Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

November 2016

Chemistry

Higher level

Paper 3

30 pages

Section A

Question			Answers	Notes	Total
1.	a	i	*HOCl:* +1 ***AND*** ClO_2*:* +4 ✓	*Accept "I" and "IV" but **not** "1+/1" and "4+/4" notations.*	**1**
1.	a	ii	«most» CT values are higher for «bacterium» B ***OR*** «generally» higher dosage needed for «bacterium» B ✓	*Accept converse arguments.* *Accept "concentration" for "dosage".*	**1**
1.	a	iii	«$CT = 1.50 \times 10^{-5} \times 10^{3}\,mg\,dm^{-3} \times 9.82\,min =$» 1.47×10^{-1} «$mg\,min\,dm^{-3}$» ✓		**1**
1.	a	iv	lower than CT value/minimum dosage/1.8×10^{-1} «$mg\,min\,dm^{-3}$» ***AND*** no/insufficient treatment ✓	*Accept "concentration" for "dosage".*	**1**
1.	b	i	higher CT value at lower temperature ***OR*** higher dosage «of chlorine» needed at low temperature ✓	*Accept "effectiveness decreases at lower temperature".* *Accept "concentration" for "dosage".* *Accept converse arguments.*	**1**
1.	b	ii	labeled axes (y: CT **and** x: pH) ***AND*** curve with increasing gradient ✓	*Do **not** accept axes the wrong way round.* *Accept a linear graph.*	**1**
1.	b	iii	values at pH 9.0 approximately 3 times values at pH 6.0 ***OR*** increase in CT values in same ratio ✓	*The exact ratio is 2.9 times.* *Do **not** accept just "increase in value".*	**1**
1.	b	iv	[HOCl] decreases ***AND*** [OCl^-] increases ✓		**1**

(continued)

(Question 1 continued)

Question			Answers	Notes	Total
1.	**c**		plastic disposal/pollution ***OR*** plastic bottles use up petroleum/non-renewable raw material ***OR*** chemicals in plastic bottles can contaminate water ***OR*** **«**prolonged**»** storage in plastic bottles can cause contamination of water ***OR*** plastic water bottles sometimes reused without proper hygiene considerations ✓	*Accept other valid answers.* *Accept economic considerations such as "greater production costs", "greater transport costs" or "bottled water more expensive than tap water".*	**1**

2.	**a**		repeat steps 3 and 4 ***OR*** repeat step 5 ***OR*** conduct a third heating ***OR*** **«**re**»**heat ***AND*** **«**re**»**weigh ✓ water still present ***OR*** need two consistent readings ***OR*** heat to constant mass ✓	*Do **not** accept "cleaning/washing the crucible".*	**2**

(continued)

(Question 2 continued)

Question			Answers	Notes	Total
2.	**b**		soot/carbon deposited ***OR*** incomplete combustion ***OR*** air hole of Bunser burner closed/not fully open ✓ **«**value of **x»** lower ✓	*Accept "using a yellow **«**Bunsen burner**»** flame" for M1.* *Only award M2 if M1 correct.*	**2**
2.	**c**		all mass loss is due to water loss ✓ all the water **«**of crystallization**»** is lost ✓ crucible does not absorb/lose water ✓ crystal/$BaCl_2$ does not decompose/hydrolyse/oxidize/react with oxygen/air **«**when heated**»** ✓	*Accept "no loss of crystals/$BaCl_2$ occurs", "no impurities in the **«**weighed hydrated**»** salt", "reaction goes to completion", "heat was consistent/strong", "crystal/$BaCl_2$ does not absorb water during cooling", "balance has been calibrated" or "crucible was clean at the start".* *Do **not** accept "heat loss to surroundings" or "no carbon deposited on crucible".* *Reference to defects in apparatus not accepted.* *Do **not** penalize if $BaCl_2.\mathbf{x}H_2O$ is used for $BaCl_2$.*	**2 max**

Section B

Option A — Materials

Question			Answers	Notes	Total
3.	a		*MgO:* ionic ***AND*** *SiC:* covalent ✓	*Accept "covalent network/network covalent" for "covalent" but not just "network".*	1
3.	b		metallic «bonding» ✓		1

4.	a		«$0.300\,A \times 9.00 \times 10^3\,s$ =» 2.70×10^3 «C» ✓		1
4.	b		«mol $e^- = \frac{2700\,C}{96500\,C\,mol^{-1}}$ =» 2.80×10^{-2} «mol» ✓		1
4.	c		«$\frac{1.07\,g}{0.0280\,mol}$ =» 38.2 «g» ✓		1
4.	d		«$\frac{114.82\,g}{38.2\,g\,mol^{-1}}$ e^- =» 3.01/3.00 «mol e^-» ✓		1
4.	e		In^{3+}/3+ ***AND*** $In_2(SO_4)_3$ ✓	*Do **not** accept "+3/3".*	1

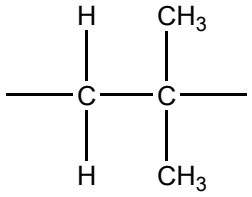
5.	a		pores/cavities/channels/holes/cage-like structures ✓ «only» reactants with appropriate/specific size/geometry fit inside/go through/are activated/can react ✓	*Accept "molecules/ions" for reactants.*	2

