Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2016

Chemistry

Higher level

Paper 3

27 pages

Subject Details: Chemistry HL Paper 3 Markscheme

Mark Allocation

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		*Ozone:* yes because it absorbs IR/is IR active ✓ *Oxygen:* no because it does not absorb IR/is IR inactive ✓	*Award **[1 max]** for stating "ozone/O_3 is a greenhouse gas but oxygen/O_2 is not".* *Award **[1 max]** for stating "ozone/O_3 absorbs IR/is IR active but oxygen/O_2 does not/is IR inactive".* *Accept "oxygen/O_2 is not a greenhouse gas because it absorbs UV".*	**2**
1.	b	i	*Any value or range within the range:* 1300–1500 «$km\,mol^{-1}$» ✓	*(It is in fact 1403 «$km\,mol^{-1}$» using the same measurement technique as that used to get the data in the table).*	**1**

(continued)

Question			Answers	Notes	Total
1.	b	ii	CCl_4 is symmetrical/dipoles of C–Cl bonds cancel out ***OR*** C–F bond more polar «than C–Cl bond» ✓ «vector» sum of bond polarities in CCl_3F non-zero/greater ***OR*** dipoles of «three» C–Cl bonds do not cancel the dipole of the C–F bond ✓	*Accept suitable diagrams with dipoles represented as vectors illustrating M1 and/or M2.* *Accept "fluorine/F more electronegative «than chlorine/Cl»" for M1.* *Accept converse statements throughout.* *Accept "dipoles will not cancel out in CCl_3F" for M2.*	**2**
1.	b	iii	GWP increases as IR intensity increases ✓	*Accept "GWP proportional to IR intensity".* *Accept "there is a positive correlation/ relationship".* *Accept converse statement.*	**1**
1.	b	iv	no relationship ***AND*** CO_2 and CCl_4/CF_4 are non-polar/have zero dipole moment «but» have very different integrated IR intensities ***OR*** no relationship ***AND*** CCl_2F_2 and $CClF_3$ have «almost» the same dipole moment but have very different integrated IR intensities ***OR*** no relationship ***AND*** sometimes there is a positive relationship between the two «variables» and sometimes there is a negative/no relationship between them ***OR*** no relationship ***AND*** as F atoms are «gradually» added to CCl_4, integrated IR intensity always increases while dipole moment increases and then decreases ✓	*Accept a plot or sketch with a comment that "changes along x-axis produce random changes along y-axis".* *Accept "yes there is a relationship, as there is still a weak overall «statistical» positive correlation".* *Accept "dipole" for "dipole moment".*	**1**

(continued)

Question			Answers	Notes	Total
1.	b	v	«data from table such as integrated IR and GWP indicate that they» contribute significantly to global warming/enhanced greenhouse effect ✓ cause ozone depletion ***OR*** chlorine/Cl released when exposed to ultra-violet/UV «radiation» ✓	*Do **not** just accept "contributes to global warming" without an indication that the effect is large.* *Do **not** accept just "contributes significantly to climate change".* *Award **[1 max]** for "persistent in atmosphere".* *Accept a consequence of global warming for M2.*	**2**

2.	a		*Key Procedural Steps:* use volumetric flask ✓ mix the solution ✓ fill up to line/mark/«bottom of» meniscus/1 dm^3 «with deionized/distilled water» ✓ *Key Technique Aspects:* use balance that reads to two decimal places/use analytical balance/use balance of high precision ✓ mix pellets in beaker with deionized/distilled water «and stir with glass rod to dissolve» ✓ use a funnel «and glass-rod» to avoid loss of solution ✓ need to rinse «the beaker, funnel and glass rod» and transfer washings to the «volumetric» flask ✓ *Safety Precautions:* NaOH corrosive/reacts with water exothermically ✓ keep NaOH in dessicator ✓ let the solution cool ✓	*Two marks may be awarded from two different categories or from within one category.* *Do **not** accept "use of a funnel to transfer the solid".* *Do **not** accept "keep volumetric flask in cold water/ice".*	**2 max**
2.	b	i	blue to green/yellow ✓		**1**

(continued)

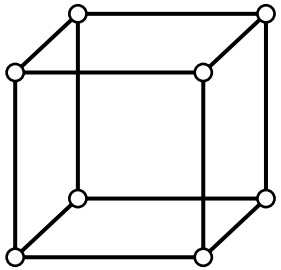
Question			Answers	Notes	Total
2.	b	ii	equivalence point has been exceeded ***OR*** greater volume of/too much acid has been added ✓ «calculated» concentration increased ✓	*Accept "end-point" for "equivalence point".*	**2**
2.	c		colour difficult to detect ***OR*** used different HCl standards ***OR*** no significant figures used in subsequent calculation ***OR*** incorrect method of calculation ✓	*Accept any valid hypothesis.* *Do **not** accept any mistakes associated with technique (based on stem of question) eg. parallax error, not rinsing glassware, etc.* *Do **not** accept "HCl was not standardized".* *Accept "reaction of NaOH with CO_2 «from air»".* *Accept "NaOH hygroscopic/absorbs moisture/H_2O «from the air/atmosphere»".* *Accept "impurities in NaOH".* *Accept "temperature changes during experiment".* *Ignore a general reference to random errors.*	**1**

