Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

November 2019

Chemistry

Higher level

Paper 3

45 pages

Subject details: Chemistry higher level paper 3 markscheme

Candidates are required to answer **ALL** questions in Section A **[15 marks]** and all questions from **ONE** option in Section B **[30 marks]**.
Maximum total = **[45 marks]**.

1. Each row in the "Question" column relates to the smallest subpart of the question.

2. The maximum mark for each question subpart is indicated in the "Total" column.

3. Each marking point in the "Answers" column is shown by means of a tick (✓) at the end of the marking point.

4. A question subpart may have more marking points than the total allows. This will be indicated by "**max**" written after the mark in the "Total" column. The related rubric, if necessary, will be outlined in the "Notes" column.

5. An alternative word is indicated in the "Answers" column by a slash (*/*). Either word can be accepted.

6. An alternative answer is indicated in the "Answers" column by "***OR***". Either answer can be accepted.

7. An alternative markscheme is indicated in the "Answers" column under heading **ALTERNATIVE 1** *etc*. Either alternative can be accepted.

8. Words inside chevrons **« »** in the "Answers" column are not necessary to gain the mark.

9. Words that are <u>underlined</u> are essential for the mark.

10. The order of marking points does not have to be as in the "Answers" column, unless stated otherwise in the "Notes" column.

11. If the candidate's answer has the same "meaning" or can be clearly interpreted as being of equivalent significance, detail and validity as that in the "Answers" column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect) in the "Notes" column.

12. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

13. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script.

14. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the “Notes” column.

15. If a question specifically asks for the name of a substance, do not award a mark for a correct formula unless directed otherwise in the “Notes” column. Similarly, if the formula is specifically asked for, do not award a mark for a correct name unless directed otherwise in the “Notes” column.

16. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the “Notes” column.

17. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the “Notes” column.

Section A

Question			Answers	Notes	Total
1.	a		best-fit smooth curve ✓	*Do **not** accept a series of connected lines that pass through all points **OR** any straight line representation.*	1
1.	b	i	tangent drawn at time zero ✓ g day^{-1} ✓ 0.16 ✓	*Accept other reasonable units for initial rate eg, mol dm^{-3} s^{-1}, mol dm^{-3} min^{-1}, g s^{-1} **OR** g min^{-1}.* *M3 can only be awarded if the value corresponds to the correct unit given in M2.* *Accept values for the initial rate for M3 in the range:* *0.13 – 0.20 g day^{-1} **OR*** *1.5 × 10^{-6} g s^{-1} – 2.3 × 10^{-6} g s^{-1} **OR*** *7.5 × 10^{-8} – 1.2 × 10^{-7} mol dm^{-3} s^{-1} **OR*** *4.5 × 10^{-6} – 6.9 × 10^{-6} mol dm^{-3} min^{-1} **OR** 9.0 × 10^{-5} – 1.4 × 10^{-4} g min^{-1} **OR** a range based on any other reasonable unit for rate.* *Ignore any negative rate value.* *Award **[2 max]** for answers such as 0.12/0.11 g day^{-1}, incorrectly obtained by using the first two points on the graph (the average rate between t = 0 and 1 day).* *Award **[1 max]** for correctly calculating any other average rate.*	3

(continued…)

(Question 1b continued)

Question			Answers	Notes	Total
1.	**b**	**ii**	acid used up ***OR*** acid is the limiting reactant ✓ concentration of acid decreases ***OR*** less frequent collisions ✓	*Award **[1 max]** for "surface area decreases" if the idea that $CaCO_3$ is used up/acts as the limiting reactant" is conveyed for M1.* *Do **not** accept "reaction reaches equilibrium" for M2.*	**2**
1.	**b**	**iii**	surface area not uniform ***OR*** limestone pieces do not have same composition/source ***OR*** limestone absorbed water **«**which increased mass**»** ***OR*** acid removed from solution when limestone removed ***OR*** **«**some**»** calcium sulfate deposited on limestone lost ***OR*** pieces of paper towel may have stuck to limestone ***OR*** beakers not covered/evaporation ***OR*** temperature was not controlled ✓	*Accept "acids impure".* *Accept "**«**limestone**»** contains impurities".* *Accept "loss of limestone when dried" **OR** "loss of limestone due to crumbling when removed from beaker".*	**1**

Question			Answers	Notes	Total
1.	c	i	sulfuric acid is diprotic/contains two H^+ **«**while nitric acid contains one H^+**»**/releases more H^+ **«**so reacts with more limestone**»** ***OR*** higher concentration of protons/H^+ ✓	*Ignore any reference to the relative strengths of sulfuric acid and nitric acid.* *Accept "sulfuric acid has two hydrogens «whereas nitric has one»".* *Accept "dibasic" for "diprotic".*	**1**
1.	c	ii	calcium sulfate remained/deposited on limestone **«**in sulfuric acid**»** ***OR*** reaction prevented/stopped by slightly soluble/deposited/layer of calcium sulfate ✓	*Answer must refer to calcium sulfate.*	**1**