(continued)

(Question 5 continued)

Question			Answers	Notes	Total
5.	**b**	**i**	iron**«**0**»«**penta**»**carbonyl/$Fe(CO)_5$ **«**catalyst**»** decomposes ***OR*** $Fe(CO)_5(g) \rightarrow Fe(s) + 5CO(g)$ ***OR*** metal nanocatalyst/clusters/particles formed **«***in situ***»** ✓ $2CO(g) \rightarrow CO_2(g) + C(s)$ ✓	*Accept "cobalt-molybdenum/Co-Mo/CoMo" as a catalyst.* *Accept "conversion of CO molecules into CNTs/ SWNTs" for M2.*	**2**
5.	**b**	**ii**	higher efficiency per unit mass/volume of catalyst **«**due to higher surface to mass/volume ratio**»** ***OR*** greater selectivity **«**due to metal nanoclusters/surface topology/pore size**»** ***OR*** higher stability of catalyst **«**due to lower tendency to aggregation**»** ***OR*** reduced cost of catalyst/product/chemicals **«**as precious metals can be replaced with nanocatalysts made of inexpensive materials**»** ✓	*Accept "high conversion efficiency".* *Accept specific examples such as use of nanocatalysts in fuel cells/catalytic converters **«**leading to reduced use of Pt/Rh/Pd**».*** *Accept "lower energy consumption / reduced carbon footprint / reduced global warming", "often operate under milder conditions **«**so less energy consumption involved/promoting principles of green chemistry**»**, "often have long lifetimes **«**so more economical**»" or "have enzyme mimicking activities".*	**1**

(continued)

Question			Answers	Notes	Total
6.	a		 ***OR*** $-CH_2C(CH_3)_2-$ ✓	*Continuation bonds needed for mark.* *No penalty if brackets present or "n" appears after the bracket/formula.*	**1**
6.	b		«same mass of product as reactant, thus» 100 «%» ✓	*Accept "less than 100 %" only if a reason is given (eg, the catalyst is not converted into the product, or other reasonable answer).*	**1**
6.	c	i	due to stability of plastics / strong covalent bonds ***OR*** low volatility preventing good mixing with oxygen «gas» ***OR*** lack of/insufficient oxygen ***OR*** plastics are often parts of devices with non-combustible components «which mechanically prevent the combustion of plastic components» ***OR*** PVC already partly oxidized «because some C–H bonds are replaced with C–Cl bonds», so it cannot produce enough heat for complete combustion ***OR*** many industrial/household materials contain additives that reduce their flammability/act as flame retardants ✓		**1**

(continued)

(Question 6 continued)

Question			Answers	Notes	Total
6.	**c**	**ii**	weakly bound to PVC/no covalent bonds to PVC/only London/dispersion/ instantaneous induced dipole-induced dipole forces between DEHP and PVC ***AND*** leach/evaporate **«**from PVC**»** to atmosphere/food chain ***OR*** has low polarity/contains non-polar hydrocarbon chains ***AND*** fat-soluble/ deposits in the fatty tissues ***OR*** has unusual structural fragments/is a xenobiotic/difficult to metabolise ***AND*** stays in the body for a long time ✓		**1**
6.	**d**	**i**	$HO–CH_2–CH_2–CH_2–OH$ ***AND*** $HOOC–C_6H_4–COOH$ ✓	*Accept full or condensed structural formulas. Labelling of monomers not required but penalize incorrect labels.*	**1**
6.	**d**	**ii**	*Name of linkage:* ester ***AND*** *Name of inorganic product:* water ✓	*Do **not** accept "esterification".* *Do **not** accept formulas.*	**1**

7.	**a**		<table><tr><th>*Lyotropic LCs*</th><th></th><th>*Thermotropic LCs*</th></tr><tr><td>solutions</td><td>***AND***</td><td>pure substances</td></tr><tr><td>LC over certain <u>concentration</u> range</td><td>***AND***</td><td>LC over a <u>temperature</u> range **«**between solid and liquid phases**»**</td></tr></table> ✓ ✓	*Do **not** award any credit if one type only is described as the question asks how they differ.*	**2**

(continued)

Question			Answers	Notes	Total
8.	a	i	$2d\sin\theta$ ***OR*** 2|AB| / 2|BC| / |AB| + |BC| / |AB| ***AND*** |BC| ✓	*Vertical lines indicating lengths not required. Answer may be conveyed in words also. Do **not** accept |AC| – reference must be made to B.*	**1**
8.	a	ii	extra distance travelled/|AB| + |BC| = $n\lambda$/a whole number of wavelengths ✓	*Accept notations of extra distance as in (a)(i).*	**1**
8.	b	i	« $\frac{52.00\,\text{g mol}^{-1}}{17.28\times10^{-23}\,\text{g unit cell}^{-1}}$ =» 3.009×10^{23} «unit cells mol^{-1}» ✓		**1**
8.	b	ii	« $\frac{6.02\times10^{23}\,\text{atoms mol}^{-1}}{3.01\times10^{23}\,\text{unit cells mol}^{-1}}$ =» 2 «atoms per unit cell» ✓		**1**