Section B

Option A — Materials

Question			Answers	Notes	Total
3.	a		$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(l) + 3CO_2(g)$ ✓		1
3.	b		*Fe_2O_3:* paramagnetic ***AND*** unpaired electrons present **«**so magnetic moments do not cancel out**»** ✓ *Al_2O_3:* diamagnetic ***AND*** no unpaired electrons/all electrons are paired **«**so magnetic moments cancel out**»** ✓	*Award **[1 max]** for "Fe_2O_3 paramagnetic **AND** Al_2O_3 diamagnetic".* *Award **[1 max]** for "Fe_2O_3 unpaired electrons present **AND** Al_2O_3 no unpaired electrons/all electrons are paired".* *Award **[1 max]** for "Magnetic moments do not cancel out in Fe_2O_3 but do in Al_2O_3".* *Unpaired and paired electrons may also be conveyed by orbital diagrams for the respective ions.*	2
3.	c		$n(e) = \frac{2.00 \times 10^6}{96500}$ / 20.7 **«**mol**»** ***OR*** $n(Al) = \frac{1}{3} n(e)$ / 6.91**«**mol**»** ✓ $m(Al)$ = **«**6.91×26.98 =**»**186 **«**g**»** ✓	*Award **[2]** for correct final answer for any value within the range 186–189 **«**g**»**.*	2

(continued)

Question			Answers	Notes	Total
3.	d	i	collisions between electrons ***AND*** positive ions/cations/metal atoms/metal lattice ✓	*Accept "irregularities/non-uniformity in metal lattice «caused by impurities» but do **not** accept just "impurities present". Do **not** accept "attractions" for "collisions".*	**1**
3.	d	ii	metal II is a <u>superconductor</u> ✓ passing electrons «slightly» deform lattice/displace positive ions/cations ***AND*** couple/form Cooper pairs/condense with other electrons ✓ energy propagates along the lattice in wave-like manner/as phonons ✓ Cooper pair/electron condensate moves through lattice freely ***OR*** phonons are «perfectly» elastic/cause no energy loss ✓		**3 max**
3.	e	i	 ✓ «coordination number =» 6 ✓	*Do **not** accept diagram of a lattice showing multiple unit cells.*	**2**
3.	e	ii	«Bragg equation, $n = 1$» «$d = \frac{8.80 \times 10^{-11}}{2 \times \sin(13.0)} =$» 1.96×10^{-10} «m» ✓		**1**

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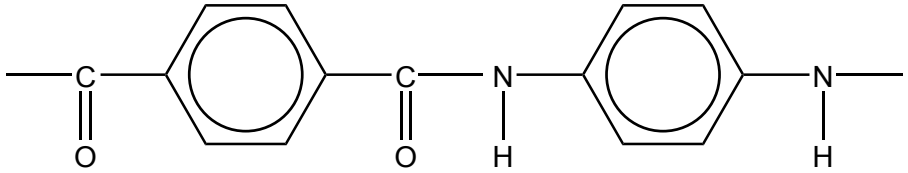
Question			Answers	Notes	Total
4.	a		possible toxicity «of small airborne particles» ***OR*** unknown health effects ***OR*** small particle size «and large surface area» may increase reaction rate to dangerous levels ***OR*** immune system/allergy concerns ***OR*** uncertain impact on environment ✓	*Accept specific health effect (eg. may cause cancer/effect on respiratory system, etc).*	**1**
4.	b		pores/cavities/channels/holes/cage-like structures «in zeolites» have specific shape/size ✓ only reactants «with appropriate size/geometry» fit inside/go through/are activated/can react ✓		**2**
4.	c		*Catalyst:* iron/Fe ***OR*** iron«0» «penta» carbonyl/$Fe(CO)_5$ ✓ *Conditions:* high temperature/any value or range within the range 900–1600 °C ***AND*** high pressure/any value or range within the range 10–100 atm ✓	*Accept "cobalt-molybdenum/Co-Mo/CoMo".* *Accept high pressures expressed in kPa/Pa.*	**2**

(continued)

Question			Answers	Notes	Total
5.			ceramics have «giant» ionic/covalent/ionic ***AND*** covalent structures ✓ metals contain lattice of positive ions/cations in sea of delocalized electrons ✓	*Accept **[1 max]** for "ionic/covalent/ionic and covalent bonds in ceramics **AND** metallic bonds in metals".* *Accept suitable diagram for M2.*	**2**

