

# Markscheme

May 2019

Chemistry

Higher level

Paper 3

37 pages

No part of this product may be reproduced in any form or by any electronic or mechanical means, including information storage and retrieval systems, without written permission from the IB.

Additionally, the license tied with this product prohibits commercial use of any selected files or extracts from this product. Use by third parties, including but not limited to publishers, private teachers, tutoring or study services, preparatory schools, vendors operating curriculum mapping services or teacher resource digital platforms and app developers, is not permitted and is subject to the IB's prior written consent via a license. More information on how to request a license can be obtained from <http://www.ibo.org/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

Aucune partie de ce produit ne peut être reproduite sous quelque forme ni par quelque moyen que ce soit, électronique ou mécanique, y compris des systèmes de stockage et de récupération d'informations, sans l'autorisation écrite de l'IB.

De plus, la licence associée à ce produit interdit toute utilisation commerciale de tout fichier ou extrait sélectionné dans ce produit. L'utilisation par des tiers, y compris, sans toutefois s'y limiter, des éditeurs, des professeurs particuliers, des services de tutorat ou d'aide aux études, des établissements de préparation à l'enseignement supérieur, des fournisseurs de services de planification des programmes d'études, des gestionnaires de plateformes pédagogiques en ligne, et des développeurs d'applications, n'est pas autorisée et est soumise au consentement écrit préalable de l'IB par l'intermédiaire d'une licence. Pour plus d'informations sur la procédure à suivre pour demander une licence, rendez-vous à l'adresse <http://www.ibo.org/fr/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

No se podrá reproducir ninguna parte de este producto de ninguna forma ni por ningún medio electrónico o mecánico, incluidos los sistemas de almacenamiento y recuperación de información, sin que medie la autorización escrita del IB.

Además, la licencia vinculada a este producto prohíbe el uso con fines comerciales de todo archivo o fragmento seleccionado de este producto. El uso por parte de terceros —lo que incluye, a título enunciativo, editoriales, profesores particulares, servicios de apoyo académico o ayuda para el estudio, colegios preparatorios, desarrolladores de aplicaciones y entidades que presten servicios de planificación curricular u ofrezcan recursos para docentes mediante plataformas digitales— no está permitido y estará sujeto al otorgamiento previo de una licencia escrita por parte del IB. En este enlace encontrará más información sobre cómo solicitar una licencia: <http://www.ibo.org/es/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

**Section A**

Question			Answers	Notes	Total
1.	a		6 ✓	Accept "orange juice".	1
1.	b	i	equilibrium is being established «between lead in solution and in mug» <b>OR</b> solution becoming saturated <b>OR</b> concentration of lead ions/[Pb <sup>2+</sup> ] in the solution has increased «over time» <b>OR</b> acid concentration has decreased «as reacted with lead» <b>OR</b> surface lead has decreased/formed a compound/forms insoluble layer on surface <b>OR</b> acid reacts with other metals «because it is an alloy» ✓	Do <b>not</b> accept "concentration of cola, orange juice, etc... has decreased"  Do <b>not</b> accept a response that only discusses mathematical or proportional relationships.	1
1.	b	ii	no <b>AND</b> experiment 7/beer has lowest rate and intermediate acidity/pH <b>OR</b> no <b>AND</b> experiment 6/orange juice has fastest rate but lower acidity/higher pH than lemonade <b>OR</b> no <b>AND</b> experiment 6/orange juice has highest rate and intermediate acidity/pH ✓	Accept no <b>AND</b> any comparison, <b>with experimental support</b> , that concludes no pattern/increase with acidity eg: "rate of Pb/lead dissolving generally decreases with acidity as tap water has highest rate (after orange juice) while lemonade (lower pH) has lower rate".	1

Question			Answers	Notes	Total
1.	c	i	equilibrium shifts to the left/towards reactants ✓  lead «compounds/ions» precipitate  <b>OR</b>  concentration of lead «ions»/[Pb <sup>2+</sup> ] decreases ✓	Award [2] for “equilibrium shifts to the left/towards reactants due to common ion effect”.  Accept “lead ions/[Pb <sup>2+</sup> ] removed from solution” for M2.	2
1.	c	ii	«daily limit = $5.0 \times 10^{-6} \text{ g kg}^{-1} \times 80.0 \text{ kg} \Rightarrow 4.0 \times 10^{-4} \text{ «g of lead»} \checkmark$  «volume = $\frac{4.0 \times 10^{-4} \text{ g}}{1.5 \times 10^{-2} \text{ g dm}^{-3}} \Rightarrow 2.7 \times 10^{-2} / 0.027 \text{ «dm}^3\text{»} \checkmark$	Award [2] for correct final answer	2

Question		Answers	Notes	Total
2.	a	tangent drawn to curve at $t = 20 \text{ s}$ ✓ slope/gradient calculation ✓ $0.35 \text{ cm}^3 \text{ s}^{-1}$ ✓	Accept values in the range $0.32\text{--}0.42 \text{ cm}^3 \text{ s}^{-1}$ .	3
2.	b	<p><b>ALTERNATIVE 1</b>                      colour ✓  <math>\text{Br}_2</math> /reactant is coloured «<math>\text{Br}^-</math> (aq) is not» ✓</p> <p><b>ALTERNATIVE 2</b>                      conductivity ✓                      greater/increased concentration of ions in products ✓</p> <p><b>ALTERNATIVE 3</b>                      mass/pressure ✓                      gas is evolved/produced ✓</p> <p><b>ALTERNATIVE 4</b>                      pH ✓                      methanoic acid is weak <b>AND</b> HBr is strong  <b>OR</b>                      increase in <math>[\text{H}^+]</math> ✓</p>	<p>Do <b>not</b> accept “changes in temperature” or “number of bubbles”.</p> <p>Do <b>not</b> accept “mass of products is less than mass of reactants”.</p>	2