9.	a		creation of a mirror image magnetic field of an external field «below the critical temperature/T_c of the superconductor» ***OR*** expulsion of a magnetic field from a superconductor «below its critical temperature/T_c» ✓		**1**
9.	b		*Type 1 superconductors* / ***AND*** / *Type 2 superconductors* sharp transitions to superconductivity / ***AND*** / more gradual transitions to superconductivity ***OR*** lower critical temperatures/T_c / ***AND*** / higher critical temperatures/T_c ✓	*Accept "Type 1: «most» metals **AND** Type 2: alloys/metal oxide ceramics/ perovskites".*	**1**

(continued)

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>10.</td><td>a</td><td></td><td>
One similarity:
both involve hydroxyl/•OH «radicals» ✓

One difference:
<table>
<tr><th>Fenton reaction mechanism</th><th></th><th>Haber-Weiss reaction mechanism</th></tr>
<tr><td>hydroxyl «radical»/•OH «concentration» dependent mechanism
OR</td><td>AND</td><td>hydroxyl «radical»/•OH «concentration» independent mechanism</td></tr>
<tr><td>Fe^{2+} is the catalyst
OR</td><td>AND</td><td>Fe^{3+} is the catalyst</td></tr>
<tr><td>Fe^{3+} is the intermediate
OR</td><td>AND</td><td>Fe^{2+} is the intermediate</td></tr>
<tr><td>$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + HO\bullet + OH^-$
and
$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HOO\bullet + H^+$

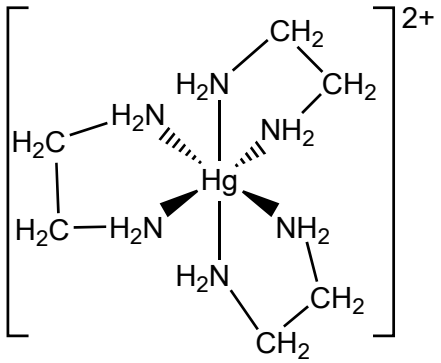
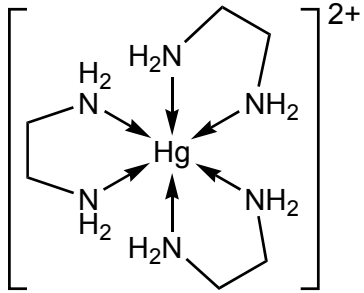
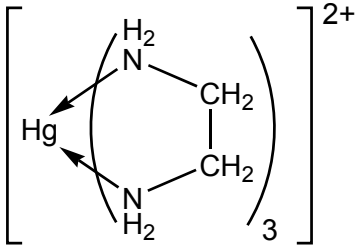
OR</td><td>AND</td><td>$Fe^{3+} + \bullet O_2^- \rightarrow Fe^{2+} + O_2$
and
$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + HO\bullet + OH^-$</td></tr>
<tr><td>$2H_2O_2 \rightarrow HO\bullet + HOO\bullet + H_2O$</td><td>AND</td><td>$H_2O_2 + \bullet O_2^- \rightarrow O_2 + \bullet OH + OH^-$</td></tr>
</table>
✓
</td><td>
Accept “hydroxy” for “hydroxyl”.

Do not penalize missing radical symbols if consistent throughout.

Accept “$H_2O_2 \rightarrow 2\bullet OH$” for the Fenton mechanism.
</td><td>2</td></tr>
</table>

(continued)

(Question 10 continued)

Question			Answers	Notes	Total
10.	**b**	**i**	molecules/ions/substances are attracted to/form «non-covalent» interactions with the surface of the adsorbent ✓		**1**
10.	**b**	**ii**	 2+ ***OR***  2+ ***OR***  2+ 3 ✓	*Do **not** penalize missing charge or square brackets.* *Bonds to Hg must be shown (in any format).*	**1**

Option B — Biochemistry

Question			Answers	Notes	Total
11.	**a**		*Name of the chemical link:* ester ***AND*** *Name of the other product:* water ✓	*Do **not** accept formulas.* *Do **not** accept "esterification".*	**1**
11.	**b**	**i**	coconut oil ***AND*** lowest **«**percentage of**»** unsaturated fatty acids ***OR*** coconut oil ***AND*** smallest number of C=C bonds ***OR*** coconut oil ***AND*** highest **«**percentage of**»** saturated fatty acids ✓	*Accept "fats" for "fatty acids".*	**1**
11.	**b**	**ii**	soybean oil ***AND*** highest **«**percentage of**»** polyunsaturated fatty acids ***OR*** soybean oil ***AND*** greatest number of C=C bonds ***OR*** soybean oil ***AND*** lowest **«**percentage of**»** saturated fatty acids ✓	*Accept "fats" for "fatty acids".*	**1**
11.	**b**	**iii**	*Beef fat:* **«**P/S $= \frac{3}{59}$ **=»** 0.05 ***AND*** *Soybean oil:* **«**P/S $= \frac{50 + 8}{14}$ **=»** 4.1 ✓		**1**
11.	**b**	**iv**	**«**higher proportion of**»** polyunsaturated fatty acids decrease risk of atherosclerosis/heart disease/cardiovascular disease/CVD ***OR*** **«**higher proportion of**»** polyunsaturated fatty acids which are less likely to be deposited on the walls of arteries **«**than saturated fatty acids**»** ✓	*Accept converse arguments.* *Accept correct arguments in terms of HDL and LDL but not in terms of "good" and "bad" cholesterol.* *Accept "fats" for "fatty acids".*	**1**