6.	**a**		«CN group makes» molecule polar ✓ alignment/orientation of molecules can be controlled by electric field ***OR*** allows molecules to align in an electric field/when a voltage is applied ✓	*Accept "CN is polar".*	**2**
6.	**b**	**i**	 / —$COC_6H_4CONHC_6H_4NH$— ✓	*Continuation bonds are necessary for the mark but brackets and n can be ignored. If more than one repeating unit is drawn, do **not** award the mark.*	**1**
6.	**b**	**ii**	H bonds «form between chains from NH of one chain to CO of the next» ✓		**1**

(continued)

Question			Answers	Notes	Total
7.	a		«plasticizer molecules» fit between chains ***OR*** «plasticizer molecules» prevent chains from forming crystalline regions ***OR*** «plasticizer molecules» keeps strands/chains/molecules separated ***OR*** «plasticizer molecules» increase space/volume between chains ✓ weakens intermolecular/dipole-dipole/London/dispersion/instantaneous induced dipole-induced dipole/van der Waals/vdW forces ✓	*Do **not** accept "«plasticizer molecules» lower density".*	**2**
7.	b		does **not** degrade/biodegrade/break down «easily» ✓ occupies more space in landfills ✓ incineration produces dioxins/hydrochloric acid/HCl «which can contribute to acid rain» ✓	*Accept "plasticizer added to PVC can be a health hazard".* *Accept "combustion" for "incineration".* *Do **not** accept simply "toxic compounds" for M3.*	**1 max**

8.	a		$Fe^{3+} + \bullet O_2^- \rightarrow Fe^{2+} + O_2$ ✓ $Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \bullet OH + OH^-$ ✓	*Award **[1]** for the net equation $H_2O_2 + \bullet O_2^- \rightarrow HO\bullet + OH^- + O_2$.* *Accept the hydroxyl and superoxide radicals represented without the radical symbols as long as there is consistent use of the radical symbol.*	**2**
8.	b		$K_{sp} = [Zn^{2+}][OH^-]^2$ ***OR*** $[OH^-] = 2[Zn^{2+}]$ ✓ «$[Zn^{2+}] = \sqrt[3]{7.5 \times 10^{-18}}$ =» 2.0×10^{-6} «$mol\,dm^{-3}$» ✓	*Award **[2]** for correct final answer.* *Award **[1 max]** for 5.5×10^{-9} **OR** 6.0×10^{-9} «$mol\,dm^{-3}$».*	**2**

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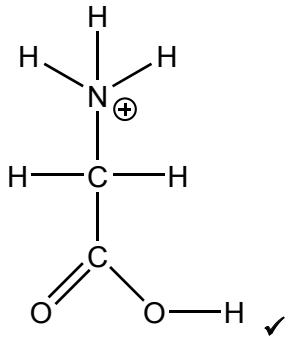
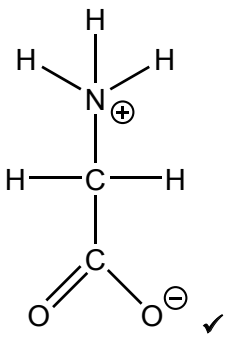
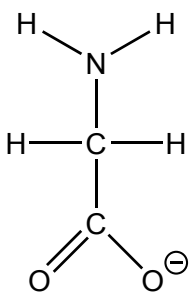
Option B — Biochemistry

Question			Answers	Notes	Total
9.	**a**	**i**	alkenyl/ethanylylidene ✓		**1**
9.	**a**	**ii**	four-ring «steroidal» backbone ***OR*** fused ring structure ***OR*** three 6-membered rings ***AND*** a 5-membered ring ✓	*Award **[1]** for a sketch of the steroidal backbone.*	**1**
9.	**b**		medical uses of steroids «under physician supervision» ***OR*** detection of banned substances can be improved ✓	*Accept any specific medical use.* *Accept answers such as "their effects «either positive or negative» are better understood".*	**1**

10.	**a**		pH 1.0  ✓ pH 6.0  ✓ pH 11.0  ✓	*Charges must be shown on the correct atoms in each structure for mark. Penalize repeated mistakes once.* *Although question asks specifically for structures, accept condensed structural formulas, but charges must be given.*	**3**