Question			Answers	Notes	Total
2.	c	i	<p><b>ALTERNATIVE 1</b></p> <p>gas may leak/be lost/escape</p> <p><b>OR</b></p> <p>plunger may stick/friction «so pressure is greater than atmospheric pressure»</p> <p><b>OR</b></p> <p>syringe may be tilted «up» so plunger moves less «with gravity acting on plunger»</p> <p><b>OR</b></p> <p>CO<sub>2</sub> dissolved in water ✓</p> <p>calculated rate lower ✓</p> <p><b>ALTERNATIVE 2</b></p> <p>syringe may be tilted «down» so plunger moves more «with gravity acting on plunger»</p> <p><b>OR</b></p> <p>syringe is held in hand so gets warmer and gas expands ✓</p> <p>calculated rate higher ✓</p>	<p><i>Calculated rate is lower or higher must be stated for M2.</i></p> <p><i>Do not accept “scale on syringe is inaccurate”, “errors in reading syringe”, or “bubbles in syringe”.</i></p>	2
2.	c	ii	<p>human reaction time/delay «starting/stopping the stopwatch» ✓</p>	<p><i>Do not accept “inaccurate stopwatch”.</i></p>	1

## Section B

## Option A — Materials

Question	Answers	Notes	Total
3.	<i>Shape of molecules:</i> linear <b>OR</b> rod «shaped» ✓  <i>Distribution:</i> no positional order <b>AND</b> «some» directional order ✓	<i>Accept "partly ordered".</i>	2

Question		Answers	Notes	Total
4.	a	moles of electrons $\llcorner = \frac{48\,250\text{ C}}{96\,500\text{ C mol}^{-1}} \llcorner = 0.5000 \llcorner \text{mol} \llcorner \checkmark$ moles of aluminium $\llcorner = \frac{0.5000\text{ mol}}{3} \llcorner = 0.1667 \llcorner \text{mol} \llcorner \checkmark$ mass of aluminium $\llcorner = 26.98\text{ g mol}^{-1} \times 0.1667\text{ mol} \llcorner = 4.50 \llcorner \text{g} \llcorner \checkmark$	<i>Award [3] for correct final answer.</i>	3
4.	b	<i>Any two of:</i> larger linear calibration $\checkmark$ «accurate» detection of multiple elements/metals $\checkmark$ «accurate» detection of elements in low concentration $\checkmark$ temperature around 10 000 K atomises/ionises every material $\checkmark$		2 max
4.	c	<i>Any two of:</i> reactant(s) adsorb onto active sites/surface $\checkmark$ bonds weakened/broken/stretched «in adsorbed reactants» <b>OR</b> activation energy lowered $\checkmark$ products desorbed $\checkmark$	<i>Accept "products released" for M3.</i>	2 max
4.	d	<i>Conduct electricity:</i> «delocalized/valence» electrons free to move «under potential difference» $\checkmark$  <i>Harder than pure metals:</i> atoms/ions of different sizes prevent layers «of atoms/ions» from sliding over one another $\checkmark$		2
4.	e	$2\text{CO (g)} \rightarrow \text{C (s)} + \text{CO}_2\text{ (g)} \checkmark$		1



Question		Answers	Notes	Total
5.	a	$  \begin{array}{cccccccc}  \text{H} & \text{Cl} & \text{H} & \text{Cl} & \text{H} & \text{Cl} & \text{H} & \text{Cl} \\    &   &   &   &   &   &   &   \\  \text{---C---C---C---C---C---C---C---C---} \\    &   &   &   &   &   &   &   \\  \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H}  \end{array}  $ <p>correct bonding ✓ Cl atoms all on same side and alternate ✓</p>	<p><i>Continuation bonds must be shown.</i></p> <p><i>Award [1 max] if less than or more than four units shown.</i></p> <p><i>Accept a stereo formula with all atoms and bonds shown.</i></p>	2
5.	b	«strong additional» absorption at 600–800 «cm <sup>-1</sup> » ✓		1
5.	c	<p><i>Any two of:</i></p> <p>embedded/fit between chains of polymers ✓</p> <p>prevent chains from forming crystalline regions ✓</p> <p>keep polymer strands/chains/molecules separated/apart ✓</p> <p>increase space/volume between chains ✓</p> <p>weaken intermolecular/dipole-dipole/London/dispersion/instantaneous dipole-induced dipole/van der Waals/vdW forces «between chains» ✓</p> <p>increase flexibility/durability/softness ✓</p> <p>make polymers less brittle ✓</p>	Accept “lowers density/melting point”.	2 max
5.	d	<p>leach into foodstuffs/environment</p> <p><b>OR</b></p> <p>«unknown» health/environmental consequences ✓</p>	Accept “plasticizers cannot be recycled”.	1

Question		Answers	Notes	Total
5.	e	<p>addition produces only the polymer «<b>AND</b> more green»</p> <p><b>OR</b></p> <p>addition has no by/side-product/condensation produces by-product/small molecules/HCl/NH<sub>3</sub> «<b>AND</b> less green»</p> <p><b>OR</b></p> <p>addition has high atom economy/condensation has lower atom economy «<b>AND</b> less green»</p> <p><b>OR</b></p> <p>condensation polymers «often» more biodegradable than addition polymers «<b>AND</b> more green» ✓</p>	<p>Accept “if water produced by condensation «<b>AND</b> condensation and addition equally green»”.</p> <p>Accept for addition “all of reactants change into products”.</p>	1
5.	f	$\begin{array}{c} \text{H} \quad \text{O} \\   \quad    \\ \text{---N---C---} \end{array} \checkmark$	<p>Continuation bonds must be shown.</p> <p>Do <b>not</b> accept condensed formula.</p>	1