(continued)

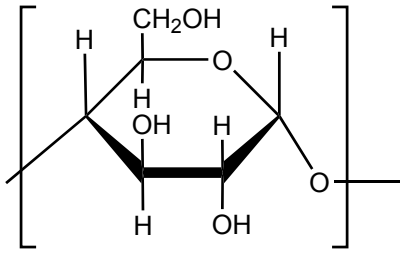
(Question 11 continued)

Question			Answers	Notes	Total
11.	**b**	**v**	*Any two of:* cotton seed oil has **«**a higher proportion of**»** longer chain/greater molar mass fatty acids ✓ molecules of cotton seed oil have greater surface area/higher electron density ✓ stronger London/dispersion/instantaneous induced dipole-induced dipole forces **«**between chains**»** in cotton seed oil ✓	*Accept converse arguments.* *Accept "molecules of cotton seed oil are packed more closely/have more regular structure" for M2.*	**2 max**

12.	**a**		CO_2 ***AND*** H_2O ***AND*** sun ✓	*Accept names.* *Accept "sunlight/light/photons" instead of "sun".*	**1**
12.	**b**	**i**	both have formula $C_x(H_2O)_y$ ***OR*** both contain several OH/hydroxyl **«**groups**»** ***AND*** a C=O/carbonyl **«**group**»** ✓	*Accept "both have formula $C_nH_{2n}O_n$/empirical formula CH_2O" but do **not** accept "both have same molecular formula/have formula $C_3H_6O_3$".* *Accept "hydroxy" but not "hydroxide/OH^-" for "hydroxyl".* *Accept "aldehyde or ketone" for "carbonyl".*	**1**

(continued)

(Question 12 continued)

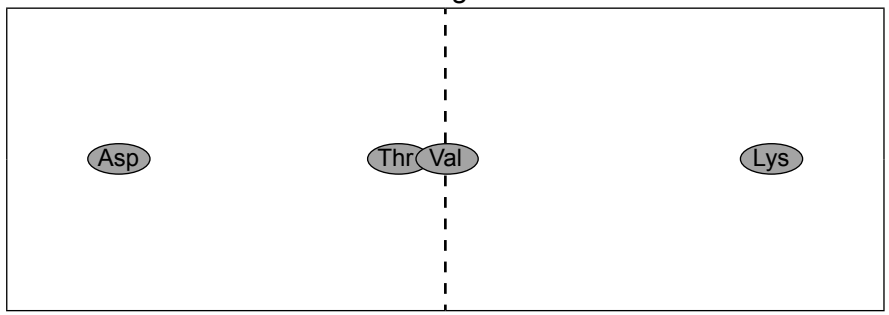
Question			Answers	Notes	Total
12.	**b**	**ii**	***X*** RCHO/CHO ***OR*** C=O/carbonyl «group with C» bonded to H ***OR*** formyl «group» ***OR*** C=O/carbonyl «group» at end of chain/at C–1 «atom» ***AND*** ***Y*** R_2CO/RCOR' ***OR*** carbonyl/C=O «group with C» bonded to two C/R «groups» ***OR*** C=O/carbonyl «group» in middle of chain/at C–2 «atom» ✓	*Accept "alkyl" for "R".* *Accept "**X**: aldose/aldehyde **AND** **Y**: ketose/ ketone".* *Accept "CO" for "C=O".*	**1**
12.	**c**	**i**	 continuation bonds ***AND*** open O on either but not both ends ✓	*Brackets are not necessary for the mark.* *Do **not** accept β-isomer.* *Mark may be awarded if a polymer is shown but with the repeating unit clearly identified.* *3D representation is **not** required.*	**1**

(continued)

(Question 12 continued)

Question			Answers	Notes	Total
12.	**c**	**ii**	*Advantage:* *Any one of:* biodegradable / break down naturally/by bacteria ✓ compostable ✓ does not contribute to land-fill ✓ renewable/sustainable resource ✓ starch grains swell ***AND*** help break up plastic ✓ lower greenhouse gas emissions ✓ uses less fossil fuels than traditional plastics ✓ less energy needed for production ✓ *Disadvantage:* *Any one of:* land use **«**affects biodiversity/loss of habitats**»** ✓ growing corn for plastics instead of food ✓ **«**starch**»** breakdown can increase acidity of soil/compost ✓ **«**starch**»** breakdown can produce methane **«**especially when buried**»** ✓ sensitive to moisture/bacteria/acidic foods ✓ **«**bioplastics sometimes**»** degrade quickly/before end of use ✓ cannot be reused ✓ poor mechanical strength ✓ eutrophication ✓ increased use of fertilizers/pesticides/phosphorus/nitrogen **«**has negative environmental effects**»** ✓	*Ignore any reference to cost.* *Do **not** accept just "decompose easily".* *Accept "prone to site explosions/ fires" or "low heat resistance" for disadvantage.* *Only award **[1 max]** if the same example is used for the advantage and disadvantage.*	**2 max**