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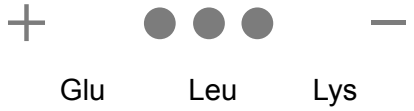
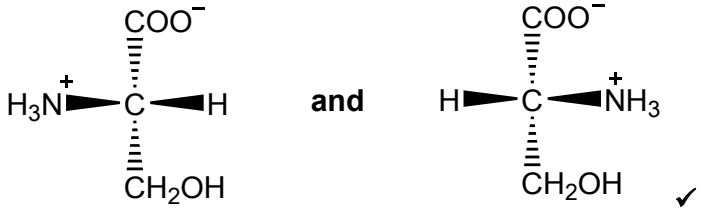
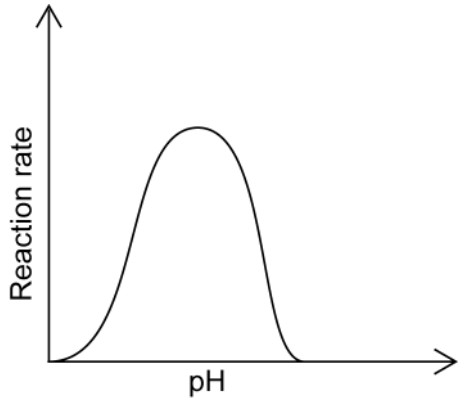
Question			Answers	Notes	Total
10.	**b**	**i**	 ✓✓	*Award **[2]** for correct order.* *Award **[1 max]** for Leu in centre if order is incorrect.*	**2**
10.	**b**	**ii**	6 ✓	*Accept 27.*	**1**
10.	**c**	**i**	 **and** ✓	*Accept un-ionized or zwitterionic forms.* *Accept any other correct representation which clearly indicates 3-dimensional structure at chiral centre.* *Accept Fischer projections with the chiral carbon atom represented by crossing lines or shown as C.*	**1**
10.	**c**	**ii**	L ✓		**1**

11.	**a**		$C_6H_{12}O_6(aq) + 6O_2(aq) \rightarrow 6CO_2(aq) + 6H_2O(l)$ ✓	*Accept equations for anaerobic respiration, such as $C_6H_{12}O_6\,(aq) \rightarrow 2C_3H_6O_3(aq)$.* *Ignore ATP if added as a product.*	**1**
11.	**b**		$n(C_6H_{12}O_6)\left(= \frac{15.0}{180.18}\right) = 0.0833$ «mol» ✓ «energy $= 0.0833 \times 2803 =$» 233 «kJ» ✓	*Award **[2]** for correct final answer.* *Accept -233 «kJ».*	**2**

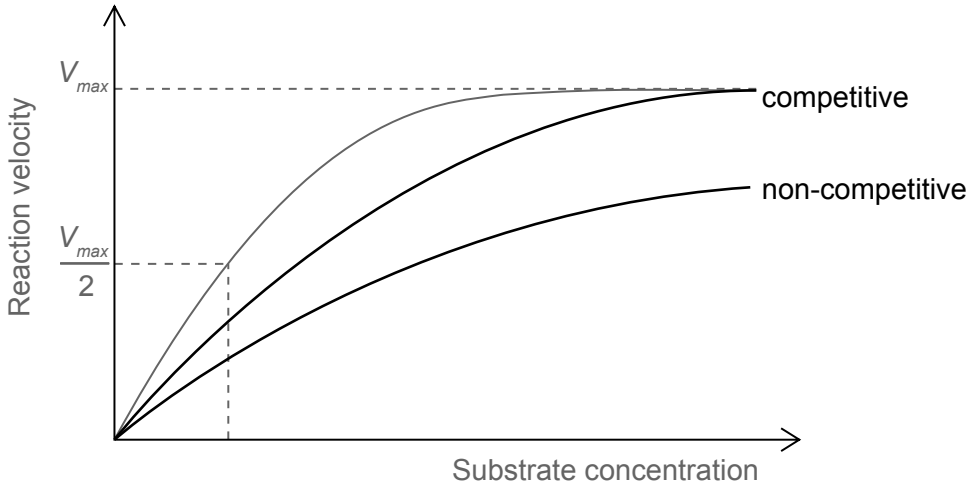
(continued)

Question			Answers	Notes	Total
11.	c		*Two advantages:* renewable resource ✓ broken down/digested by bacteria or other organisms within a relatively short time/quickly ✓ reduce «volume of» plastic waste/landfill ✓ reduce use of petrochemicals ***OR*** reduce use of fossil fuels as hydrocarbon source ✓ degrade into non-toxic products ✓ *Two disadvantages:* require use of land «for crop production» ✓ increased use of fertilizers/pesticides «leading to pollution» ***OR*** eutrophication ✓ might break down before end of use ✓ release of methane/CH_4/greenhouse gas «during degradation» ✓	*Any **two** advantages for **[2 max]**.* *M2: reference must be made to time. Do **not** accept "biodegradable" (since stated in question).* *Ignore any mention of cost.* *Any **two** disadvantages for **[2 max]**.* *Ignore any mention of cost.*	**4 max**

(continued)

Question			Answers	Notes	Total
11.	**d**		 typical curve as shown in example above ✓	*Accept any curve with a single maximum (not just bell-shaped).* *Ignore features such as pH values on a pH scale or a pH value at maximum (if given).* *Do **not** penalize if curve does not touch the x-axis.*	**1**

