (outer, most loosely bound) electron / easily oxidised** (6)
[Allow (6) for any of ‘large atomic radius’ or ‘number of shells’ or ‘much screening of nucleus by electrons in inner shells’ or ‘unstable’ or ‘alkali metal’ or ‘Group 1 element’.]
[HOW and JUSTIFY not linked.]

(*ii*) PREDICT: **FrOH (francium hydroxide) //**
H_2 (hydrogen) (2 + 1)

QUESTION 6

(*a*) (*i*) WHAT: structural **isomer**s (✓)

(*ii*) WHY: **same number of carbons / same** relative **molecular mass**es **(*M_r*) / same molecular formulae / similar (same) boiling points** (✓)

(*iii*) EXPLAIN: **A** because it has the **longest chain / A** because it **least branched /**
A is **straight-chained / A** has **lowest octane number (rating)** (✓)

(*iv*) GIVE:

A: **pentane** (✓)
B: 2-**methylbutane** (✓)
C: 2,2-**dimethylpropane** (✓)
[Numbering not essential but use of incorrect numbers unacceptable.]

Award 5 marks for each of the first two correct ticks and
2 marks for each of the other correct ticks.
(5 + 5 + 2 + 2 + 2 + 2)

(*b*) (*i*) NAME: catalytic **cracking** (6)

(*ii*) DEDUCE: **$C_{14}H_{30}$ / correct structure for $C_{14}H_{30}$** (3)
[Treat as mathematical slip three correct formulae added incorrectly.]
[Allow (2) for formulae C_8H_{18} and C_3H_6.]

(*c*) (*i*) WHAT: **to reduce auto-ignition (knocking, pinking, pre-ignition) /**
to increase the octane rating (number) of the fuel **/**
source of free radicals (3)
[Allow 'protects valves in engine'.]

(*ii*) WHY: **toxic / poisonous / harmful /** probably **carcinogenic /**
damages (poisons) catalytic converters /
damages (harmful to) environment / pollutant (3)

(*iii*) CALCULATE: **−6,277.7** kJ mol^{-1} **(17)**

ΔH = $\Sigma\Delta H_{\text{formation products}}$ − $\Sigma\Delta H_{\text{formation reactants}}$

= **−6,296** kJ (3) + (**−5,716)** (3) + (**−438**.0) kJ (3) **− (105.4)** kJ (3)

or = **−12,450** kJ (9) **− 105.4** kJ (3)

and = **−12,555.4** kJ mol^{-1} (3)

$\Delta H_{\text{combustion}}$ = −12 555.4 ÷ 2 **= −6,277.7** kJ mol^{-1} (2)

or

$\Delta H_{\text{combustion}}$ = $\Sigma\Delta H_{\text{formation products}}$ − $\Sigma\Delta H_{\text{formation reactants}}$

= **−3,148** kJ (3) + (**−2,858)** kJ (3) + (**−219**.0) kJ (3) **− (52.7)** kJ (3)

or = **−6,225** kJ (9) **− 52.7** kJ (3)

and $\Delta H_{\text{combustion}}$ = **−6,277.7** kJ mol^{-1} (5)

or

$16C + 16O_2 \rightarrow 16CO_2$	ΔH =	**−6,296** kJ	(3)
$20H_2 + 10O_2 \rightarrow 20H_2O$	ΔH =	**−5,716** kJ	(3)
$2Pb + O_2 \rightarrow 2PbO$	ΔH =	**−438**.0 kJ	(3)
$2(C_2H_5)_4Pb \rightarrow 16C + 20H_2 + 2Pb$	ΔH =	**−105.4** kJ	(3)
$2(C_2H_5)_4Pb + 27O_2 \rightarrow 16CO_2 + 20H_2O + 2PbO$	ΔH =	**−12,555.4** kJ mol^{-1}	(3)
	$\Delta H_{\text{combustion}}$ = =	−12,555.4 ÷ 2 = **−6,277.7** kJ mol^{-1}	(2)

or

$8C + 8O_2 \rightarrow 8CO_2$	ΔH =	**−3,148** kJ	(3)
$10H_2 + 5O_2 \rightarrow 10H_2O$	ΔH =	**−2,858** kJ	(3)
$Pb + \frac{1}{2}O_2 \rightarrow PbO$	ΔH =	**−219**.0 kJ	(3)
$(C_2H_5)_4Pb \rightarrow 8C + 10H_2 + Pb$	ΔH =	**−52.7** kJ	(3)
$(C_2H_5)_4Pb + 13\frac{1}{2}O_2 \rightarrow 8CO_2 + 10H_2O + PbO$	$\Delta H_{\text{combustion}}$ =	**−6,277.7** kJ mol^{-1}	(5)