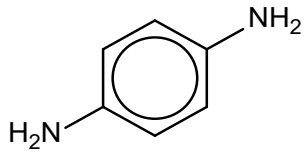
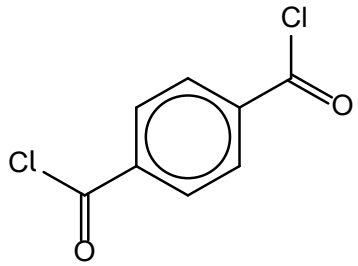
Question			Answers	Notes	Total
2.	a	i	*Ethanal using Pt/C:* decreases ✓ *Carbon dioxide using PtRu/C:* «generally» increases ***AND*** then decreases ✓	*Accept "no clear trend/pattern" **OR** "increases and decreases" **OR** "increases, reaches a plateau and «then» decreases".*	**2**
2.	a	ii	*From ethanol to ethanal:* −2 to −1 ***OR*** +1/increases by 1 ✓ *From ethanol to carbon dioxide:* −2 to +4 ***OR*** +6/increases by 6 ✓	*Do **not** accept "2− to 1−".* *Do **not** accept "2− to 4+".* *Do **not** penalize incorrect notation twice.* *Penalize incorrect oxidation state value of carbon in ethanol once only.*	**2**
2.	a	iii	ethanal < ethanoic acid < carbon dioxide ✓	*Accept formulas.* *No ECF from 2aii calculations.*	**1**
2.	b		Pt/platinum/PtC ***AND*** highest yield of CO_2 «at all voltages» ✓	*ECF from 2aiii.*	**1**

Section B

Option A — Materials

Question			Answers	Notes	Total
3.	a		reactant(s) adsorb onto active sites/surface ✓ «reactant» bonds weakens «and products are desorbed» ✓	*Do **not** accept "absorb" for "adsorb" for M1.* *Accept "bonds to" for "adsorb" for M1.* *Accept "bonds break/stretch «and products are desorbed»".* *Award **[1 max]** for "lowers activation energy".*	**2**
3.	b		high temperature used ✓ oxygen/O_2 reacts with carbon/C ***OR*** carbon dioxide/CO_2 can form ✓		**2**

Question			Answers	Notes	Total
4.	**a**	**i**	electrons collide with cations/positive ions ✓		**1**
4.	**a**	**ii**	increased vibrations of **«**lattice**»** ions ✓ increased **«**probability of**»** collisions **«**between electrons and cations**»** ✓	*Accept "increases lattice vibrations" for M1.*	**2**
4.	**b**		*Any two of:* Type I have sharper transitions to superconductivity **«**than Type II**»** ✓ Type I have lower critical/operating temperatures **«**than Type II**»** ✓ Type I have lower critical magnetic field **«**strength than Type II**»** ✓ Type I carry lower currents **«**than Type II**»** ✓ Type I are **«**pure**»** metals/metalloids ***AND*** Type II are alloys/metal oxide ceramics/perovskites/metallic compounds ✓ Type II exist in a mixed state/are partly permeable to the magnetic field ***AND*** Type I do not/are not ✓		**2 max**

Question			Answers	Notes	Total
5.	a		 ***OR*** $H_2NC_6H_4NH_2$ ✓  ***OR*** $Cl(O)CC_6H_4C(O)Cl$ ✓		**2**
5.	b		increases flexibility/softness/plasticity ✓ break/weaken intermolecular forces/IMF/H-bonds «between chains» ✓		**2**

Question			Answers	Notes	Total
5.	**c**		*Any two of:* collection/transportation of plastic waste ✓ separation/sorting of different types «of plastic» ***OR*** separation/sorting of plastic from other materials ✓ melting plastic ✓ processing/washing/cleaning/drying/manufacture of recycled plastic ✓		**2 max**

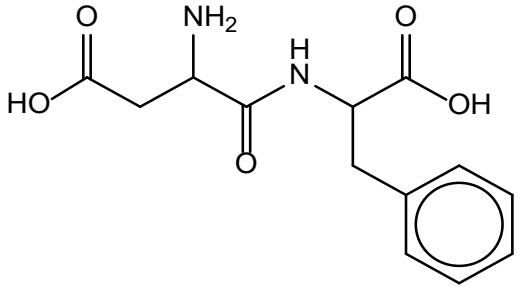
Question			Answers	Notes	Total
6.	a		ions of more reactive metals are harder to reduce ***OR*** more reactive metals have more negative electrode potentials ✓ electrolysis is needed/used for most reactive metals ***OR*** carbon is used to reduce metal oxides of intermediate reactivity/less reactive than carbon ***OR*** heating ore is sufficient for less reactive metals ✓	*Award **[1 max]** for "«ease of reduction/extraction» depends on reactivity".*	**2**
6.	b	i	electronegativity difference = 1.8 «and average electronegativity = 2.5» ✓ 57 «%» ✓	*Accept any value in the range 52–65 %.* *Award **[2]** for correct final answer.*	**2**
6.	b	ii	*Anode (positive electrode):* $2O^{2-} \rightarrow O_2(g) + 4e^-$ ***OR*** $2O^{2-} + C \rightarrow CO_2(g) + 4e^-$ ✓ *Cathode (negative electrode):* $Al^{3+} + 3e^- \rightarrow Al(l)$ ✓ O_2 gas ***AND*** Al liquid ✓	*Award **[1 max]** for M1 and M2 if correct half-equations are given at the wrong electrodes **OR** if incorrect reversed half-equations are given at the correct electrodes.* *Only state symbols of **products** required, which might be written as (g) and (l) in half-equations. Ignore any incorrect or missing state symbols for reactants.*	**3**