Question		Answers	Notes	Total
6.	a	$\ll 8 \times \frac{1}{8} + 6 \times \frac{1}{2} = \gg 4 \checkmark$		1
6.	b	$a = \ll \frac{4r}{\sqrt{2}} = \frac{4 \times 1.97 \times 10^{-10} \text{ m}}{\sqrt{2}} = \gg 5.572 \times 10^{-10} \ll \text{m} \gg$ <b>OR</b> volume of unit cell = $\ll (5.572 \times 10^{-10} \text{ m})^3 \times 10^6 = \gg 1.73 \times 10^{-22} \ll \text{cm}^3 \gg \checkmark$  mass of unit cell = $\ll \frac{40.08 \text{ g mol}^{-1} \times 4}{6.02 \times 10^{23} \text{ mol}^{-1}} = \gg 2.66 \times 10^{-22} \ll \text{g} \gg \checkmark$  density = $\ll \frac{2.66 \times 10^{-22} \text{ g}}{(5.572 \times 10^{-10})^3 \times 10^6} = \gg 1.54 \ll \text{g cm}^{-3} \gg \checkmark$	<i>Award [3] for correct final answer.</i>	3

7.	a	$\ll \text{material with} \gg$ no electrical resistance $\checkmark$		1
7.	b	Type 1 has sharper transition to superconductivity $\checkmark$	<i>Accept annotated plot of electrical resistance against temperature.</i>	1

Question		Answers	Notes	Total
8.	a	<p>Any one of:</p> <p>disrupt endocrine system</p> <p><b>OR</b></p> <p>compete for active sites of enzymes/cellular receptors</p> <p><b>OR</b></p> <p>form complexes with/inhibit enzymes</p> <p><b>OR</b></p> <p>denature proteins</p> <p><b>OR</b></p> <p>change shape of active site ✓</p> <p>participate in redox reactions</p> <p><b>OR</b></p> <p>disturb normal redox balance «in cells» ✓</p> <p>initiate «free» radical reactions «in electron transfer» ✓</p>		1 max
8.	b	<p>«<math>K_{sp} = 7.40 \times 10^{-14}</math>»</p> <p><math>K_{sp} = [Pb^{2+}][CO_3^{2-}]</math> ✓</p> <p><math>[Pb^{2+}] \llcorner = \frac{7.40 \times 10^{-14}}{1.10 \times 10^{-4}} \llcorner = 6.73 \times 10^{-10}</math> «mol dm<sup>-3</sup>» ✓</p>	Award [2] for correct final answer.	2
8.	c	<p>Any one of:</p> <p>chelation «by EDTA/polydentate ligand anchored» ✓</p> <p>ion exchange systems ✓</p> <p>adsorption by «water» plants ✓</p>	Accept “use of zeolites”.	1 max

Option B — Biochemistry

Question			Answers	Notes	Total
9.	a	i	$\beta$ /beta pleated/sheet ✓		1
9.	a	ii	<p><i>One similarity:</i> hydrogen bonding <b>OR</b> attractions between C=O and N–H «on main chain» ✓</p> <p><i>One difference:</i> <math>\alpha</math>-helix has hydrogen bonds between amino acid residues that are closer than <math>\beta</math>-pleated sheet <b>OR</b> H-bonds in <math>\alpha</math>-helix parallel to helix axis <b>AND</b> perpendicular to sheet in <math>\beta</math>-pleated sheet <b>OR</b> <math>\alpha</math>-helix has one strand <b>AND</b> <math>\beta</math>-pleated sheet has two «or more» strands <b>OR</b> <math>\alpha</math>-helix is more elastic «since H-bonds can be broken easily» <b>AND</b> <math>\beta</math>-pleated sheet is less elastic «since H-bonds are difficult to break» ✓</p>	<p>Accept a diagram which shows hydrogen bonding between O of C=O and H of NH groups for M1.</p> <p>Accept “between carbonyl/amido/amide/carboxamide” but not “between amino/amine” for M1.</p>	2
9.	b		<p>enzyme denatured/ loss of 3-D structure/conformational change <b>OR</b> «interactions responsible for» for tertiary/quaternary structures altered ✓</p> <p>shape of active site changes <b>OR</b> fewer substrate molecules fit into active sites ✓</p>		2

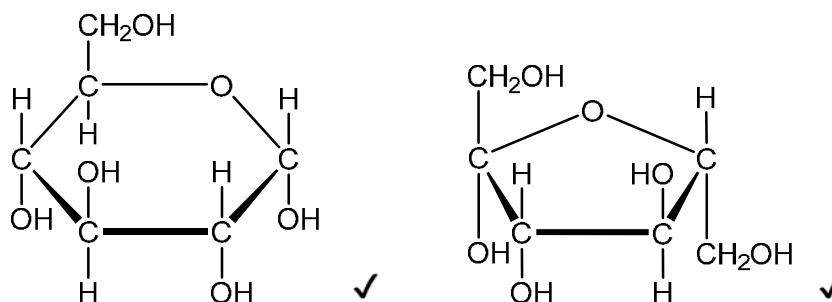
Question			Answers	Notes	Total
9.	c		$V_{\max}$ unchanged ✓ at high substrate concentration substrate outcompetes inhibitor/need a higher substrate concentration to reach $V_{\max}$ ✓	Accept suitable labelled diagram.	2
9.	d	i	Any two of: surface water is warmer «so faster reaction rate»/more light/energy from the sun ✓ more oxygen «for aerobic bacteria/oxidation of oil» ✓ greater surface area ✓		2 max
9.	d	ii	Any one of: non-hazardous/toxic to the environment/living organisms ✓ energy requirements «during production» ✓  quantity/type of waste produced «during production» <b>OR</b> atom economy ✓  safety of process ✓	Accept “use of solvents/toxic materials «during production»”.  Do <b>not</b> accept “more steps involved”.	1 max