(continued)

Question			Answers	Notes	Total
13.	**a**		2-amino-4-methylpentanoic acid ✓	*Accept "4-methyl-2-aminopentanoic acid".*	**1**
13.	**b**	**i**	Origin (+) Anode  (–) Cathode Lys on cathode side ***AND*** Asp on anode side ✓ Val at origin ***AND*** Thr on anode side but closer to origin than Asp ✓	*Val and Thr need not overlap.* *Accept any (reasonable) size and demarcation of position so long as position relative to origin is correct.* *Accept crosses for spots.* *Award **[1 max]** for any two correct.* *Award **[1 max]** if net direction of spots is reversed.* *Award **[1 max]** if the four points are in the correct order but not in a straight line.*	**2**
13.	**b**	**ii**	different sizes/molar masses/chain lengths **«**so move with different speeds**»** ✓		**1**
13.	**c**		**«**$-COOH \rightleftharpoons -COO^- + H^+$ $(-COOH = HA\ ;\ -COO^- = A^-)$**»** $pH = pK_a + \log \frac{[A^-]}{[HA]} / 3.0 = 4.0 + \log \frac{[-COO^-]}{[-COOH]} / -1.0 = \log \frac{[-COO^-]}{[-COOH]}$ ✓ $10^{-1} = \frac{[-COO^-]}{[-COOH]}$ ✓ **«**percentage ionized/$-COO^- = \frac{1}{1+10} \times 100$ **=»** 9.1 **«%»** ✓	*Award **[3]** for correct final answer.*	**3**

(continued)

Question			Answers	Notes	Total
14.	**a**	**i**	K_m *hexokinase:* approx. 1.7 **«**mmol dm^{-3}**»** ***AND*** K_m *glucokinase:* approx. 8.5 **«**mmol dm^{-3}**»** ✓	*Accept answers in the range 1.0-2.0 for hexokinase and 7.0-9.0 for glucokinase.*	**1**
14.	**a**	**ii**	glucokinase as it is not saturated **«**with substrate at normal concentration of blood glucose**»** ***OR*** glucokinase as its saturation increases with increased glucose concentration in the blood ✓	*Accept "at the normal levels of blood glucose concentration, relative velocity of glucokinase still dependent on concentration of glucose".*	**1**
14.	**b**	**i**	glucose-6-phosphate lowers enzyme activity/acts as enzyme inhibitor ✓		**1**
14.	**b**	**ii**	**«**inhibitor binds at**»** allosteric site ✓	*Accept "outside/away from active site".*	**1**
15.	**a**		phosphato/phosphate **«**group**»** ✓	*Do not accept "phosphoric acid", "phosphorus" or any formula.*	**1**
15.	**b**		mass spectrometry / X ray diffraction/crystallography / nuclear magnetic resonance **«**spectroscopy**»** ***OR*** bacteria able to grow in absence of phosphorus ***OR*** reproducible data ✓	*Accept abbreviations (eg, MS, NMR).* *Accept "elemental analysis" or "atomic absorption spectroscopy/ AA(S)".*	**1**
16.	**a**		**«**extensive**»** conjugation **«**of double bonds**»**/delocalization **«**of electrons**»** ***OR*** **«**many**»** alternating single/C–C ***AND*** double/multiple/C=C bonds ✓		**1**
16.	**b**		in aqueous solution ***AND*** hydroxyl/OH/ionic/oxonium/O^+ **«**groups**»** ✓	*Accept "polar/hydroxy" for "hydroxyl".* *Do **not** accept "OH^-/hydroxide/ oxygen".*	**1**

(continued)

(Question 16 continued)

Question			Answers	Notes	Total
16.	**c**		pH 2: **«**absorption peak 520 nm**»** red ***AND*** pH 11: **«**absorption peak 620 nm**»** blue ✓ complementary/opposite colour observed **«**to wavelength absorbed**»** ***OR*** pH 2: **«**absorption peak 520 nm**»** green absorbed ***AND*** pH 11: **«**absorption peak 620 nm**»** orange absorbed ✓	*Award **[1 max]** if colour absorbed and colour observed are correct for either at pH 2 or pH 11.*	**2**