Question			Answers	Notes	Total
7.			«$d = \frac{n\lambda}{2\sin\theta}$» d = «$\frac{1 \times 1.54 \times 10^{-10}\ \text{m}}{2 \times \sin 22.3\,°}$ =» 2.03×10^{-10} «m» ✓		**1**

8.			«$[OH^-] = \frac{1.40 \times 10^{-3}\ \text{g}}{40.00\ \text{g mol}^{-1} \times 0.2500\ \text{dm}^3}$ =» 1.40×10^{-4} «mol dm^{-3}» ✓ «$[OH^-]$ from dissolved $Pb(OH)_2$ is negligible» $K_{sp} = [Pb^{2+}][OH^-]^2$ ***OR*** $1.43 \times 10^{-20} = [Pb^{2+}] \times (1.40 \times 10^{-4})^2$ ✓ $[Pb^{2+}]_{final} = 7.30 \times 10^{-13}$ «mol dm^{-3}» ✓ «change in $[Pb^{2+}] = 1.00 \times 10^{-11} - 7.30 \times 10^{-13}$ =» 9.27×10^{-12} «mol dm^{-3}» ✓	*Accept «ratio* $\frac{[Pb^{2+}]_{initial}}{[Pb^{2+}]_{final}}$ *=» 13.7* ***OR*** *«ratio* $\frac{[Pb^{2+}]_{final}}{[Pb^{2+}]_{initial}}$ *=» 0.0730 for M4.* *Award* ***[4]*** *for correct final answer.* *Award* ***[3]*** *for correct* $[Pb^{2+}]_{final}$.	**4**

Question			Answers	Notes	Total
9.	**a**		molecules point/align in same direction/orientation ***OR*** molecules have directional order ✓ molecules randomly distributed ***OR*** molecules not in a layered arrangement ***OR*** molecules do not have positional order ✓	*Accept suitable diagram for M1 and M2.*	**2**
9.	**b**		molecules align with field ✓		**1**

Option B — Biochemistry

Question			Answers	Notes	Total
10.	**a**		 amide link (*eg,* CONH) ✓ correct order and structures of amino acids ✓	*Accept a skeletal formula or a full or condensed structural formula.* *Accept zwitterion form of dipeptide.* *Accept CO–NH but **not** CO–HN for amide link.*	**2**
10.	**b**	**i**	*Any three of:* **«**gel**»** electrophoresis **«**technique**»** ***OR*** mixture **«**in buffer solution**»** placed on gel/paper ✓ voltage/potential **«**difference**»** applied ✓ amino acids move differently **«**depending on pH/isoelectric point**»** ✓ compare/measure distances travelled/R_f values ✓	*Accept "mixture placed on plate covered with polyacrylamide **«**gel**» OR** "mixture put in a gel **«**medium**»**".*	**3 max**

(continued…)

(Question 10b continued)

Question			Answers	Notes	Total
10.	**b**	**ii**	different sizes/molar masses/chain lengths **«**so move with different speeds**»** ✓	*Do **not** accept "different side-chains/R-groups/number of carbons".*	**1**
10.	**b**	**iii**	**«**$6.0 = 4.83 + \log \frac{[A^-]}{[HA]}$**»** **«**$\log \frac{[A^-]}{[HA]} = 1.17$**»** **«**$[A^-] : [HA] =$**»** $14.8 : 1$ ✓	*Accept "15:1".* *Do **not** accept 1:14.8.*	**1**

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>11.</td><td>a</td><td></td><td>K_m is inverse measure of affinity of enzyme for a substrate
OR
K_m is inversely proportional to enzyme activity
OR
high value of K_m indicates higher substrate concentration needed for enzyme saturation
OR
low value of K_m means reaction is fast at low substrate concentration ✓</td><td>Idea of inverse relationship must be conveyed.
Accept “high value of K_m indicates low affinity of enzyme for substrate/less stable ES complex/lower enzyme activity”.
Accept “low value of K_m indicates high affinity of enzyme for substrate/stable ES complex/greater enzyme activity”.</td><td>1</td></tr>
<tr><td>11.</td><td>b</td><td></td><td><table>
<tr><th></th><th>Competitive inhibitor</th><th></th><th>Non-competitive inhibitor</th></tr>
<tr><td>Binding site on enzyme</td><td>active site</td><td>AND</td><td>allosteric site ✓</td></tr>
<tr><td>V_{max}</td><td>not affected</td><td>AND</td><td>decreased ✓</td></tr>
<tr><td>K_m</td><td>increased</td><td>AND</td><td>not affected ✓</td></tr>
</table></td><td>Accept “outside/away from active site” for “allosteric site”.
Award [1] for any two correct effects from any of the six listed.</td><td>3</td></tr>
</table>