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

Final Answer **$8CO_2 + 10H_2O + PbO \rightarrow (C_2H_5)_4Pb + 13\frac{1}{2}O_2$ ΔH = 6,277.7 kJ**
is worth 14 marks **only** with this equation /
6,277.7 kJ is worth 5 marks if accompanied by any other equation or by no equation

Final Answer **$16CO_2 + 20H_2O + 2PbO \rightarrow 2(C_2H_5)_4Pb + 27O_2$ ΔH = 12,555.4 kJ**
is worth 12 marks **only** with this equation
12,555.4 kJ is worth 3 marks if accompanied by any other equation or by no equation

QUESTION 7

(*a*) USE: (*i*) $\mathbf{H_2O + HCl \rightleftharpoons H_3O^+ + Cl^-}$ (3)

[Accept any style arrow, equals sign or equilibrium indicator.]

(*ii*) $\mathbf{H_2O + NH_3 \rightleftharpoons NH_4^+ + OH^-}$

[Accept any style arrow, equals sign or equilibrium indicator.] (3)

EXPLAIN: (*iii*) **strong acid / good proton donor / equilibrium lies on right / forward reaction favoured / Cl^- cannot readily accept protons / Cl^- poor proton acceptor**

[Accept 'fully dissociated'.]

(3)

(*iv*) **weak base / poor proton acceptor / equilibrium lies on left / reverse reaction favoured / NH_4^+ readily donates protons / NH_4^+ good proton donor**

[Accept 'not fully dissociated'.] (3)

(*b*) (*i*) WRITE: K_w = $\mathbf{[H_3O^+][OH^-]}$ **/** K_w = $\mathbf{[H^+][OH^-]}$ (6)

[Allow 3 if $[H_2O]$ appears in expression]

[Deduct 3 for brackets not square.]

Temperature (°C)	K_w
0	0.1×10^{-14}
10	0.3×10^{-14}
20	0.7×10^{-14}
30	1.4×10^{-14}
40	2.9×10^{-14}
50	5.3×10^{-14}
60	9.3×10^{-14}

(*ii*) ARE: **endothermic** (3)

JUSTIFY: **more ions at higher temperature (when heated) / K_w bigger at higher temperature (when heated) / forward reaction favoured (equilibrium moves to the right) at higher temperature (when heated)**

[ARE and JUSTIFY linked.]

(*iii*) PLOT: A: **one axis labelled temperature (°C)** (3)

B: **appropriate correct numeric scales on both axes** (3)

C: careful **plotting of 7 points to give** smooth **curve** of correct shape (8)

[Deduct (1) in C for <u>each</u> of the following:
poor curve;
all pairs of points connected with straight lines;
graph not on graph paper.]
[Temperature *versus* K_w graph acceptable.]

(*iv*) USE: $\mathbf{2.3 \times 10^{-14}}$ **[$\mathbf{2.1 \times 10^{-14}}$ – $\mathbf{2.5 \times 10^{-14}}$]** (6)

(*v*) USE: **1.5**1 **×** $\mathbf{10^{-7}}$ **[$\mathbf{1.44 \times 10^{-7}}$ – $\mathbf{1.59 \times 10^{-7}}$]** (3)

$[H^+] = \sqrt{K_w}$ / $[H^+] = \sqrt{2.3 \times 10^{-14}}$ ⇒
$[H^+]$ = **1.5**1 × $\mathbf{10^{-7}}$ (3)

(*vi*) FIND: **40** °C (3)

$[H^+]$ = **inverse log (–6.77) /** $[H^+]$ = **antilog(–6.77) /** $[H^+]$ = $\mathbf{10^{-6.77}}$ **/** $[H^+]$ = $\mathbf{1.69 \times 10^{-7} - 1.7 \times 10^{-7}}$ (2)
$K_w = 2.9 \times 10^{-14}$ ⇒ **40** °C (1)

Accept for 3 marks trial and error testing by getting square root of $\boldsymbol{K_w}$ values and pH of corresponding $[H^+]$ values if correct temperature is deduced.

QUESTION 8

(*a*) (*i*) WHAT: **two carbon (C) atoms attached to carbon (C) to which the OH (alcohol group, hydroxyl** group**) is attached** (5)

or

one hydrogen (H) attached to carbon (C) to which the OH (alcohol group, hydroxyl group**) is attached** (5)
[Do not allow hydroxide for hydroxyl and OH^- for –OH.]
[Allow 'OH group not attached to terminal (end) carbon (C) or OH group attached to middle carbon (C) of chain' for (4).]