Option C — Energy

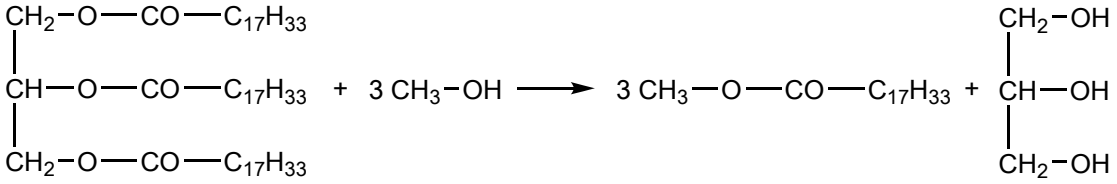
Question			Answers	Notes	Total
17.	**a**	**i**	«$\frac{1.58 \times 10^7\,\text{J}}{80.0\,\text{kg}} = \frac{15.8\,\text{MJ}}{80.0\,\text{kg}} =$» 1.98×10^{-1} «MJ kg^{-1}» ✓		**1**
17.	**a**	**ii**	gasoline releases more energy from a given mass of fuel ***OR*** gasoline has higher specific energy ✓	*Do not accept volume in place of mass as question refers to specific energy, not energy density.*	**1**
17.	**b**	**i**	«$\frac{15.8\,\text{MJ}}{34.3\,\text{MJ dm}^{-3}}$» $= 4.61 \times 10^{-1}$ «dm^3» ✓		**1**
17.	**b**	**ii**	«$4.61 \times 10^{-1}\,\text{dm}^3 \times 32.0\,\text{km dm}^{-3} \times 4$» $= 59.0/59.1$ «km» ✓		**1**

18.	**a**		«tends to» decrease with longer/larger/heavier alkanes ✓ «tends to» increase with bulkier/more branched alkanes ✓	*Accept "octane number decreases with the separation between branches" **OR** "increases with the more central position of branches".* *Accept converse argument.*	**2**
18.	**b**		$C_7H_{16} \rightarrow C_6H_5CH_3 + 4H_2$ ✓	*Accept "C_7H_8" for "$C_6H_5CH_3$".*	**1**

(continued)

Question			Answers	Notes	Total
19.	**a**		*Any two of:* $CO_2(g) \overset{H_2O(l)}{\rightleftharpoons} CO_2(aq)$ ✓ $CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ ***OR*** HCO_3^- and H^+ ions are formed **«**by dissolved CO_2**»** ✓ **«**increasing $[CO_2]$**»** shifts equilibrium to right/increases acidity/decreases pH ✓	*$H_2O(l)$ not required over equilibrium sign for M1.* *State symbols required in the equation in M1.* *Accept "H_2CO_3" at either side of the equilibrium in M2.* *Equilibrium sign required for M1 but **not** for M2.*	**2 max**
19.	**b**		bond length/C=O changes ***OR*** **«**asymmetric**»** stretching **«**of bonds**»** ***OR*** bond angle/OCO changes ✓ photon re-emitted in random direction ***OR*** polarity/dipole **«**moment**»** changes ***OR*** dipole **«**moment**»** created **«**when molecule absorbs IR**»** ✓	*Accept "bonds/atoms vibrate" for M1.* *Accept appropriate diagrams.*	**2**

(continued)

Question			Answers	Notes	Total
20.			 methyl ester formula ***AND*** glycerol formula ✓ correct balancing ✓	*Award M2 only if M1 correct.*	**2**

21.	**a**		*Negative electrode (anode):* $CH_3COO^-(aq) + 2H_2O(l) \rightarrow 2CO_2(g) + 7H^+(aq) + 8e^-$ ✓ *Positive electrode (cathode):* $O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$ ✓	*Accept equilibrium signs in equations.* *Award **[1 max]** if correct equations are given at wrong electrodes.*	**2**
21.	**b**	**i**	concentration cell has different concentrations of electrolyte **«**solutions**»** **«**but same electrodes and electrolytes**»** ***OR*** standard voltaic cell has different electrodes/electrolytes **«**but same concentration of electrolytes**»** ✓	*Accept "both half-cells in concentration cell made from same materials".*	**1**
21.	**b**	**ii**	**«**$E = 1.10 - \left(\frac{RT}{nF}\right)\ln\frac{\left[Zn^{2+}\right]}{\left[Cu^{2+}\right]} = 1.10 - \left(\frac{8.31 \times 298}{2 \times 96500}\right)\ln\frac{10^{-4}}{10^{-1}} = 1.10 + 0.0886 =$**»** (+) 1.19 **«**V**»** ✓	*3 significant figures needed for mark.*	**1**
21.	**b**	**iii**	more spontaneous because $E > E^{\ominus}_{cell}$ ✓		**1**

(continued)

(Question 21 continued)

Question			Answers	Notes	Total
21.	**c**	**i**	photon/«sun»light absorbed by the dye/photosensitizer/«transition» metal complex ***OR*** dye/photosensitizer/«transition» metal complex excited by photon/«sun»light ✓ electron«s» move«s» to conduction band ***OR*** electron«s» transferred to semiconductor/TiO_2 ✓		**2**
21.	**c**	**ii**	$I_3^- + 2e^- \rightarrow 3I^-$ «at cathode» ***OR*** triiodide ions/I_3^- reduced into/produce iodide ions/I^- «at cathode» ✓ iodide ions/I^- reduce dye/act as reducing agent ***AND*** oxidized into/produce triiodide ions/I_3^- ***OR*** $dye^+ + e^- \rightarrow$ dye ***AND*** $3I^- \rightarrow I_3^- + 2e^-$ ✓		**2**

22.	**a**	**i**	product has higher binding energy «per nucleon»/more stable ***OR*** nucleons in product more tightly bound «with one another» ✓ lighter elements «than Fe» can fuse/combine with loss of mass/mass defect «and release vast amount of energy» ✓	*Accept "mass converted into energy" for M2.*	**2**

(continued)