Question			Answers	Notes	Total
10.	a	i	<p><math>pK_{a2}</math> <b>AND</b> pH of solution &gt; pH of isoelectric point «as anion present»  <b>OR</b>  <math>pK_{a2}</math> <b>AND</b> zwitterion has lost <math>H^+</math> to become anion «so in basic solution»  <b>OR</b>  <math>pK_{a2}</math> <b>AND</b> «only» anion «and zwitterion» present ✓</p>		1
10.	a	ii	<p>«<math>pH = 9.1 + \log \left[ \frac{0.30}{0.60} \right]</math>»                      «= <math>9.1 + (-0.3)</math>» = 8.8 ✓</p>		1
10.	b		<p>sequence of bases in DNA ✓                      codon/triplet code/each set of three bases codes for an amino acid ✓</p>		2

Question			Answers	Notes	Total
11.	a	i	$  \begin{array}{c}  \text{O} \\  \parallel \\  \text{H}_2\text{C}-\text{O}-\text{P}-\text{O}-\text{CH}_2-\text{CH}_2-\text{N}^+(\text{CH}_3)_3 \\    \\  \text{O}^- \\  \text{HC}-\text{O}-\text{C}-(\text{CH}_2)_{10}\text{CH}_3 \\  \parallel \\  \text{O} \\  \text{H}_2\text{C}-\text{O}-\text{C}-(\text{CH}_2)_{10}\text{CH}_3 \\  \parallel \\  \text{O}  \end{array}  $ <p>phosphodiester correctly drawn ✓ both ester groups correctly drawn ✓</p>	<p>Accept protonated phosphate. Accept phosphodiester in centre position.</p>	2
11.	a	ii	condensation ✓	<p>Accept "esterification". Accept "nucleophilic substitution/S<sub>N</sub>".</p>	1
11.	b		<p>phospholipid bilayer/double layer <b>OR</b> two layers of phospholipids ✓</p> <p>polar/hydrophilic heads facing aqueous environment <b>AND</b> non-polar/hydrophobic tails facing away from aqueous environment ✓</p>	<p>Award [2] for a suitably labelled diagram. Award [1] for a correct but unlabelled diagram.</p> <p>Accept "polar/hydrophilic heads on outside <b>AND</b> non-polar/hydrophobic tails on inside" for M2.</p>	2



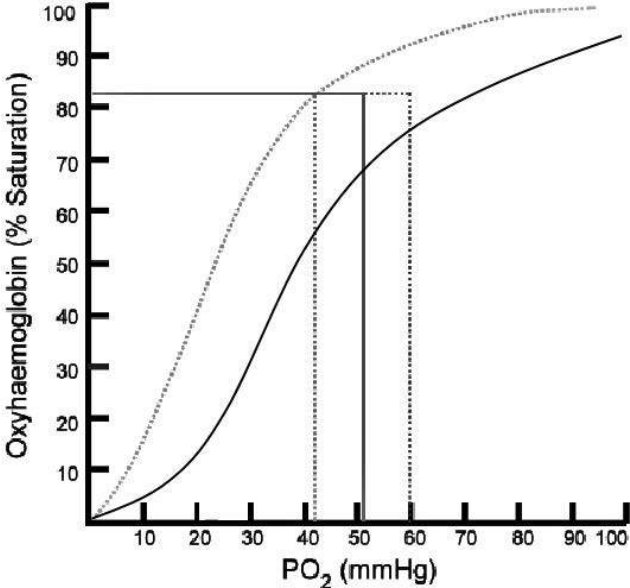
Question		Answers	Notes	Total
11.	c	long non-polar/hydrocarbon chain «and only one hydroxyl group» <b>OR</b> forms London/dispersion/van der Waals/vdW interactions with fat ✓	Accept "alcohol/hydroxy/OH" for "hydroxyl" but <b>not</b> "hydroxide".	1
11.	d	Any one of: atherosclerosis/cholesterol deposition «in artery walls» ✓ increases risk of heart attack/stroke/cardiovascular/heart disease/CHD ✓	Accept "arteries become blocked/walls become thicker", "increases blood pressure", or "blood clots". Do <b>not</b> accept "high cholesterol".	1 max

Question		Answers	Notes	Total
12.	a	acetal <b>OR</b> ether ✓	Accept "glycosidic bond/linkage" but <b>not</b> "glucosidic". Do <b>not</b> accept "hemiacetal".	1
12.	b	$\alpha$ -isomer <b>AND</b> hydroxyl group on carbon 1 and $-\text{CH}_2\text{OH}$ are trans <b>OR</b> $\alpha$ -isomer <b>AND</b> hydroxyl group on carbon 1 is below plane of ring <b>OR</b> $\alpha$ -isomer <b>AND</b> glycosidic linkage between rings is below plane of ring ✓	Accept "ether linkage" for M3.	1
12.	c			2

Question			Answers	Notes	Total
13.	a		extensive conjugated system <b>OR</b> extensive delocalized bonding system <b>OR</b> extended system of alternating double and single bonds ✓  absorbs green <b>OR</b> complementary to red light ✓		2
13.	b	i	sigmoid/S-shaped <b>OR</b> as oxygen binds to one active site, shape of other active sites change ✓  affinity of other sites for oxygen increases/ability to bind oxygen is increased by initial binding of oxygen <b>OR</b> cooperative binding ✓	Accept description of sigmoid/S-shaped curve if not stated for M1.	2

(continued...)