(*ii*) PLOT: A: **correct numeric scales on both axes and one axis labelled (boiling point, °C)** (3)
[A marks not available if not on graph paper.]

B: **points correctly plotted** (6)
SIX POINTS: (6 × 1)
[Points need not be joined up.]
[Allow any lines or curves joining points.]

(*iii*) STATE: **increasing** (3)

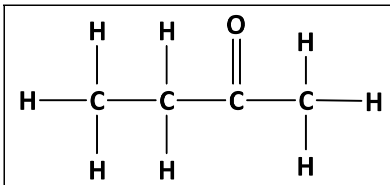
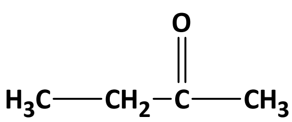
EXPLAIN: **more (stronger) intermolecular (van der Waals, dispersion, London) forces (bonds, interactions) / more (stronger)** temporary (induced) **dipoles / number of electrons increasing / electron cloud** that produces intermolecular forces **increasing** (3)
[Stronger (more) hydrogen bonds or stronger (more) permanent dipole-dipole unacceptable and cancellation applies. Reference to breaking covalent bonds unacceptable and cancellation applies.]

(*iv*) PREDICT: **105 – 130** °C (3)
[Method/reasoning need not be shown.]

(*b*) (*i*) GIVE: (6)

1-**butanal / butan**-1-**al //**
1-**butanoic acid / butan**-1-**oic acid**
TWO NAMES: (2 × 3)
[Numbering not essential but use of incorrect numbers unacceptable.]

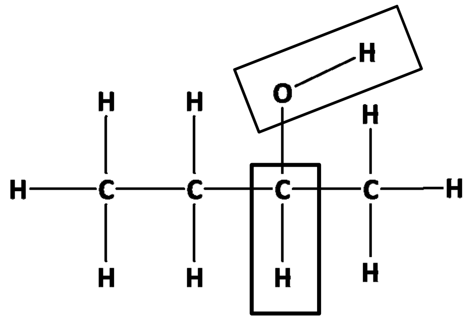
(*ii*) DRAW: (3)

 [Hs need not be explicitly shown.]		**$CH_3CH_2COCH_3$**

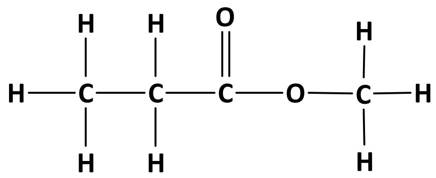
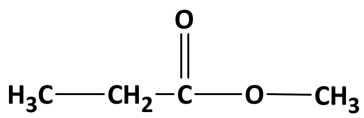
(*iii*) IDENTIFY: (6)

OH bond **//**
CH bond of **carbon to which OH (hydroxyl, alcohol group, functional group) is attached** /
CH bond **with OH (hydroxyl, functional group) attached to same C** /
CH bond of carbon (C) 2
TWO BONDS: (4 + 2)
[Information acceptable in diagram form.]

[Allow corresponding bonds in incorrect secondary alcohols.]



(*c*) (*i*) DRAW: (4)

 [Hs need not be explicitly shown.]		$CH_3CH_2COOCH_3$

(*ii*) HOW MANY: **3** (6)

[HOW MANY not linked to DRAW.]
[Award the mark in (*ii*) for the correct number of tetrahedral carbon atoms for an incorrect ester drawn at (*i*).]

(*iii*) WHAT: (2)

methanol / CH_3OH //
sodium propanoate / sodium propionate / **CH_3CH_2COONa / C_2H_5COONa**
TWO PRODUCTS: (2 × 1)

QUESTION 9

(*a*) DEFINE:

change in concentration per unit time (rate of change of concentration, $\frac{\textit{change in concentration}}{\textit{time}}$ **)** of one reactant (product)

or

$\frac{d[reactant]}{dt}$ **/** $\frac{-d[reactant]}{dt}$ **/** $\frac{d[product]}{dt}$ (6)

(*b*) USE: $\frac{0.002}{500}$ = **4.**0 × **10**$^{-6}$ M s^{-1} of C (3)

HOW: **smaller / less / average** rate **greater (bigger) /**
numerical value for instantaneous rate smaller than 4.0 × **10**$^{-6}$ M s^{-1} (3)

(*c*) EXPLAIN: **catalyst in a different phase from reactants** and products (3)
[Allow state for phase.]