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>12.</td><td>a</td><td></td><td>«one C=C bond»
«1 mole iodine : 1 mole oleic acid»
«$\frac{100 \times 253.80}{282.46}$ =» 89.85 «g of I_2» ✓</td><td>Accept “90 «g of I_2»”.</td><td>1</td></tr>
<tr><td>12.</td><td>b</td><td></td><td>
<table>
<tr><th>Rancidity</th><th>Site of reactivity in the molecule</th><th></th><th>Conditions that favour the reaction</th></tr>
<tr><td>hydrolytic</td><td>ester «linkages in triglycerides»</td><td>AND</td><td>moisture/heat/enzymes/ bacteria/acid ✓</td></tr>
<tr><td>oxidative</td><td>C=C/carbon–carbon double bond «in unsaturated triglycerides»</td><td>AND</td><td>oxygen «from air»/light ✓</td></tr>
</table>
</td><td>Award [1] for any two sites or conditions from any of the four listed.
Accept “high temperature” for “heat”. Accept "lipase" for "enzyme".
Do not accept just “double bond”.
Accept “air” for “oxygen” and “UV/sun” for “light”.
Ignore any reference to heat/high temperature as a condition for oxidative.</td><td>2</td></tr>
</table>

Question			Answers	Notes	Total
12.	c		*Similarity:* **«**derived from**»** propane-1,2,3-triol/glycerol/glycerin/glycerine ***OR*** **«**derived from**»** at least two fatty acids ***OR*** contains ester linkages ***OR*** long carbon chains ✓ *Difference:* phospholipids contain two fatty acids **«**condensed onto glycerol**»** ***AND*** triglycerides three ***OR*** phospholipids contain phosphate/phosphato **«**group**»**/residue of phosphoric acid ***AND*** triglycerides do not ✓	*Do **not** accept "two fatty acids as both a similarity and a difference".* *Do **not** accept just "hydrocarbon/carbon chains".* *Accept "phospholipids contain phosphorus **AND** triglycerides do not".* *Accept "phospholipids are amphiphilic **AND** triglycerides are not" **OR** "phospholipids have hydrophobic tails and hydrophilic heads **AND** triglycerides do not".*	**2**

Question			Answers	Notes	Total
13.	a		*Any two correct for **[1]**:* pentose **«**sugar**»** ***OR*** deoxyribose ✓ phosphate/phosphato **«**group**»**/residue of phosphoric acid ✓ **«**organic**»** nitrogenous base ***OR*** nucleobase ***OR*** nucleic base ***OR*** purine ***OR*** pyrimidine ✓	*Accept "$–OPO_3^{2–}$/$–OPO_3H^–$/$–OPO_3H_2$" but **not** "$PO_4^{3–}$".* *Accept the four bases together: "adenine/A, guanine/G, cytosine/C, thymine/T".* *Accept names or formulas.*	**1 max**
13.	b		*Any two of:* H-bonding between bases in each pair ✓ hydrophobic interactions/π-stacking between bases ✓ polar/charged/hydrophilic groups in sugar-phosphate backbone interactions with aqueous solution/water ***OR*** H-bonding ***AND*** ion-dipole interactions between phosphato **«**groups**»** and water/histones ✓	*Accept "phosphate groups are hydrophilic and form H-bonds with water".* *Accept "H-bonding with histones".*	**2 max**

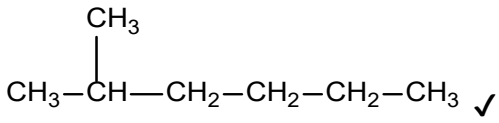
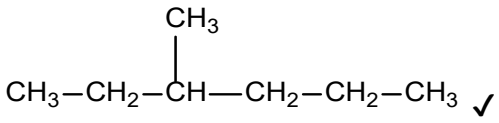
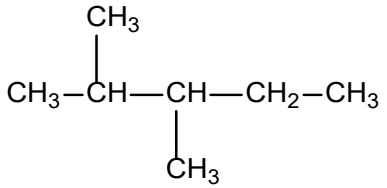
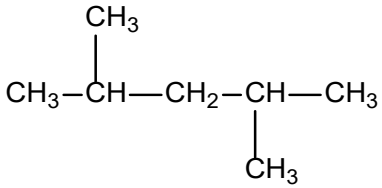
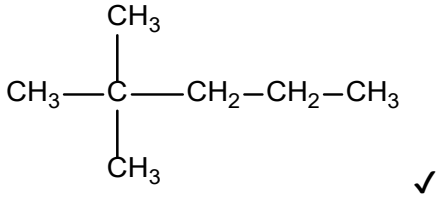
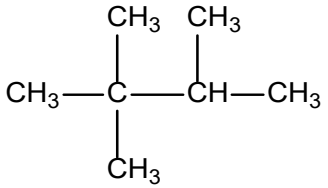
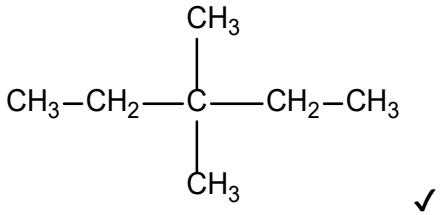
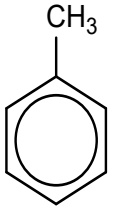
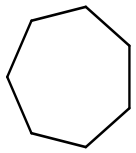
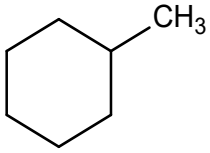
Question			Answers	Notes	Total
14.	**a**		as pH decreases, protons/CO_2 bind to allosteric sites ***OR*** as pH decreases, protons/CO_2 act as non-competitive inhibitor ***OR*** active/binding site changes shape ✓ saturation decreases ***OR*** more oxygen released ***OR*** affinity to oxygen decreases ✓		**2**
14.	**b**		accumulates in fat/tissues/living organisms ***OR*** cannot be metabolized/does not break down **«**in living organisms**»** ***OR*** not excreted / excreted **«**very**»** slowly ✓ passes **«**unchanged**»** up the food chain ***OR*** increased concentration as one species feeds on another **«**up the food chain**»** ✓	*Accept "lipids" for "fat".*	**2**
14.	**c**		hydroxyl ✓	*Accept "hydroxy" but **not** "hydroxide".* *Accept "alkenyl".* *Do **not** accept formula.*	**1**