(continued)

Question			Answers	Notes	Total
12.	**a**		 graph showing competitive inhibitor eventually reaching V_{max} ✓ graph showing non competitive inhibitor not reaching V_{max} ✓	*Curves must be labelled and should not cross given curve.* *Penalize one mark if one or both sketched curve(s) cross the given curve.* *Award **[1 max]** if curves are not labelled competitive or non-competitive **OR** are labelled the wrong way round.*	**2**
12.	**b**		$\log\frac{(3.70\times10^{-3})}{(2.60\times10^{-3})} = 0.153$ ✓ «pH = 4.76 + 0.153 =» 4.91 ✓	*Award **[2]** for correct final answer.* *Accept other method of calculation.*	**2**

13.	**a**		A and D have one/few polar/hydroxyl/OH groups «but C has many of those» ***OR*** A and D have hydrocarbon/six-membered «carbon» rings «but C has heterocyclic/five-membered ring» ***OR*** A and D have long hydrocarbon chains/consist of mainly non-polar components ✓	*Accept other valid similarities or differences.* *Accept "hydroxy/alcohol" but not "hydroxide" for "hydroxyl".*	**1**
13.	**b**		0.47 ***AND*** chlorophyll b ✓	*Accept any R_f value in the range 0.44–0.50.*	**1**

(continued)

Question			Answers	Notes	Total
14.	**a**		low CO_2 level causes more oxygen to be bound to the heme ✓ high pH causes more oxygen to be bound to the heme ✓ low temperature causes more oxygen to be bound to the heme ✓ organic phosphates/2,3-BPG/DPG can decrease affinity for oxygen ✓ CO decreases saturation/binds to active site/acts as a competitive inhibitor ✓	*Accept reverse statements for mark.* *Award **[2]** if the effects of CO_2 **AND** pH are discussed in combination.*	**3 max**
14.	**b**		contains two gamma units «instead of the two beta units found in adults» ***OR*** differs in amino acid sequence «from the two beta units found in adults» ✓ less sensitive to inhibitors/2,3-BPG/DPG ✓ receives O_2 from «partly deoxygenated» blood so can work at low pO_2 ✓	*Accept reverse statements for mark.*	**2 max**

Option C — Energy

Question			Answers	Notes	Total
15.	**a**	**i**	2,2-dimethylbutane ***OR*** 2,3-dimethylbutane ***OR*** 3-methylpentane ***OR*** 2-methylpentane ***OR*** cyclohexane ***OR*** methylcyclopentane ***OR*** benzene ✓	*Accept name or structural formula.* *Accept any mono or poly-substituted cycloalkane with a total of six carbon atoms.*	**1**
15.	**a**	**ii**	increased branching (for acyclic hydrocarbons)/aromatic/aromaticity (for benzene)/cyclic hydrocarbon ***OR*** tertiary radicals are more stable ***OR*** higher octane rating ✓	*Response in M1 must be consistent with molecule chosen in a (i).*	**1**
15.	**b**	**i**	«$\frac{5470}{114.26}$ =» 47.9 «$kJ\,g^{-1}$» ✓		**1**

(continued)

Question			Answers	Notes	Total
15.	b	ii	*Advantage:* ethanol does not produce particulates/has less incomplete combustion/CO/HCs/VOCs/is less polluting ***OR*** ethanol has high octane rating ***OR*** ethanol is renewable ***OR*** less environmental risks associated with spills for ethanol ***OR*** less carbon dioxide/CO_2 produced if renewable energy source used ***OR*** economic advantages for countries that cannot produce crude oil ✓ *Disadvantage:* reduces efficiency/lowers specific energy/lowers energy density ***OR*** ethanol is more volatile/evaporates easily «than octane or its isomers» ***OR*** land that could be used for food production used to produce crops for ethanol ***OR*** biodiversity can be affected/loss of habitats «due to energy crop plantations» ***OR*** phosphorus/nitrogen used in production has negative environmental effects ***OR*** modification of current engines «may be required» if ethanol used ✓	*Accept any valid advantage and disadvantage.* *Ignore any mention of cost.* *Ignore any mention of NO_x.* *Accept "if the fuel blend consists of nearly pure ethanol, engine is difficult to start in cold weather".* *Accept for disadvantage any engine-related problem affected by ethanol use (eg. effect on fuel pumps, incorrect fuel quantity indicators, older cars may not be suitable for ethanol use, etc.).*	**2**

(continued)

Question			Answers	Notes	Total
15.	**c**		$2C(s) + 2H_2O(g) \rightarrow CH_4(g) + CO_2(g)$ ***OR*** $3C(s) + 2H_2O(g) \rightarrow CH_4(g) + 2CO(g)$ ✓	*Accept a two-step process.*	**1**