DESCRIBE: (9)

reactants adsorbed on (chemisorbed, bond weakly **with) surface (catalyst) /**
reactants occupy active sites on catalyst **//**

reaction takes place on surface (catalyst) /
bonds in reactant molecules **weaken (stretch, break)** on surface (catalyst) **/**
product bonds begin to **form** on surface (catalyst) **/**
higher reactant concentration on surface (catalyst) **/**
reactants closer **together** on surface (catalyst) **/**
activation energy (E_A**) lowered** on surface (catalyst) **/**
reactants orientated (oriented) correctly for reaction on surface (catalyst) **/**
intermediate formed on surface (catalyst) **//**

products leave (desorb from) surface (catalyst)

ANY TWO PARTS: (6 + 3)

EXPLAIN: **surface area** of pellets **small**er than powder's / **surface area of powder great**er than pellets' / **fewer active sites available** with pellets **/ more active sites** available **with powder** (3)

(*d*) EXPLAIN: (6)

minimum combined **energy of colliding particles (molecules) //**
for reaction to take place between them

or

minimum combined **energy** of particles (molecules) //
for effective collisions

TWO PARTS : (2 × 3)

[*At least one mention of collisions or colliding is essential*.]

STATE: **increase concentration (pressure)** of reactants (4)

EXPLAIN: **reactants (**reactant **molecules) closer together / more reactant particles (molecules) per unit volume / greater frequency of collisions** between reactants (2)
[Allow 'more collisions' for 'greater frequency of collisions'.]
[STATE and EXPLAIN linked]

STATE: **increase temperature** (4)
[Allow add heat.]

EXPLAIN: **reactants (**reactant **molecules) move faster (have more energy) /**
greater frequency of collisions between reactants /
more collisions reach (have) activation energy (E_A) (2)
[Allow 'more collisions' for 'greater frequency of collisions'.]
[STATE and EXPLAIN linked]
[**'greater frequency of collisions** between reactants' need only be mentioned once]

or allow

STATE: **decrease particle size** of reactants (4)

EXPLAIN: **surface area great**er / **more contact between reactant and catalyst** (2)
[STATE and EXPLAIN linked]

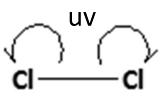
(*e*) IS: **no** (3)

EXPLAIN: **no A left at end (after 2500 s) / all A gone at end (after 2500 s) / only B and C left at end (after 2500 s) / in an equilibrium reaction there would be some of A, B and C present / no** evidence for **reverse reaction / goes to completion /** single **arrow in equation** (2)
[IS and EXPLAIN are linked.]

QUESTION 10

(*a*) A cross is unacceptable for a dot to indicate a free radical in (*i*), (*ii*), (*iii*) or (*iv*).

(*i*) EXPLAIN: **atom**s **(group**s **of atoms, molecule**s, **ion**s**, particles, species, substances** whose molecules**)** that **has (have) an unpaired electron / very reactive atom (group of atoms)** (✓)

(*ii*) HOW: $Cl_2 \xrightarrow{uv} 2Cl^\bullet$ / $Cl—Cl \xrightarrow{uv} 2Cl^\bullet$ / 

/
chlorine molecule (bond) broken to give two chlorine free radicals /
homolysis (homolytic fission) of Cl_2 by ultraviolet (uv) light (✓)
[uv not essential]

(*iii*) WHAT: **propagation** (✓)

WRITE: $Cl^\bullet + CH_4 \rightarrow HCl + CH_3^\bullet$ (✓)

$CH_3^\bullet + Cl_2 \rightarrow CH_3Cl + Cl^\bullet$ (✓)

[Any order for these two propagation steps acceptable.]

(*iv*) IDENTIFY: **ethane (C_2H_6, CH_3CH_3)** (✓)

EXPLAIN: **most methyl radicals ($CH_3^\bullet$) react with chlorine (Cl_2) /**
collisions (reaction) between methyl radicals ($CH_3^\bullet$) unlikely/
collisions (reaction) between methyl radicals ($CH_3^\bullet$) less likely than other collisions (reactions) /
probability of collisions (reaction) between methyl radicals ($CH_3^\bullet$) small /
concentration of methyl radical ($CH_3^\bullet$) small at all times **/**
collisions of methyl radicals ($CH_3^\bullet$) with chlorine (Cl_2) much **more likely /**
chlorine concentration much **greater than methyl radical ($CH_3^\bullet$) concentration /**
more chlorine (Cl_2) present than methyl radicals ($CH_3^\bullet$) (✓)

[IDENTIFY and EXPLAIN linked.]
[Allow propane, butane, etc only if their formation is fully and correctly justified.]