Question			Answers	Notes	Total
15.	**a**		absorbs/traps light **«**energy**»** ✓ initiates redox reactions ***OR*** transfers electrons ✓		**2**
15.	**b**		*One similarity:* 1–4/glycosidic linkage ***OR*** glucose monomers/residues ✓ *One difference:* starch has α-glucose ***AND*** cellulose has β-glucose **«**monomers**»** ***OR*** starch can form coiled/spiral/helical chains **«**and straight chains**»** ***AND*** cellulose cannot/can only form straight chains/can only form a linear structure ***OR*** starch **«**in amylopectin**»** also has 1–6 glycosidic links ***AND*** cellulose does not ✓	*Accept "both are polysaccharides".* *Accept "cellulose has alternate glucose monomers upside down with respect to each other **AND** starch does not".*	**2**
15.	**c**		**«**solubility depends on forming many**»** H-bonds with water ✓ maltose has many hydroxyl/OH/oxygen atoms/O **«**and forms many H-bonds**»** ✓	*Reference to "with water" required.* *Accept "hydroxy" for "hydroxyl" but **not** "hydroxide".* *Reference to many/several OH groups/O atoms required for M2.*	**2**

Option C — Energy

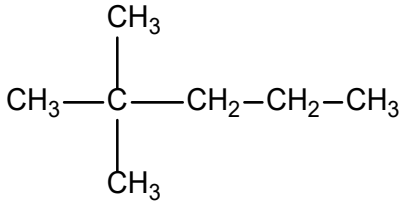
Question			Answers	Notes	Total
16.	**a**		«similar specific energy and» pentane has «much» larger energy density ✓ *Any two for **[2 max]**:* similar number of bonds/«C and H» atoms in 1 kg «leading to similar specific energy» ***OR*** only one carbon difference in structure «leading to similar specific energy» ✓ pentane is a liquid ***AND*** butane is a gas «at STP» ✓ 1 m^3 of pentane contains greater amount/mass than 1 m^3 of butane ✓	*Accept "both are alkanes" for M2.* *Accept "pentane would be easier to transport".* *Accept "same volume" for "1 m^3" and "more moles" for "greater amount" for M4.*	**3**
16.	**b**		energy converted to heat ***OR*** energy converted to less useful/dispersed forms ***OR*** energy converted to forms that have lower potential to do work ***OR*** heat transferred to the surroundings ✓	*Reference to energy conversion/transfer required. Do **not** accept reference to loss of energy.*	**1**

Question			Answers	Notes	Total
17.	**a**		low knocking/auto-ignition ***OR*** more efficient fuel ***OR*** high compression ***OR*** more power extracted ***OR*** more air going into engine **/** turbocharging ***OR*** less engine damage ✓	*Do **not** accept "pre-ignition".* *Accept "less CO_2 emissions since knocking engine uses more fuel **«**to produce the same power**»**".*	**1**

Question			Answers	Notes	Total
17.	b	i	*Any two of:*  ✓  ✓  ✓  ✓  ✓  ✓  ✓  ✓  ✓  ✓	*Accept skeletal formulas or full or condensed structural formulas.* *Accept any other branched cycloalkane that contains 7 carbons.* *Do **not** accept any alkenes.* *Penalise missing hydrogens or bond connectivities once only in Option C.* *Accept hydrogen as the second product if the first product is toluene or a cycloalkane.*	**2 max**

(continued…)

(Question 17b continued)

Question			Answers	Notes	Total
17.	**b**	**ii**	 / $(CH_3)_3C(CH_2)_2CH_3$ ✓	*Accept a skeletal formula or a full or condensed structural formula.* *Penalise missing hydrogens or bond connectivities once only in Option C.*	**1**

Question			Answers	Notes	Total
18.	a	i	${}^{4}_{2}\text{He} + {}^{8}_{4}\text{Be} \rightarrow {}^{12}_{6}\text{C}$ ✓	*Do **not** penalize missing atomic numbers.*	1
18.	a	ii	***ALTERNATIVE 1*** binding energy per nucleon is larger in carbon-12/product **«**than beryllium-8 and helium-4/reactants**»** ✓ difference in **«**total**»** binding energy is released **«**during fusion**»** ✓ ***ALTERNATIVE 2*** mass of carbon-12/product **«**nucleus**»** is less than **«**the sum of**»** the masses of helium-4 and beryllium-8 **«**nuclei**»**/reactants ***OR*** two smaller nuclei form a lager nucleus ✓ mass lost/difference is converted to energy **«**and released**»** ***OR*** $E = mc^2$ ✓		2
18.	a	iii	Δm = **«**12.000000 amu − (4.002602 amu + 8.005305 amu) =**»** −0.007907 **«**amu**»** ✓ **«**0.007907 amu × 1.66×10^{-27} kg amu^{-1} =**»** 1.31×10^{-29} **«**kg**»** ✓ **«**$E = mc^2 = 1.31 \times 10^{-29}\,\text{kg} \times (3.00 \times 10^{8}\,\text{m s}^{-1})^2$ =**»** 1.18×10^{-12} **«**J**»** ✓	*Accept "0.007907 **«**amu**»**".* *Award **[2 max]** for "7.12 x 10^{14} «J»".* *Award **[3]** for correct final answer.*	3