16.	**a**		*Reagent:* methanol/CH_3OH ***OR*** ethanol/C_2H_5OH ✓ *Catalyst:* strong acid ***OR*** strong base ✓	*Do **not** accept just "alcohol".* *Accept any strong acid such as sulfuric acid/H_2SO_4.* *Accept any strong base such as sodium hydroxide/NaOH.*	**2**
16.	**b**		different solutions/statistical data can be compared/combined ***OR*** best ideas can be shared to arrive at global/local solutions ***OR*** acceleration of research ***OR*** discoveries become available to everyone ***OR*** improved confidence in validity of results «if multiple scientists/ research groups are involved» ***OR*** money/effort/time is not wasted duplicating work others have already done ✓	*Do **not** accept scientists simply working together to share ideas – look for a little more detail.* *Accept other valid suggestions.*	**1**

(continued)

Question			Answers	Notes	Total
17.	a		${}^{232}_{90}\text{Th} + {}^{12}_{6}\text{C} \rightarrow {}^{240}_{96}\text{Cm} + 4\,{}^{1}_{0}\text{n}$ ✓	*Accept* $^{232}Th + {}^{12}C \rightarrow {}^{240}Cm + 4n$. *Accept "4n" for "*$4\,{}^{1}_{0}n$*" in any equation.*	**1**
17.	b	i	«$\lambda = \frac{\ln 2}{7.038 \times 10^{8}}$ =» 9.849×10^{-10} «years^{-1}» ✓		**1**
17.	b	ii	«3 half-lives, so» 2.11×10^{9} «years» ✓	*Accept any value within range* $2.11–2.13 \times 10^{9}$ *«years».*	**1**
17.	b	iii	produces radicals ✓ «initiates chain reactions that can» damage DNA/ionizes biologically important molecules ***OR*** «initiates chain reactions that can» damage cells ***OR*** «DNA damage causes» mutations/cancer/apoptosis/cell death/weakening of immune system ✓	*Do* ***not*** *accept just "have long half-lives so can harm living organisms".* *Accept other negative biochemical and/or medical effects.*	**2**
17.	c	i	mass of helium-4 nucleus = $4 \times 1.66 \times 10^{-27}$ / 6.64×10^{-27} «kg» ***OR*** mass of nucleons = $2 \times 1.672622 \times 10^{-27} + 2 \times 1.674927 \times 10^{-27}$ / 6.695098×10^{-27} «kg» ✓ «mass defect = $6.695098 \times 10^{-27} - 6.64 \times 10^{-27}$ =» 5.51×10^{-29} / 0.06×10^{-27} / 6×10^{-29} «kg» ✓	*Award* ***[2]*** *for correct final answer.*	**2**
17.	c	ii	«binding energy $= \frac{\Delta m \times c^{2}}{\text{nucleons}} = \frac{6 \times 10^{-29} \times (3.00 \times 10^{8})^{2}}{4 \times 1000}$ » $= 1 \times 10^{-15}$ «kJ nucleon^{-1}» ✓	*The use of* 5.51×10^{-29} *and* 5.00×10^{-29} *will respectively give* 1.24×10^{-15} *and* 1.13×10^{-15} *«kJ* nucleon^{-1}*».*	**1**

(continued)

Question			Answers	Notes	Total
18.			$CO_2(g) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ ***OR*** $CO_2(g) \rightleftharpoons CO_2(aq)$ ***AND*** $CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ ✓ **«**increasing $[CO_2]$**»** shifts equilibrium/reaction to right ✓ pH decreases ✓	*Accept "$H_2CO_3(aq)$" for "$CO_2(aq) + H_2O(l)$".*	**3**

19.			bond length/C=O changes ***OR*** **«**asymmetric**»** stretching **«**of bonds**»** ***OR*** bond angle/OCO changes/bends ✓ polarity/dipole **«**moment**»** changes ***OR*** a dipole **«**moment**»** is created **«**when the molecule absorbs IR**»** ✓	*Accept appropriate diagrams.*	**2**

20.	**a**		*Negative electrode (anode):* $CH_3OH(aq) + H_2O(l) \rightarrow CO_2(g) + 6H^+(aq) + 6e^-$ ✓ *Positive electrode (cathode):* $O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$ ✓	*Award **[1 max]** if correct half-equations are given but at the wrong electrodes.* *Accept e for e–.* *Accept any correct half-equation with fractional coefficients.*	**2**

(continued)