[Reference to chloride radical instead of chlorine unacceptable; **Cl^-** instead of **$Cl^\bullet$** unacceptable. Penalise (3) once each in (*ii*) and (*iii*) and (1) once (*iv*).]

[Provided initiation described before propagation and propagation before termination, marks may be awarded for information provided without reference to numbering of parts (*ii*), (*iii*), (*iv*).]

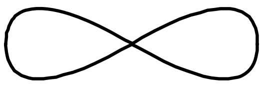
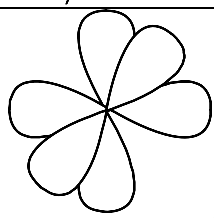
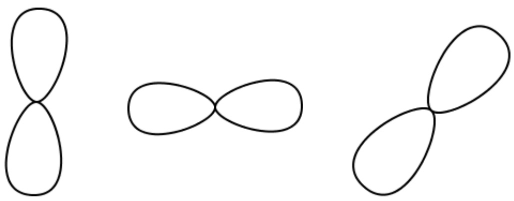
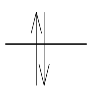
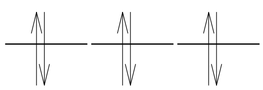
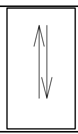
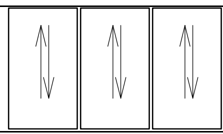
Award 6 marks for each of the first two correct ticks, 3 marks for each of the next four correct ticks and one for the final correct tick. (6 + 6 + 3 + 3 + 3 + 3 + 1) (*b*) (*i*) WHAT: **discrete (definite, fixed) amount of energy of an electron** in an atom (4)

(*ii*) GIVE: (6)

Bohr **orbit**	**orbital**
pathway **/** **2-d**imensional	**region (space, volume) /** **3-d**imensional
capacity $2n^2$ electrons **/ capacity 2, 8, etc** electrons	**capacity 2** electrons
electron definitely located there	**high probability of finding electron** there
fixed distance from nucleus / circle (circular)	***no fixed distance from nucleus / not circular / spheres, dumbbells, etc***
definite shape (size)	***no absolute (definite) boundary (size)***
inconsistent with wave properties of electron	***electron can have wave properties***
uncertainty principle not taken into account	***uncertainty principle taken into account***

ANY TWO LINES FROM TABLE: (2 × 3)
[Where line is in italics statement on either side can be taken to infer the other.]

(*iii*) USE: (6)

p orbital	*p* sub-level (subshell)
	 /  If separate orbitals are not labelled *x*, *y* and *z* they must have different orientations
	
	

ANY LINE: (2 × 3)
Take order of question unless one diagram labelled to justify reverse order.

(*iv*) WRITE: (6)

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$/$1s^2\ 2s^2\ 2p_x^2 2p_y^2 2p_z^2\ 3s^2\ 3p_x^2 3p_y^2 3p_z^2$ / [Ar] //
$4s^2\ 3d^8$ / $3d^8\ 4s^2$

TWO PARTS: (2 × 3)

[*Allow subscripts instead of superscripts.*]

[*Arrows to represent numbers of electrons acceptable but sub-level symbols must be given.*]

(*v*) STATE: atomic (emission, absorption, line) **spectrum (spectra) /** atomic **spectroscopy /**
fixed (certain, definite) frequencies (wavelengths, colours, lines) emitted (given off, absorbed) by atoms **/**
photons emitted (absorbed) by atoms **/**
first **ionisation energies /**
successive **ionisation energies** of same element (3)

(*c*) (*i*) WHAT MASS: 0**.46**0 g C_3N_4 (12)

M_r mercury thiocyanate = 317*
$\frac{3.17}{317^*}$ = 0**.01**0** moles mercury thiocyanate
0.010 ÷ 2 ⇒ 0**.005** moles C_3N_4
M_r C_3N_4 = 92***
92 × 0.005 = 0**.46**0 g
(6 + 3 + 3)

[**Addition must be shown for error to be treated as slip.*]
[**See note below part (*iv*).]
[***Addition must be shown for error to be treated as slip.*]

(*ii*) HOW MANY: 0**.336** litres O_2 (6)

0.005 moles CS_2 × 3 ⇒ 0**.015** moles O_2	(3)
0.015 × 22.4 = 0**.336** litres O_2	(3)

[24 litres unacceptable for molar volume here.]