Question			Answers	Notes	Total
18.	b		***ALTERNATIVE 1*** 3 half-lives ✓ 0.500 g «of beryllium-8 remain» ✓ ***ALTERNATIVE 2*** $m = 4.00 \left(\frac{1}{2}\right)^{\frac{2.01 \times 10^{-16}}{6.70 \times 10^{-17}}}$ ✓ 0.500 g «of beryllium-8 remain» ✓ ***ALTERNATIVE 3*** $\lambda = \text{«}\frac{\ln 2}{6.70 \times 10^{-17}}\text{»} = 1.03 \times 10^{16}$ «s^{-1}» ✓ $m = \text{«}4.00\ e^{-1.03 \times 10^{16} \times 2.01 \times 10^{-16}}\ \text{=»}$ 0.500 «g» ✓	*Award **[2]** for correct final answer.*	**2**

Question			Answers	Notes	Total
19.	**a**		$C_2H_5OH\,(l) + 3O_2\,(g) \rightarrow 2CO_2\,(g) + 3H_2O\,(l)$ ✓		**1**
19.	**b**		*Any two of:* **«**showing strong**»** correlation between **«**atmospheric**»** CO_2 concentration/greenhouse gas concentration and average **«**global/surface/ocean**»** temperature ✓ lab evidence that greenhouse gases/CO_2 absorb(s) infrared radiation ✓ **«**advanced**»** computer modelling ✓ ice core data ✓ tree ring data ✓ ocean sediments / coral reefs / sedimentary rocks data ✓	*Do **not** accept "global warming" for "average temperature".* *Do **not** accept "traps/reflects heat" **OR** "thermal energy".* *Evidence must be outlined and connected to data.* *Accept references to other valid greenhouse gases other than carbon dioxide/CO_2, such as methane/CH_4 or nitrous oxide/N_2O.*	**2 max**
19.	**c**		biofuel raw material/sugar/glucose formed by photosynthesis ***OR*** biofuel raw material/sugar/glucose uses up carbon dioxide during its formation ***OR*** biofuel from capturing gases due to decaying organic matter formed from photosynthesis ✓ $6CO_2\,(g) + 6H_2O\,(l) \rightarrow C_6H_{12}O_6\,(aq) + 6O_2\,(g)$ ✓	*Accept arguments based on material coming from plant sources consuming carbon dioxide/carbon for M1.*	**2**

Question			Answers	Notes	Total
20.	**a**		*Anode (negative electrode):* $H_2(g) \rightarrow 2H^+(aq) + 2e^-$ ✓ *Cathode (positive electrode):* $O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$ ✓	*Accept any correct integer or fractional coefficients.* *Award **[1 max]** for M1 and M2 if correct half-equations are given at the wrong electrodes **OR** if incorrect reversed half-equations are given at the correct electrodes.*	**2**
20.	**b**	**i**	(+)1.23 **«**V**»** ✓	*Do **not** accept "-1.23 **«**V**»**".*	**1**
20.	**b**	**ii**	connect several fuel cells in series ***OR*** increase pressure/concentration of reactant/hydrogen/oxygen ✓	*Do **not** accept changes in $[H^+]$/pH as they do not affect cell potential in this case.* *Do **not** accept reference to quantity for "concentration".*	**1**
20.	**c**		liquid in cell is less/not corrosive ***OR*** does not contain lead/toxic chemicals ***OR*** larger energy density/charge capacity/current per unit mass ***OR*** does not have to be charged prior to use / is always ready for use **«**as long as fuel is available**»** ✓		**1**

Question			Answers	Notes	Total
20.	**d**	**i**	*Dye:* absorbs photons/light ***OR*** releases electrons ✓ *TiO_2:* conducts current/electricity ***OR*** semiconductor ✓ *Electrolyte:* reduces/regenerates «the oxidized» dye ✓		**3**

(continued…)

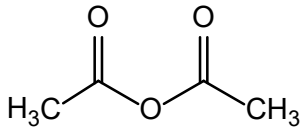
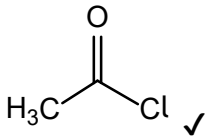
(Question 20d continued)

Question			Answers	Notes	Total
20.	**d**	**ii**	*Any one of:* cheaper/ease of manufacture ***OR*** plentiful and renewable resources **«**to construct DSSC cells**»** ✓ use light of lower energy/lower frequency/longer wavelength ***OR*** use of nanoparticles provides large surface area for exposure to sunlight/sun/light ***OR*** can absorb better under cloudy conditions ✓ operate at lower **«**internal**»** temperatures ***OR*** better at radiating heat away **«**since constructed with thin front layer of conductive plastic compared to glass box in photovoltaic cells**»** ✓ better conductivity ✓ more flexible/durable ✓	*Accept "lower mass/lighter **«**so greater flexibility to integrate into windows etc.**»**" **OR** "greater power-conversion efficiency **«**with latest DSSC models**»**".*	**1 max**