Question			Answers	Notes	Total
20.	**b**		*Advantage:* produces continuous supply of electricity **«**on addition of more raw materials**»** ***OR*** does not need to be recharged ***OR*** less hazardous if broken/exposed to the environment ***OR*** weighs less for same energy output/has higher energy density/has higher specific energy than lead-acid battery ✓ *Disadvantage:* **«**more**»** expensive ***OR*** needs constant supply of fuel ***OR*** methanol/ethanol fuel cells difficult to use in cold weather ***OR*** methanol/ethanol fuel cells produce carbon dioxide ***OR*** storage/transport of gases/hydrogen a problem in hydrogen fuel cell ***OR*** does not produce high current ***OR*** potentially explosive/hydrogen is flammable ✓	*Do **not** accept "water is non-polluting".* *Do **not** accept "weighs less" without reference to energy output/power/capacity etc.* *Do **not** accept "fuel cells are prone to poisoning by impurities in fuel".*	**2**

21.	**a**		*n-type:* **«**small amount of**»** As/Sb/P/group 15 element added ***AND*** **«**extra**»** electrons ✓ *p-type:* **«**small amount of**»** Ga/In/B/group 13 element added ***AND*** **«**extra electron**»** holes ✓	*Award **[1 max]** if only doping elements or only charge carriers are given.* *Accept "group 5/group 5A/group V" for "group 15".* *Accept "group 3/group 3A/group III" for "group 13".*	**2**

(continued)

Question			Answers	Notes	Total
21.	b		large surface area «increases chance photon will be absorbed» ✓ «dye allows» absorption of a wide range of wavelengths ***OR*** dye converts most/all absorbed photons into electrons ✓		**2**

Option D — Medicinal chemistry

Question			Answers	Notes	Total
22.	**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*** amide/amido group «in ring» is «highly» reactive ✓ binds to/reacts with/interferes with/inactivates transpeptidase/enzyme responsible for bacterial cell wall formation/cross-linking ✓	*Do **not** accept "cell membrane" for "cell wall".* *Accept "bonds to" for "binds to" in M3.*	**3**
22.	**b**		*Any **two** for **[1 max]** from:* leads to «bacterial» resistance «of antiobiotics» ***OR*** makes antibiotics less effective ***OR*** increased side effects due to larger dosages ✓ proportion of resistant bacteria increases ✓ destroys useful/beneficial bacteria ***OR*** destroyed bacteria replaced by more harmful bacteria ✓ resistant bacteria pass on their resistance/mutation to next generation ✓ damage to ecosystems ✓	*Accept "superbugs such as MRSA develop" but superbug must be identified.*	**1 max**

(continued)

Question			Answers	Notes	Total
23.	a		<table><tr><th>Reagent</th><th>By-product</th></tr><tr><td>$(CH_3CO)_2O$ ***OR*** CH_3COCl ***OR*** CH_3COOH ✓</td><td>CH_3COOH ***OR*** HCl ***OR*** H_2O ✓</td></tr></table>	*Accept names or structural formulas for reagent and by-product.* *Accept IUPAC or alternative names of compounds e.g. acetic acid.* *Award M2 only if the by-product corresponds to the reagent.*	**2**
23.	b		morphine has «two» hydroxyl «groups» ***AND*** diamorphine/heroin has «two» ester/ethanoate/acetate «groups» ✓ morphine is more polar than diamorphine/heroin ✓ diamorphine/heroin crosses the blood-brain barrier «easily» ✓ morphine is <more> soluble in blood «plasma» ***OR*** diamorphine/heroin is «more» soluble in lipids ✓	*Accept converse argument throughout.* *Accept "alcohol/hydroxy" for "hydroxyl" but not "hydroxide".* *Do **not** accept "diamorphine/heroin is non-polar" for M2.*	**3 max**
23.	c		spectrum A is diamorphine because it has a «strong» peak at 1700–1750 «cm^{-1}» ***OR*** spectrum A is diamorphine because it has a C=O/carbonyl (group)/ester ✓ spectrum B is morphine because it has a «strong broad» peak at 3200–3600 «cm^{-1}» ***OR*** spectrum B is morphine because it has a –OH/hydroxyl (group) ✓	*Award **[1 max]** for "spectrum A is diamorphine **AND** spectrum B is morphine" **OR** correctly identified peaks associated with the correct compounds (eg. C=O for diamorphine etc.).* *Accept "alcohol/hydroxy" for "hydroxyl" but not "hydroxide".*	**2**

24.	a		$Mg(OH)_2(s) + 2HCl(aq) \rightarrow 2H_2O(l) + MgCl_2(aq)$ ***OR*** $Mg(OH)_2(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + 2H_2O(l)$ ✓		**1**

(continued)