(*iii*) WHAT IS: **6**.0 **×** $\mathbf{10^{21}}$ atoms Hg (6)

0**.01**0 moles Hg	(3)
0.010 × 6.0 × 10^{23} = **6**.0 **×** $\mathbf{10^{21}}$ atoms Hg	(3)

(*iv*) WHAT IS: 0**.035** moles gaseous product (1)

0.010 moles SO_2 from burning 0.010 moles HgS ⇒ 0.010 moles	
0.005 moles CO_2 and 0.010 moles SO_2 from burning 0.005 moles CS_2 ⇒ 0.015 moles	
0.0075 moles $(CN)_2$ and 0.0025 N_2 from decomposition 0.005 moles C_3N_4 ⇒ 0.010 moles	
0.010 + 0.015 + 0.010 ⇒ 0**.035**** moles gaseous product	(1)

[***Must be 3.5 × number moles mercury thiocyanate from first box.*]

QUESTION 11

(*a*) (*i*) DEFINE: (6)

number expressing the **relative (measure of) attraction of an atom //**
for shared pair(s) of **electrons / for electrons in a covalent bond**
TWO PARTS: (4 + 2)

(*ii*) ACCOUNT:

effective **nuclear charge increasing / number of (more) protons /**
atomic number (Z) increasing /
atomic radius decreasing (6)

(*iii*) USE: slightly **polar** covalent (3)

(*iv*) STATE: **v**-shaped planar **/ bent** (3)
[Diagram acceptable.]

ACCOUNT: **4 pairs** electrons of which **2 lone pairs /**
2 bond pairs electrons and **2 lone pairs** (3)
[Diagram acceptable and allow a line (single bond) to represent a bond pair.]
[STATE and ACCOUNT not linked.]

(*v*) SELECT: **103**.0° (3)

REASONS: repulsion(s) between **2 bond pairs (2 b.p.) and 2 lone pairs (2 l.p.) reduce(s)** regular (expected, tetrahedral) **angle /**
repulsion(s) between **2 lone pairs (2 l.p.) push 2 bond pairs (2 b.p.)** closer **together** so bond angle is less than 109.5°

or

180.0° corresponds to exactly **2 bond pairs (2 b.p.)**
120.0° corresponds to exactly **3 bond pairs (3 b.p.)**
109.5° corresponds to exactly **4 bond pairs (4 b.p.)**

or

109.5° corresponds to exactly **4 bond pairs (4 b.p.)**
180.0° and 120.0° too large when 4 pairs electrons repel (are involved)

or allow

lone pair lone pair (l.p. l.p.) repulsion(s) **> lone pair bond pair (l.p. b.p.)** repulsion(s) **> bond pair bond pair (b.p. b.p.)** repulsions

(1)

[SELECT and REASONS are linked.]

(*b*) (*i*) WRITE: $K_c = \frac{[Br_2][Cl_2]}{[BrCl]^2}$ (6)

[Square brackets essential.][Marks may be awarded for this formula given in CALCULATE.]

(*ii*) CALCULATE: **48%** First correct tick 6, each other correct tick 2 marks (12)

Let *x* = number of moles of Br_2 (or Cl_2) produced

	$2BrCl_{(g)}$	⇋	$Br_{2\,(g)}$	+	$Cl_{2\,(g)}$	
Initially:	0.200 mol		0 mol		0 mol	
Change:	– 2*x* mol		+ *x* mol		+ *x* mol	
Equil:	**0.200 – 2*x***		***x*** mol		***x*** mol /	
Equil:	$\frac{0.200-2x}{5}$ mol/l		$\frac{x}{5}$ mol/l		$\frac{x}{5}$ mol/l	A = (✓)

(K_c =) $0.220 = \frac{x^2}{(0.200-2x)^2}$ / $0.220 = \frac{\frac{x^2}{25}}{\frac{(0.200-2x)^2}{25}}$ / $0.220 = \frac{x^2}{4x^2-0.8x+0.04}$ / $0.12x^2 + 0.176x - 0.0088 = 0$

B = (✓)

square rooting both sides ⇒ $0.469 = \frac{x}{0.200-2x}$ ⇒ $0.0938 - 0.938x = x$ ⇒ x = **0.0484** mol /

solving quadratic ⇒ $0.12x^2 + 0.176x - 0.0088 = 0 \Rightarrow x = \frac{-0.176 \pm\sqrt{0.176^2-4(0.12)(-0.0088)}}{0.24}$ ⇒ x = **0.0484** mol

C = (✓)