(Question 13b continued)

Question			Answers	Notes	Total
13.	b	ii	 <p>The graph plots Oxyhaemoglobin (% Saturation) on the y-axis (0 to 100) against PO<sub>2</sub> (mmHg) on the x-axis (0 to 100). Two sigmoidal curves are shown. The original curve (solid line) has a P<sub>50</sub> of approximately 50 mmHg. The shifted curve (dotted line) has a P<sub>50</sub> of approximately 60 mmHg. A horizontal line at 80% saturation intersects the original curve at ~40 mmHg and the shifted curve at ~58 mmHg. A vertical line at 50 mmHg intersects the original curve at ~68% saturation and the shifted curve at ~82% saturation.</p> <p>curve to right of original ✓</p> <p>[Source: Ratznum, <a href="https://commons.wikimedia.org/wiki/File:Oxyhaemoglobin_dissociation_curve.png">https://commons.wikimedia.org/wiki/File:Oxyhaemoglobin_dissociation_curve.png</a>]</p>		1

Option C — Energy

Question	Answers	Notes	Total
14.	<p><b>Advantage</b>  <i>Any one of:</i>                      renewable ✓                      predictable supply ✓                      tidal barrage may prevent flooding ✓                      effective at low speeds ✓                      long life-span ✓                      low cost to run ✓</p> <p><b>Disadvantage</b>  <i>Any one of:</i>                      cost of construction ✓                      changes/unknown effects on marine life ✓                      changes circulation of tides in the area ✓                      power output is variable ✓                      limited locations where feasible ✓                      equipment maintenance can be challenging ✓                      difficult to store energy ✓</p>	<p><i>Do not accept vague generalisations.</i>  <i>Do not accept economic issues for both advantage and disadvantage.</i>  <i>Do not accept sustainable.</i>                      Accept “energy” or “electricity” for “power”.</p>	2 max

Question		Answers	Notes	Total	
15.	a	<p><b>Fractional distillation:</b> Any two of: <b>1 max</b></p> <p>physical process</p> <p>separation of compounds by boiling point/vapour pressure</p> <p>breaking intermolecular forces</p> <p>different molar masses</p> <p>does not use catalyst</p>	<p><b>Cracking:</b> Any two of: <b>1 max</b></p> <p>chemical process</p> <p>new compounds formed</p> <p>increasing branching/ring formation</p> <p>short hydrocarbon chains formed</p> <p>breaking «and remaking»/changing covalent bonds</p> <p>uses catalyst</p>	<p>Award <b>[1]</b> for any two correct answers from one column <b>OR</b> one from each column.</p> <p>Award <b>[2]</b> for any two correct from each column; eg: fractional distillation – any two correct award <b>[1 max]</b> <b>AND</b> cracking – any two correct, award <b>[1 max]</b>.</p>	2 max
		<p>specific energy = «<math>\frac{4163 \text{ kJ mol}^{-1}}{86.2 \text{ g mol}^{-1}}</math>» ⇒ 48.3 «kJ g<sup>-1</sup>» ✓</p> <p>energy density = «48.3 kJ g<sup>-1</sup> × 0.660 g cm<sup>-3</sup>» ⇒ 31.9 «kJ cm<sup>-3</sup>» ✓</p>	<p>Award <b>[1 max]</b> if either or both answers not expressed to three significant figures.</p>	2	
15.	c	<p>Any two of:</p> <p>«hydrocarbons are heated with» catalyst ✓</p> <p>long chains break and reform</p> <p><b>OR</b></p> <p>branching/aromatisation occurs</p> <p><b>OR</b></p> <p>isomerisation/reforming/platforming/cracking ✓</p> <p>zeolite separates branched from non-branched</p> <p><b>OR</b></p> <p>products are distilled</p> <p><b>OR</b></p> <p>«distillation» separates reformed and cracked products ✓</p>	<p>Accept a specific catalyst name or formula for M1 such as Pt/Re/Rh/Pd/Ir.</p>	2 max	

Question			Answers	Notes	Total
16.	a	i	${}_{40}^{103}\text{Zr}$ ✓		1
16.	a	ii	minimum mass to «self-»sustain chain reaction <b>OR</b> if mass of fissile material is too small, too many neutrons produced pass out of the nuclear fuel <b>OR</b> at least one neutron produced causes further reaction ✓		1
16.	a	iii	Any one of: reduction in emission of greenhouse gases «from burning fossil fuels» ✓ economic independence/self-sufficiency «from crude oil/producing states» ✓ uranium is more abundant on Earth «in terms of total energy that can be produced from this fuel» than fossil fuels ✓	Accept specific greenhouse gases (such as carbon dioxide/CO <sub>2</sub> ) but <b>not</b> pollutants or other general statements.	1 max
16.	b		Any one of: fuel is inexpensive/readily available ✓ no/less radioactive waste is formed ✓ lower risk of accidents/large-scale disasters ✓ impossible/harder to use for making materials for nuclear weapons ✓ larger amounts of energy released per unit mass ✓ does not require a critical mass ✓ can be used continuously ✓	Accept “higher specific energy for fusion”.  Do <b>not</b> accept “no/less waste produced for fusion”. Accept specific example for a disaster.	1 max
16.	c		mass difference between reactants and products <b>AND</b> $E = mc^2$ ✓		1