Question			Answers	Notes	Total
24.	**b**		*Award **[1 max]** for any similarity:* both compounds relieve symptoms of acid reflux/heartburn/indigestion ***OR*** both increase the stomach pH ✓ both cause diarrhoea ✓ *Award **[2 max]** for any two differences:* omeprazole stops the production of acid/is a proton-pump inhibitor ***AND*** magnesium hydroxide neutralizes the **«**excess**»** acid that is present ✓ omeprazole takes longer **«**than magnesium hydroxide**»** to provide relief ✓ omeprazole is used to treat ulcers while magnesium hydroxide is not ✓ omeprazole can prevent long term damage from overproduction of acid ***AND*** magnesium hydroxide does not ***OR*** omeprazole has a long term effect ***AND*** magnesium hydroxide has a short-term effect **«**only**»** ✓ magnesium hydroxide affects ionic balance in the body ***AND*** omeprazole does not ✓	*Award **[1 max]** if two or three correct points are given about one of the compounds without addressing the other compound.*	**3 max**

(continued)

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>25.</td><td>a</td><td></td><td>
<table>
<tr><th>Example</th><th></th><th>Treatment</th></tr>
<tr><td>gowns/protective clothing/ shoe covers/gloves/ syringes/needles/«cotton» swabs/tools/paper/tissue/ mops
OR
low level waste/LLW</td><td>AND</td><td>storage «in shielded container» until isotope has decayed/for a period of time «then dispose as non-radioactive waste» ✓</td></tr>
<tr><td>radioactive sources/ equipment
OR
named isotope
OR
intermediate/medium level waste/ILW/MLW</td><td>AND</td><td>storage «in shielded container in concrete chambers» underground/in caves
OR
storage «in shielded container» until isotope has decayed for a long period of time/for several half lives then dispose ✓</td></tr>
</table>
</td><td>Award [1] for example AND corresponding treatment.

Award [1 max] for the two examples.</td><td>2</td></tr>
<tr><td>25.</td><td>b</td><td></td><td>$^{216}_{84}Po \rightarrow {}^{4}_{2}He + {}^{212}_{82}Pb$
correct reactant ✓
correct alpha particle ✓</td><td>Atomic numbers not required for mark.
Accept “α”/“$^{4}_{2}\alpha$” for “$^{4}_{2}He$”.</td><td>2</td></tr>
</table>

(continued)

Question			Answers	Notes	Total
25.	**c**		*Advantage:* selectively kills cancer cells/targets cancer cells only ***OR*** does not damage healthy cells ✓ *Cancer treatment:* melanoma ***OR*** leukemia ***OR*** rectal ***OR*** breast ***OR*** ovarian ***OR*** prostate ***OR*** pancreatic ***OR*** cancers that spread around the body/produce metastasis/dispersed cancers ✓✓	*Do **not** accept "targets cancer".* *Reference must be made to "cells".* *Accept "skin cancer".*	**2**

(continued)

Question			Answers	Notes	Total
25.	**d**		***ALTERNATIVE 1:*** λ «$= \frac{\ln 2}{6.01}$» ≈ 0.115 «h^{-1}» ✓ «remaining mass $= 5.80 \times 10^{-9} \times e^{-0.115 \times 24.04}$ =» 3.63×10^{-10} «g» ✓ ***ALTERNATIVE 2:*** «$\frac{24.04}{6.01}$ =» 4 «half-lives» ✓ «$\frac{5.80 \times 10^{-9}}{2^4}$ =» 3.63×10^{-10} «g» ✓	*Award **[2]** for correct final answer.*	**2**
25.	**e**		risk vs benefit «patient and environment» ***OR*** providing adequate information to patients about risks ***OR*** security concerns if nuclear radioactive material ended up with terrorists ***OR*** cultural resistance/superstition/lack of education ***OR*** «potential» exposure of health workers «to radioactivity» ***OR*** proper training «in radioactive hazards» not always given to workers ***OR*** proper disposal of radioactive materials ✓	*Accept other valid ethical implications (note that risk of cancer to the patient is not an ethical issue, while risk of cancer to the health worker is).* *Do **not** accept "security concerns" alone – there must be some reference to an ethical implication.*	**1**

(continued)

Question			Answers	Notes	Total
26.	**a**		ether ✓	*Do **not** accept "C–O–C".*	**1**
26.	**b**		*Number of signals:* 3 **«**signals**»** ✓ *Relative integration:* 6:4:1 ✓	 *Accept any correct ratio order.*	**2**
26.	**c**	**i**	polarimeter ✓	*Accept other alternative techniques such as "GC/HLPC/chromatography using a chiral column".* *Do **not** accept just "polarizer".*	**1**
26.	**c**	**ii**	**«**plane-**»**polarized light passed through sample ✓ analyzer/second polarizer determines the angle of rotation of the plane of polarized light ***OR*** each enantiomer will rotate plane **«**of plane-**»**polarized light in opposite directions **«**by the same angle**»** ✓	*Accept explanation related to other alternative techniques such as GC/HLPC/chromatography using a chiral column.* *Award **[2]** for "(+)/d rotates plane of polarization to the right **AND** (–)/l rotates plane of polarization to the left".*	**2**