Option D — Medicinal chemistry

Question			Answers	Notes	Total
21.	**a**		*Any three of:* morphine has «two» hydroxyl «groups» ***AND*** diamorphine has «two» ester/ethanoate/acetate «groups» ✓ morphine is more polar than diamorphine ***OR*** groups in morphine are replaced with less polar/non-polar groups in diamorphine ✓ morphine is «more» soluble in blood «plasma» ***OR*** diamorphine is «more» soluble in lipids ***OR*** diamorphine is more soluble in non-polar environment of CNS/central nervous system than morphine ✓ diamorphine crosses the blood–brain barrier/BBB «easily» ✓	*Accept "heroin" for "diamorphine".* *Accept formulas.* *Accept "hydroxy" for "hydroxyl" but **not** "hydroxide".* *Accept "acyl" for "ester «groups»".* *Do **not** accept just "diamorphine is non-polar" for M2.* *Accept "water" for "blood".* *Accept "fats" for "lipid".*	**3 max**
21.	**b**		toxic dose for 50 % of population divided by «minimum» effective dose for 50 % of population ✓	*Accept "TD50/ED50".* *Reference to 50 % required.*	**1**

Question			Answers	Notes	Total
22.	**a**		hydrochloric acid/HCl ***AND*** strong **«**acid**»** ✓		**1**
22.	**b**		blocks/binds to H2-histamine receptors **«**in cells of stomach lining**»** ***OR*** prevents histamine molecules binding to H2-histamine receptors **«**and triggering acid secretion**»** ***OR*** prevents parietal cells from releasing/producing acid ✓	*Do **not** accept "antihistamine" by itself.* *Accept "H2-receptor antagonist/H2RA" **OR** "blocks/inhibits action of histamine".* *Accept "blocks receptors in parietal cells **«**from releasing/producing acid**»**".* *Do **not** accept "proton pump/ATPase inhibitor".*	**1**
22.	**c**		**«**$pK_a = 4.76$**»** **«**$pH = pK_a + \log\left(\frac{[CH_3COO^-]}{[CH_3COOH]}\right)$**»** **«**$pH = 4.76 + 0.40 =$**»** 5.16 ✓		**1**

Question			Answers	Notes	Total
23.	**a**		ethanoic anhydride/acetic anhydride /  ***OR*** ethanoyl chloride/acetyl chloride /  ✓	*Accept condensed structural formulas.* *Accept "ethanoic acid/acetic acid/CH_3COOH".* *Accept "$C_4H_6O_3$" **OR** "C_2H_3OCl".*	**1**
23.	**b**		react with sodium hydroxide/NaOH/**«**strong**»** base ***OR*** convert to **«**ionic**»** salt ✓ $C_6H_4(OCOCH_3)COOH\,(s) + NaOH\,(aq) \rightarrow C_6H_4(OCOCH_3)COONa\,(aq) + H_2O\,(l)$ ✓	*Accept other suitable bases (eg, $KOH/NaHCO_3/Na_2CO_3$) with corresponding equation for chosen base for M2.* *Accept "$CaCO_3$", although calcium salicylate is **not** water soluble.* *Accept ionic equation.* *Award **[2]** for M2.*	**2**

Question			Answers	Notes	Total
24.	**a**		1700–1750 **«**cm^{-1}**»** ✓	*Accept a specific wavenumber value within range.*	**1**
24.	**b**		*Any three of:* sample/liquids vaporized **«**in oven/at high temperature**»** ***OR*** sample injected into mobile phase/inert gas ***OR*** nitrogen/helium/inert gas acts as mobile phase ***OR*** sample carried by inert gas **«**through column**»** ✓ stationary phase consists of a packed column ***OR*** packing/solid support acts as stationary phase ✓ components separated by partition **«**between mobile phase and stationary phase**»** ***OR*** gases/liquids/components have different retention times/R_f ***OR*** gases/liquids/components move through tube/column at different speeds/rates ✓ detector/mass spectrometer/MS **«**at end of column**»** ***OR*** databases/library of known fragmentation patterns can be used ✓	*Award **[1 max]** for identifying suitable technique (eg GC-MS etc.).* *Do **not** accept just "gas".* *Accept description of HPLC using liquid mobile phase.* *Accept named stationary phase, such as **«**long-chain**»** hydrocarbon/polysiloxane/silica.* *Accept "area under peak proportional to quantity/amount/concentration of component present **«**in mixture**»**".*	**3 max**

Question			Answers	Notes	Total
24.	**c**		***ALTERNATIVE 1*** oxidizing agent/**«**acidified**»** potassium dichromate(VI) converts ethanol to ethanoic acid ✓ colour change **«**from orange to green**»** is measured/analysed **«**using photocell**»** ✓ ***ALTERNATIVE 2*** ethanol is oxidized to ethanoic acid **«**at anode and oxygen is reduced to water at cathode**»** ✓ current/voltage/potential is measured **«**by computer**»** ***OR*** current/voltage/potential is proportional to ethanol concentration ✓	*Accept names or formulas for reagents.* *Accept "**«**acidified**»** dichromate/$Cr_2O_7^{2-}$" for "$K_2Cr_2O_7$".* *Award **[1 max]** for "Cr(VI) going to Cr(III) **AND** colour changing/colour changing from orange to green". Do **not** penalize incorrect oxidation state notation here.* *Accept "EMF" for "voltage".*	**2**