$\frac{2x}{0.2} \times 100 = \frac{0.0968}{0.2} \times 100 = 48.4\%$ ⇒ **48%*** or **49%*** decomposed /

now working in moles per litre:

0.048 × 2 moles of BrCl decomposed ⇒ 0.0192 moles/l of initial 0.04 moles/l BrCl decomposed ⇒

$\frac{0.0192}{0.04} \times 100 = 48.4\%$ ⇒ **48%*** or **49%*** decomposed D = (✓)

Let *x* = number of moles of BrCl decomposed

	$2BrCl_{(g)}$	⇋	$Br_{2\,(g)}$	+	$Cl_{2\,(g)}$	
Initially:	0.200 mol		0 mol		0 mol	
Change:	– *x* mol		+ ½*x* mol		+ ½*x* mol	
Equil:	**0.200 – *x***		**½*x*** mol		**½*x*** mol /	
Equil:	$\frac{0.200-x}{5}$ mol/l		$\frac{x}{10}$ mol/l		$\frac{x}{10}$ mol/l	A = (✓)

(K_c =) $0.220 = \frac{x^2}{4(0.200-x)^2}$ / $0.220 = \frac{\frac{x^2}{100}}{\frac{(0.200-x)^2}{25}}$ / $0.220 = \frac{x^2}{4x^2-1.6x+0.16}$ / $0.12x^2 + 0.352x - 0.0352 = 0$

B = (✓)

square rooting both sides ⇒ $= \frac{x}{2(0.200-x)} = 0.469$ ⇒ $0.1876 - 0.938x = x$ ⇒ x = **0.0968** mol /

solving quadratic ⇒ $0.12x^2 + 0.352x - 0.0352 = 0$

$\Rightarrow x = \frac{-0.352 \pm\sqrt{0.352^2-4(0.12)(-0.0352)}}{0.24}$ ⇒ x = **0.0968** mol C = (✓)

$\frac{x}{0.2} \times 100 = \frac{0.0968}{0.2} \times 100 = 48.4\%$ ⇒ **48%*** or **49%*** decomposed /

now working in moles per litre:

0.0968 moles of BrCl decomposed ⇒ 0.0194 moles/l of 0.04 moles/l BrCl decomposed ⇒

$\frac{0.0194}{0.04} \times 100 = 48.5\%$ ⇒ **48%*** or **49%*** decomposed D = (✓)

Let x = number of moles per litre of Br_2 (or Cl_2) produced

	$2BrCl_{(g)}$	⇋	$Br_{2\,(g)}$	+	$Cl_{2\,(g)}$	
Initially:	0.200 ÷ 5 mol/l		0 mol/l		0 mol/l	
Change:	– 2x mol/l		+ x mol/l		+ x mol/l	
Equil:	0.**04 – 2*x*** mol/l		***x*** mol/l		***x*** mol/l	A = (✓)

(K_c =) 0.**22**0 $= \frac{\boldsymbol{x^2}}{(\mathbf{0.04}-\mathbf{2}\boldsymbol{x})^2}$ **/** 0.**22**0 = $\frac{\boldsymbol{x^2}}{\mathbf{4}\boldsymbol{x^2}-\mathbf{0.16}\boldsymbol{x}+\mathbf{0.0016}}$

or **$0.12x^2 + 0.0352x - 0.000352 = 0$** B = (✓)

square rooting both sides ⇒ 0.469 = $\frac{x}{0.04-2x}$ ⇒ 0.01876 – 0.938x = x ⇒ ***x* = 0.00968** mol/l /

solving quadratic ⇒ $0.12x^2 + 0.0352x - 0.000352 = 0 \Rightarrow x = \frac{-0.0352\pm\sqrt{0.0352^2-4(0.12)(-0.000352)}}{0.24}$

⇒ ***x* = 0.00968** mol/l C = (✓)

$\frac{2x}{0.04} \times 100 = \frac{0.0194}{0.04} \times 100 = 48.4\%$ ⇒ **48%*** or **49%*** decomposed **/**

now working in moles:

0.00968 × 2 moles/l of BrCl decomposed ⇒ 0.0968 *moles* of 0.20 moles BrCl decomposed ⇒

$\frac{0.0968}{0.2} \times 100 = 48.4\%$ ⇒ **48%*** or **49%*** decomposed D = (✓)

Let x = number of moles per litre of BrCl decomposed

	$2BrCl_{(g)}$	⇋	$Br_{2\,(g)}$	+	$Cl_{2\,(g)}$	
Initially:	0.200 ÷ 5 mol/l		0 mol/l		0 mol/l	
Change:	– x mol/l		+ ½x mol/l		+ ½x mol/l	
Equil:	**0.04 – *x***		**½*x*** mol/l		**½*x*** mol/l	A = (✓)