Question			Answers	Notes	Total
16.	d		$\ll N = N_0 e^{-\lambda t} \gg$ $\lambda \ll = \frac{-\ln\left(\frac{N}{N_0}\right)}{t} = \frac{-\ln\left(\frac{4.0 \times 10^{-5}}{5.0 \times 10^{-5}}\right)}{31.4 \text{ s}} \gg$ $= 7.106 \times 10^{-3} \text{ s}^{-1} \checkmark$ $\ll t_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \gg 98/97.5 \text{ «s» } \checkmark$	<p><i>Award [2] for correct final answer.</i></p>	<p><b>2</b></p>



Question	Answers	Notes	Total
17.	<p><b>Strength</b>                      Any one of:                      less flammable «than diesel» ✓                      recycles carbon «lower carbon footprint»  <b>OR</b>                      lower greenhouse gas emissions ✓                      easily biodegradable «in case of spill» ✓                      renewable  <b>OR</b>                      does not deplete fossil fuel reserves ✓                      economic security/availability in countries without crude oil ✓</p> <p><b>Limitation</b>                      Any one of:                      more difficult to ignite inside the engine «than diesel» ✓                      more viscous «than diesel» ✓                      lower energy content/specific energy/energy density ✓                      uses food sources  <b>OR</b>                      uses land that could be used for food ✓                      «production is» more expensive ✓                      less suitable in low temperatures ✓                      increased NO<sub>x</sub> emissions for biodiesel ✓                      greenhouse gases still produced ✓</p>	<p><i>Accept “«close to» carbon neutral”, “produce less greenhouse gases/CO<sub>2</sub>”.</i></p> <p><i>Accept “engines have to be modified if biodiesel used” as limitation.</i></p> <p><i>Do <b>not</b> award marks for strength and limitation that are the same topic/concept.</i></p>	2 max

Question		Answers	Notes	Total
18.	a	bond length/C=O distance changes <b>OR</b> «asymmetric» stretching «of bonds» <b>OR</b> bond angle/OCO changes ✓  polarity/dipole «moment» changes <b>OR</b> dipole «moment» created «when molecule absorbs IR» ✓	Accept appropriate diagrams.	2
18.	b	Any one of: capture where produced «and store» ✓ use scrubbers to remove ✓ use as feedstock for synthesising other chemicals ✓ carbon credit/tax/economic incentive/fines/country specific action ✓  use alternative energy <b>OR</b> stop/reduce use of fossil fuels for producing energy ✓  use carbon reduced fuels «such as methane» ✓ increase efficiency and reduce energy use ✓	Do not accept “planting more trees”. Accept specific correct examples.	1 max

Question		Answers	Notes	Total
19.	a	<p>Any three of:</p> $\text{C}_6\text{H}_{12}\text{O}_6 (\text{aq}) + 6\text{H}_2\text{O} (\text{l}) \rightarrow 6\text{CO}_2 (\text{g}) + 24\text{H}^+ (\text{aq}) + 24\text{e}^-$ <p><b>OR</b></p> <p>electrons released by oxidation of glucose ✓</p> <p>enzymes «in bacteria» oxidize glucose</p> <p><b>OR</b></p> <p>«bacteria» transfer «released» electrons directly to anode ✓</p> $24\text{H}^+ (\text{aq}) + 6\text{O}_2 (\text{g}) + 24\text{e}^- \rightarrow 12\text{H}_2\text{O} (\text{l})$ <p><b>OR</b></p> <p>electrons consumed by reduction of oxygen ✓</p> <p>PEM/membrane separates two half reactions</p> <p><b>OR</b></p> <p>PEM/membrane allows proton/<math>\text{H}^+</math> transfer from anode to cathode ✓</p> <p>electrons flow though external circuit ✓</p>	<p>Accept <math>4\text{H}^+ (\text{aq}) + \text{O}_2 (\text{g}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O} (\text{l})</math>.</p>	<p><b>3 max</b></p>

Question		Answers	Notes	Total															
19.	b	$\llcorner E = E^\ominus - \frac{RT}{nF} \times \ln Q \llcorner$ $\ln Q = \llcorner \ln \frac{[\text{Mg}^{2+}]}{[\text{Ag}^+]^2} = \frac{0.0500}{0.100^2} = \ln 5.00 \Rightarrow 1.61 \checkmark$ $E = \llcorner 3.17 \text{ V} - \frac{8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 298 \text{ K}}{2 \times 96\,500 \text{ J V}^{-1} \text{ mol}^{-1}} \times \ln \frac{0.0500}{0.100^2} = 3.17 - 0.021 = + \llcorner 3.15 \text{ V} \llcorner \checkmark$	Award [2] for correct final answer.	2															
19.	c	<p>Any one of:</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%; text-align: center;">Primary</th> <th style="width: 10%;"></th> <th style="width: 40%; text-align: center;">Secondary</th> </tr> </thead> <tbody> <tr> <td>«electrode» materials cannot be reused/regenerated</td> <td style="text-align: center;"><b>AND</b></td> <td>«electrode» materials can be regenerated/reused ✓</td> </tr> <tr> <td>non-reversible reaction(s)</td> <td style="text-align: center;"><b>AND</b></td> <td>reversible reaction(s) ✓</td> </tr> <tr> <td>lower rate of self-discharge</td> <td style="text-align: center;"><b>OR</b></td> <td>higher rate of self-discharge ✓</td> </tr> <tr> <td>only lower current demands</td> <td style="text-align: center;"><b>OR</b></td> <td>can deliver stronger current demands ✓</td> </tr> </tbody> </table>		Primary		Secondary	«electrode» materials cannot be reused/regenerated	<b>AND</b>	«electrode» materials can be regenerated/reused ✓	non-reversible reaction(s)	<b>AND</b>	reversible reaction(s) ✓	lower rate of self-discharge	<b>OR</b>	higher rate of self-discharge ✓	only lower current demands	<b>OR</b>	can deliver stronger current demands ✓	Accept “primary cannot be recharged <b>AND</b> “secondary can be recharged”.
Primary		Secondary																	
«electrode» materials cannot be reused/regenerated	<b>AND</b>	«electrode» materials can be regenerated/reused ✓																	
non-reversible reaction(s)	<b>AND</b>	reversible reaction(s) ✓																	
lower rate of self-discharge	<b>OR</b>	higher rate of self-discharge ✓																	
only lower current demands	<b>OR</b>	can deliver stronger current demands ✓																	