Question			Answers	Notes	Total
25.	**a**		ring is «sterically» strained ***OR*** angles of 90° instead of 109.5/109/120° angles ***OR*** angles smaller than 109.5/109/120°/tetrahedral/trigonal planar/triangular planar angle ✓ ring breaks up/opens/reacts «easily» ***OR*** amido/amide group «in ring» is «highly» reactive ✓ «irreversibly» binds/bonds to enzyme/transpeptidase ***OR*** inhibits enzyme/transpeptidase «in bacteria» that produces cell walls ***OR*** prevents cross-linking of «bacterial» cell walls ✓	*Accept arguments using correct descriptions of hybridization for M1.* *Do **not** accept "breaks/binds to cell walls" – a reference to the enzyme is needed for alternatives 1 and 2 for M3.* *Do **not** accept "cell membrane" for "cell wall".*	**3**
25.	**b**		«leads to bacterial» resistance «to antibiotics» ***OR*** destroys useful/beneficial bacteria ***OR*** useful/beneficial/less harmful bacteria replaced with «more» harmful bacteria ✓	*Accept "affects/disturbs micro-ecosystems".*	**1**

Question			Answers	Notes	Total
25.	**c**		*Any one of:* **«**most are**»** toxic **«**to living organisms**»** ***OR*** incomplete combustion/incineration can produce toxic products/dioxins/phosgene ***OR*** carcinogenic/can cause cancer ✓ accumulate in groundwater ***OR*** have limited biodegradability ✓ cost of disposal ✓	*Do **not** accept "harmful to the environment".* *Do **not** accept just "pollutes water".* *Do **not** accept "hazard of disposal".* *Accept "ozone depletion" only if there is some reference to chlorinated solvents.*	**1 max**

Question			Answers	Notes	Total
25.	**d**		*Any two of:* HIV difficult to detect/remains dormant ✓ HIV mutates rapidly/quickly ✓ HIV replicates rapidly/quickly ✓ HIV destroys «T-»helper cells/white blood cells/lymphocytes ***OR*** HIV attacks immune system ✓ HIV has several «significantly different» strains/subtypes ✓	*Accept "virus" for "HIV".* *Do **not** accept "AIDS mutates" without mention of the HIV/virus.* *Penalize the use of "AIDS" for "HIV" once only.* *Accept "HIV metabolism linked to that of host cell" **OR** "drugs harm host cell as well as HIV".*	**2 max**

Question			Answers	Notes	Total
26.	**a**		numerous stereoisomers/chiral carbons/chiral centres/stereocentres/optical isomers ✓	*Accept exact number of chiral carbons ie 11, but do **not** accept just "chiral".*	**1**
26.	**b**		chiral auxiliaries/molecule binds to reactant blocking one reaction site **«**by steric hindrance**»** ***OR*** asymmetric synthesis / enantioselective catalysis **«**producing a specific enantiomer**»** ***OR*** biosynthesis / genetically modified bacteria/microorganisms ✓	*Accept "use of a chiral auxiliary leading to **«**the synthesis of**»** the desired enantiomer".*	**1**

Question			Answers	Notes	Total
27.	**a**		*Any two of:* hair loss fatigue nausea sterility skin reaction diarrhoea vomiting damage to lymph system urinary/bladder changes anxiety/emotional problems joint/muscular stiffness loss of appetite sore/dry mouth loss of weight secondary cancer ✓		**1**

Question			Answers	Notes	Total
27.	**b**		*Any two of:* half-life is 6 hours/long enough for a scan to occur ***OR*** half-life short enough not to remain in body ✓ decay releases «low energy» gamma rays ***OR*** gamma rays less likely to be absorbed by cells ✓ can form several «coordination» complexes ✓ «low-energy» radiation/gamma-rays can be detected by common X-ray equipment ✓	*Accept "short half-life so patient is not exposed to lots of ionizing radiation".* *Accept "can exist in many oxidation states «so can form multiple complexes»" **OR** "chemically versatile «so can act as a tracer by bonding to several bioactive compounds»".*	**2 max**

Question			Answers	Notes	Total
27.	c		***ALTERNATIVE 1*** 4 half-lives ✓ 1.56 «μg of iodine-131 remain» ✓ ***ALTERNATIVE 2*** $m = 25.0 \left(\frac{1}{2}\right)^{\frac{32.0}{8.00}}$ ✓ 1.56 «μg of iodine-131 remain» ✓ ***ALTERNATIVE 3*** $\lambda = \text{«} \frac{\ln 2}{8.00} \text{»} = 8.66 \times 10^{-2}$ «day^{-1}» ✓ $m = \text{«} 25.0\ e^{-8.66 \times 10^{-2} \times 32.0} = \text{»}$ 1.56 «μg of iodine-131 remain» ✓	*Award **[2]** for correct final answer.*	**2**