(K_c =) 0.**22**0 = $\frac{\boldsymbol{x^2}}{\mathbf{4}(\mathbf{0.04}-\boldsymbol{x})^2}$ **/** 0.**22**0 = $\frac{\boldsymbol{x^2}}{\mathbf{4}\boldsymbol{x^2}-\mathbf{0.32}\boldsymbol{x}+\mathbf{0.0064}}$ / **$0.12x^2 + 0.0704x - 0.001408 = 0$** B = (✓)

square rooting both sides ⇒ = $\frac{x}{2(0.04-x)}$ = 0.469 ⇒ 0.03752 – 0.938x = x ⇒ x = **0.0194** mol/l **/**

solving quadratic ⇒ $0.12x^2 + 0.0704x - 0.001408 = 0$

$\Rightarrow x = \frac{-0.0704\pm\sqrt{0.0704^2-4(0.12)(-0.001408)}}{0.24}$ ⇒ x = **0.0194** mol/l C = (✓)

$\frac{0.0194}{0.04} \times 100 = 48.5\%$ ⇒ **48%*** or **49%*** decomposed **/**

now working in moles:

0.0194 moles/l of BrCl decomposed ⇒ 0.097 *moles* of 0.20 moles BrCl decomposed ⇒

$\frac{0.097}{0.2} \times 100 = 48.5\%$ ⇒ **48%*** or **49%*** decomposed D = (✓)

Mixing and matching boxes not acceptable.

**Treat as mathematical slip % decomposition not rounded to whole number.*

(*iii*) EXPLAIN: gases **more concentrated (compressed) /** gases in **smaller space (volume) /**
equal numbers of moles (molecules) of reactants and products /
no change in numbers of moles (molecules) during reaction /
same number of moles (molecules) on both (either) sides /
only temperature can change % dissociation (K_c) (7)

A (*i*) WHAT: **trapping (retention) of heat (infra-red)** energy **by** gases **(in) atmosphere** (3)

(*ii*) WHY: it makes **temperatures (climate) suitable** for life **/ warms planet (Earth) / otherwise too cold** for life **/ otherwise planet (Earth) frozen** (3)

(*iii*) GIVE: (6)

burning fossil fuels // gas flaring (extraction, processing) // transporting fossil fuels) // population rise // urbanisation // rice production (paddy fields) //
farming **livestock (cattle, sheep, goats, deer, pigs, chickens, etc) // deforestation // cement production // garbage (waste) disposal // NO_x (N_2O, NO_2) from fertilizer industry (cars) // CFCs (HCFCs, halocarbons) // etc**
ANY TWO: (4 + 2)

(*iv*) GIVE: (6)

present in different quantities / abundances different //
different abilities to absorb heat (infra-red) energy **/ different greenhouse factors //**
different residence times (broken down at different rates) in atmosphere
ANY TWO: (4 + 2)

(*v*) COMPARE: **water vapour has a greater (greatest, larger, largest)** greenhouse effect (impact) **/** greenhouse effect (impact) of **carbon dioxide less** than that of water vapour

ACCOUNT: **water vapour is** the **most (more) abundant (plentiful, present in greater concentration) / carbon dioxide** significantly **less abundant**
[COMPARE and EXPLAIN linked.] (5 + 2)

or

B (*i*) WHAT: **regular (repeating) pattern (lattice) of atoms (ions, molecules, particles) / arrangement (orderly packing) of atoms (ions, molecules, particles)** (4)

(*ii*) TO WHICH: **molecular** (3)

JUSTIFY: iodine **molecules (I_2) occupy lattice points / held together by weak intermolecular (van der Waals, London, dispersion) forces (bonds, interactions) / sublimes / low melting point (m.p.)** (3)
[TO WHICH and JUSTIFY linked.]

(*iii*) WHAT: **x-ray crystallography / x-ray scattering / x-ray analysis / x-ray diffraction** (3)

(*iv*) EXPLAIN: (6)

planes (sheets, layers) of **carbon atoms covalently (strongly) bonded //**
planes of carbon atoms **bonded (held) together (to each other) by weak (easily broken) intermolecular (van der Waals, London, dispersion) forces (bonds, interactions)**
TWO POINTS: (4 +2)

(*v*) EXPLAIN: (6)

positively charged silver **ions //**
valence (outer) electrons delocalised (in cloud, free to move)
TWO POINTS: (4 + 2)