Question		Answers	Notes	Total
20.	a	<p><i>Semiconductors:</i> increases ✓</p> <p><i>Metals:</i> decreases ✓</p>	<p><i>Accept any graph showing general increase for semiconductor.</i></p> <p><i>Accept any graph showing general decrease for metal.</i></p> <p><i>Accept a graph showing vertical section below transition temperature for a superconducting metal.</i></p>	2
20.	b	<p>dye absorbs light ✓</p> <p>electrons from «excited» dye pass to TiO<sub>2</sub>/semiconductor/electrolyte/cell</p> <p><b>OR</b></p> <p>dye undergoes photo-oxidation ✓</p>		2

Option D — Medicinal chemistry

Question		Answers	Notes	Total
21.	a	<p><i>Therapeutic window:</i> range of dosage «over which a drug» provides the therapeutic/desired effect without causing adverse/toxic effects ✓</p> <p><i>Therapeutic index:</i> toxic dose of drug for 50 % of population divided by minimum effective dose for 50 % of population</p> <p><b>OR</b></p> $\frac{TD50}{ED50} \checkmark$	<p><i>M1 may be scored from a correctly labelled diagram.</i></p> <p><i>Do not accept reference to lethal dose used in therapeutic index in animal studies.</i></p>	2
21.	b	<p>morphine has «two» hydroxyl groups <b>AND</b> diamorphine has «two» ester/ethanoate/acetate groups</p> <p><b>OR</b></p> <p>molecule of diamorphine is less polar than morphine</p> <p><b>OR</b></p> <p>groups in morphine are replaced with less polar/non-polar groups in diamorphine ✓</p> <p>«less polar molecules» cross the blood–brain barrier faster/more easily</p> <p><b>OR</b></p> <p>diamorphine is more soluble in non-polar environment of CNS/central nervous system than morphine ✓</p>	<p><i>Accept “alcohol/hydroxy” for “hydroxyl” but not “hydroxide”.</i></p> <p><i>Accept “fats” for “lipid”.</i></p> <p><i>Accept “heroin” for “diamorphine”.</i></p>	2

Question			Answers	Notes	Total
22.	a		<p>Any one of:</p> <p>1050–1410 «cm<sup>-1</sup> due to C–O» ✓</p> <p>1700–1750 «cm<sup>-1</sup> due to C=O in acids and esters» ✓</p> <p>2500–3000 «cm<sup>-1</sup> due to O–H in acids» ✓</p> <p>2850–3090 «cm<sup>-1</sup> due to C–H in alkanes and arenes» ✓</p>		1 max
22.	b	i	<p><math>n(\text{aspirin}) \llcorner n(\text{NaOH}) = \frac{16.25 \text{ cm}^3}{1000} \times 0.100 \text{ mol dm}^{-3} \llcorner = 1.625 \times 10^{-3} \llcorner \text{mol} \llcorner \checkmark</math></p> <p><math>m(\text{aspirin}) \llcorner = 1.625 \times 10^{-3} \text{ mol} \times 180.17 \text{ g mol}^{-1} \llcorner = 0.293 \llcorner \text{g} \llcorner \checkmark</math></p>	Award [2] for correct final answer.	2
22.	b	ii	<p><math>\llcorner \frac{0.293 \text{ g}}{0.300 \text{ g}} \times 100 \% \llcorner = 97.7 \llcorner \% \llcorner \checkmark</math></p>		1
22.	c		<p>convert to a salt</p> <p><b>OR</b></p> <p>react with sodium hydroxide ✓</p>	<p>Accept other reactions forming soluble salts.</p> <p>Accept “to ionize” but <b>not</b> “more polar”.</p>	1
22.	d		<p>synergistic effect/increased toxicity</p> <p><b>OR</b></p> <p>increased risk of stomach/intestines bleeding/ulcers/heartburn</p> <p><b>OR</b></p> <p>increased risk of liver toxicity/damage</p> <p><b>OR</b></p> <p>increased risk of nausea/vomiting ✓</p>		1