(Question 22 continued)

Question			Answers	Notes	Total
22.	**a**	**ii**	*Any one of:* deuterium/fuel is abundant/cheap ✓ **«**helium**»** products not radioactive ✓ fusion much less dangerous than fission ✓ large amounts/shipments of radioactive fuel not required ✓ far less radioactive waste **«**created by fast moving neutrons**»** has to be stored ✓	*Accept "reduces greenhouse gas emissions/global warming" **OR** "no radioactive waste" **OR** "more reliable power" **OR** "fewer safety issues".* *Do **not** accept "gives out a large amount of energy" as it is in the stem of the question.*	**1**
22.	**b**	**i**	**«**$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{0.693}{25.3 \text{ days}}$ **=»** $2.74 \times 10^{-2} \text{day}^{-1}$ ✓	*Need correct unit for mark.*	**1**
22.	**b**	**ii**	**«**4 half-lives; $1 \rightarrow \frac{1}{2} \rightarrow \frac{1}{4} \rightarrow \frac{1}{8} \rightarrow \frac{1}{16}$ **=»** $\frac{1}{16}$ / 6.25×10^{-2} ***OR*** **«**$\frac{N}{N_0} = e^{-\lambda t} = e^{-0.0274 \times 101.2}$**=»** 6.25×10^{-2} ✓	*Accept "6.25%".*	**1**
22.	**c**	**i**	octahedral ✓	*Accept "square bipyramidal".*	**1**
22.	**c**	**ii**	UO_2 strong bonding throughout crystal structure ✓ UF_6 molecular **«**covalent bonds between atoms**»** ***AND*** London/dispersion/ instantaneous induced dipole-induced dipole forces between molecules ✓	*Accept "UO_2 has ionic lattice".*	**2**

(continued)

Option D — Medicinal chemistry

Question			Answers	Notes	Total
23.	**a**	**i**	bond angles smaller/distorted ***OR*** instability resulting from abnormal bond angles ***OR*** bond angles **«**approximately**»** 90° instead of 109.5°/120° ✓	*Accept "109/110°" for "109.5°".*	**1**
23.	**a**	**ii**	asterisks (*) on all 3 lactam ring carbon atoms ✓	*Must mark all 3 carbon atoms.* *Ignore asterisks on the RHS carbon atoms of the five-membered ring.*	**1**
23.	**b**	**i**	beta-lactam/four-membered ring **«**in clavulanic acid**»** reacts with enzyme/ beta-lactamase ✓	*Accept "acts as enzyme inhibitor/suicide substrate/preferentially binds to enzyme".*	**1**
23.	**b**	**ii**	antibiotics not effective against viruses ***OR*** viruses have no cell wall/cell structure/target structures to attack ✓ increasing exposure of bacteria **«**to antibiotic**»** increases resistance ✓	*Accept "antibiotics kill beneficial bacteria" for M2.*	**2**

24.	**a**		**«**oral bioavailability is**»** low ***OR*** drug is broken down/pH is too low/unable to be absorbed from gut ***OR*** only a small proportion of the drug **«**taken by mouth**»** reaches the target organ ✓		**1**
24.	**b**		ethoxycarbonyl/carbonyl attached to oxygen ✓	*Accept "ester".*	**1**

(continued)

Question			Answers	Notes	Total
25.	a		***ALTERNATIVE 1:*** «theoretical yield = $\frac{1.552\,g}{138.13\,g\,mol^{-1}} \times 180.17\,g\,mol^{-1}$ =» 2.024 «g» ✓ «experimental yield = $\frac{1.124\,g}{2.024\,g} \times 100$ =» 55.53 «%» ✓ ***ALTERNATIVE 2:*** « $\frac{1.552\,g}{138.13\,g\,mol^{-1}}$ » = 0.01124 «mol salicylic acid/aspirin theoretical» ***AND*** « $\frac{1.124\,g}{180.17\,g\,mol^{-1}}$ » = 0.006239 «mol aspirin experimental» ✓ «experimental yield = $\frac{0.006239\,mol}{0.01124\,mol}$ x 100 =» 55.51 «%» ✓	*Accept answers in the range 55.4 % to 55.7 %.* *Award **[2]** for correct final answer.*	**2**
25.	b		low temperature gives greater difference between solubility of aspirin and impurities ***OR*** «product» crystallizes out from cold solution/«ice-cold water/lower temperature» speeds up crystallization process ***OR*** aspirin/product has low solubility «in water» at low temperatures ✓		**1**
25.	c		recrystallized melting point is higher ***OR*** recrystallized melting point is closer to pure substance/literature value ✓ smaller range of values ✓		**2**

(continued)

Question			Answers	Notes	Total
26.	**a**		«ranitidine» blocks/inhibits histamine binding to «H2» receptor ***OR*** ranitidine binds to same «H2» receptors «as histamine» ***OR*** competes with histamine for binding ✓		**1**
26.	**b**		proton pump ***OR*** H^+/K^+ ATPase enzyme ✓	*Accept "«secretary surface of» parietal cells".* *Do **not** accept "stomach/stomach wall".*	**1**
26.	**c**		*Any two of:* chiral molecule/auxiliary/optically active species is used/added/connected «to the starting molecule to force reaction to follow a certain path» ✓ chiral intermediate forms «only» one enantiomer ***OR*** auxiliary creates stereochemical condition «necessary to follow a certain pathway» / stereochemical induction ***OR*** existing chiral centre affects configuration of new chiral centres ✓ «after new chiral centre created» chiral auxiliary removed «to obtain desired product» ✓		**2 max**