Question			Answers	Notes	Total
23.	a	i	blocks/binds H2/histamine receptors «in cells of stomach lining» <b>OR</b> prevents histamine molecules binding to H2/histamine receptors «and triggering acid secretion» ✓		1
23.	a	ii	Any two of: ranitidine can be effective in treating ulcers «but antacid is not» ✓ ranitidine can prevent long-term damage «from overproduction of acid and antacid does not» ✓ ranitidine has a long-term effect «and antacid has short-term effect only» ✓ ranitidine does not affect ionic balance in body «and antacid does» ✓ ranitidine does not produce bloating/flatulence ✓	Accept “ranitidine stops the over production of acid in the stomach while antacids neutralise the excess acid giving temporary relief” for M2.	2 max
23.	b		« $\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{HA}]} = 10.32 + \log \frac{0.160}{0.200} = 10.32 - 0.097$ »  «pH =»10.22 ✓		1



Question		Answers	Notes	Total
24.	a	<p>Any one of:</p> <p>alter cell's genetic material so that virus cannot use it to multiply ✓</p> <p>prevent viruses from multiplying by blocking enzyme activity within host cell</p> <p><b>OR</b></p> <p>inhibit the synthesis of viral components by blocking enzymes inside the cell ✓</p> <p>prevent viruses from entering «host» cell</p> <p><b>OR</b></p> <p>bind to cellular receptors targeted by viruses</p> <p><b>OR</b></p> <p>bind to virus-associated proteins/VAPs which target cellular receptors</p> <p><b>OR</b></p> <p>prevents removal of protein coat/capsid</p> <p><b>OR</b></p> <p>prevents injection of viral DNA/RNA into cell ✓</p> <p>prevent/hinder the release of viruses from the cell ✓</p>	<p>Accept "prevents synthesis of virus by host cell".</p> <p>Accept "alters RNA/DNA/genetic material of virus".</p> <p><b>Do not accept just "mimics nucleotides".</b></p>	<p><b>1 max</b></p>

Question		Answers	Notes	Total
24.	b	<p><i>Any two of:</i></p> <p>viruses lack cell structure so difficult to target with drugs ✓</p> <p>HIV is a retrovirus</p> <p><b>OR</b></p> <p>HIV genetic material is in the form of RNA instead of DNA ✓</p> <p>HIV affects/destroys helper/T-cells which are necessary to fight infection ✓</p> <p>HIV has great genetic diversity so difficult to produce «a» vaccine ✓</p> <p>anti-retroviral agents are expensive so not everyone/country can afford them ✓</p> <p>socio-cultural issues deter people from seeking treatment/prevention/diagnosis</p> <p><b>OR</b></p> <p>lack of education/conversation/stigma associated with being HIV-positive ✓</p> <p>mutation of virus/HIV ✓</p> <p>virus/HIV metabolism linked to that of host cell ✓</p> <p>drugs harm host cell as well as virus/HIV ✓</p> <p>HIV difficult to detect/remains dormant ✓</p>		<b>2 max</b>

Question		Answers	Notes	Total
25.	a	<p><i>Any two of:</i>                      produced by genetically engineered/modified bacteria/<i>E. coli</i>  <b>OR</b>                      sustainable because synthesized and not obtained from yew trees ✓                        chiral auxiliaries «isolated and» reused ✓                      one enantiomer produced ✓                      toxicity/recycling of solvents/materials used ✓                      overall yield/atom economy/waste generated ✓</p>		2 max
25.	b	<p><i>Any two of:</i>                      «plane-» polarized light  <b>OR</b>                      light passes through polarizer/polarizing filter ✓                        enantiomers rotate plane of «plane-» polarized light «by equal angles» in opposite directions ✓                      measure angle/direction of rotation ✓</p>		2 max

Question		Answers	Notes	Total
26.	a	<p>Any two of:</p> <p>can be readily “tagged” to variety of biologically active carriers «which will deliver it to specific locations for imaging uses» ✓</p> <p>frequency of radiation is compatible with existing X-ray detection apparatus ✓</p> <p>product of decay has low radioactivity/relatively short half-life/low total exposure to patient ✓</p> <p>«but small» increased risk of cancer to patient ✓</p> <p>must be made on site ✓</p>	<p>Accept other valid answers outlining advantages or limitations of Tc-99m, such as “produces only LLW”, “Tc is a transition element forming compounds in a variety of oxidation states”, “gamma-radiation «can escape the body and» be detected by external sensors”, “activity decreases quickly, so dose must be calculated prior to each injection”.</p>	2 max
26.	b	<p><b>ALTERNATIVE 1</b></p> $\frac{N(t)}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}} \checkmark$ <p>31 «% remaining» ✓</p> <p><b>ALTERNATIVE 2</b></p> $\lambda \text{ «} = \frac{\ln 2}{t_{1/2}} \text{»} = 0.1155 \text{ hours}^{-1} \checkmark$ $\text{«} \frac{N}{N_0} \times 100 = e^{-\lambda t} \times 100 = 0.31498 \times 100 \text{»}$ <p>31 «% remaining» ✓</p>	<p>M1 is for correct substitution of values.</p> <p>Award [2] for correct final answer.</p>	2

Question		Answers	Notes	Total
27.	a	<p>Any three of:</p> <p>ethanol «in breath» is oxidized «to ethanoic acid» ✓</p> <p>electrons pass through external circuit/meter ✓</p> <p>«to cathode where» O<sub>2</sub> is reduced ✓</p> <p>current is proportional to alcohol concentration ✓</p>	<p>Accept equations for oxidation of ethanol or reduction of oxygen.</p>	3 max
27.	b	<p>Bond:</p> <p>C–O</p> <p><b>OR</b></p> <p>C–H ✓</p> <p>Reason:</p> <p>cannot use O–H bonds as in water «found in breath» ✓</p>	<p>Accept “C–O/C–H «bonds in molecules in breath» most likely to be in ethanol”.</p> <p>Do <b>not</b> apply ECF here.</p>	2