(continued)

Question			Answers	Notes	Total
27.	**a**		*Similarity:* both contain **«**at least one**»** benzene/aromatic ring ***OR*** both contain amino **«**group**»** ✓ *Difference:* diamorphine has one benzene/aromatic ring ***AND*** methadone has two phenyl **«**groups**»** ***OR*** diamorphine has one vinylene/ethenylene/1,2-ethenediyl **«**group**»** ***AND*** methadone has no vinylene/ethenylene/1,2-ethenediyl **«**group**»** ***OR*** diamorphine has one ether **«**group**»** ***AND*** methadone has no ether **«**group**»** ***OR*** diamorphine has **«**two**»** ethanoate/acetate **«**groups**»** ***AND*** methadone has no ethanoate/acetate **«**group**»** ✓	*Accept "both contain carbonyl **«**groups**»**".* *Accept "amine" for "amino **«**group**»".* *Accept "phenyl" for "benzene ring" in M1 and M2 although there are no phenyl groups in diamorphine, as the benzene ring in this compound is a part of a polycyclic structure.* *Do **not** accept "arene" or "benzene" alone in M1 and M2.* *Accept "alkenyl/alkene" for "vinylene/ethenylene/1,2-ethenediyl" and "ester" for "ethanoate/acetate".* *Accept "methadone has a ketone/carbonyl **AND** diamorphine does not/has an ester/ethanoate/acetate".* *Accept "diamorphine is a heterocycle/heterocyclic compound **AND** methadone is not a heterocycle/heterocyclic compound".*	**2**
27.	**b**		feeling depressed/anxious/irritable ***OR*** craving for opioids/heroin ***OR*** experience fever/cold sweats/nausea/vomiting/insomnia/muscle pain/cramps/diarrhea/increased rate of respiration/increased heartbeat/lacrimation ✓	*Accept listed symptoms (eg, depression, anxiety, fever etc.).* *Some of the most common symptoms are listed here – there may be other valid ones.* *Accept "headaches".*	**1**

(continued)

Question			Answers	Notes	Total
28.	**a**	**i**	$^{98}_{42}\text{Mo} + {}^{1}_{0}\text{n} \rightarrow {}^{99}_{42}\text{Mo}$ ✓	*Accept $^{98}Mo + {}^{1}n/n \rightarrow {}^{99}Mo$.*	**1**
28.	**a**	**ii**	$^{99}_{42}\text{Mo} \rightarrow {}^{99\text{m}}_{43}\text{Tc} + {}^{0}_{-1}\beta$ ✓	*Accept "$^{0}_{-1}e$" for "$^{0}_{-1}\beta$".* *Accept "$^{99}Mo \rightarrow {}^{99m}Tc + \beta$".* *Accept "$^{0}_{-1}e/e^{-}/e$" for "β".* *Do not penalize "^{99}Tc" for "^{99m}Tc".*	**1**
28.	**b**		molybdenum-99 can be easily transported **«**before it decays**»**/more stable ***OR*** **«**most of**»** technetium-99m will decay during transportation ✓	*Do **not** accept just "short half-life of Tc-99m".*	**1**
28.	**c**		emits gamma rays ***OR*** emissions escape from body ***OR*** emissions detected by gamma camera ***OR*** radiation dose is low ✓ chemically reactive/versatile/transition metal bonds to a range of **«**biologically active**»** substances ✓	*Do **not** accept "short half-life of Tc-99m".* *Accept "energy of photons produced is **«**relatively**»** low" and "no high energy beta emission" for M1.* *Accept "… has ability to form tracers" for "…bonds to a range of **«**biologically active**»** substances".*	**2**
28.	**d**		low-level **«**radioactive**»** waste/LLW ***OR*** small amounts of ionizing radiation for short time ✓		**1**

(continued)

Question			Answers	Notes	Total
29.	**a**		improvements in technology/instrumentation/analytical techniques/precision of measurements ✓	*Accept "greater awareness/knowledge of the negative effects of the drugs".*	**1**
29.	**b**	**i**	**«**components have**»** different affinities for/partition between 2 phases/mobile and stationary phase ✓ move at different rates through instrument ***OR*** have different retention times ✓		**2**
29.	**b**	**ii**	nandrolone $M = 274$ **«**$g\,mol^{-1}$**»** ***OR*** testosterone $M = 288$ **«**$g\,mol^{-1}$**»** ✓ nandrolone identified because **«**molecular ion peak of**»** $m/z = 274$ ✓	*Accept non-integer molar masses, ie, 274.44* ***«****$g\,mol^{-1}$****»*** *and 288.47* ***«****$g\,mol^{-1}$****»****.* *Accept also "m/z = 275" for "m/z = 274" in M2.* *Accept "absence of peak with m/z = 288".*	**2**