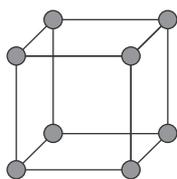


# Answers to examination questions in Chapters 22 to 25 (Options A to D)

## 22 Option A Materials

- 1 a Coordination number is six. [1]

Each unit cell has eight atoms. The corner atoms belong to eight unit cells, thus  $\frac{1}{8}$  of each corner atom belongs to the unit cell;  $\frac{1}{8} \times 1 = 1$ . [1]



b i 
$$a = \frac{n\lambda}{2 \sin \theta} = \frac{1 \times 154.05 \times 10^{-12} \text{ m}}{2 \sin(10.89^\circ)}$$
  

$$= 4.076 \times 10^{-10} \text{ m} = 4.076 \times 10^{-8} \text{ cm}$$
 [1]

ii Volume of unit cell =  $a^3 = (4.076 \times 10^{-10})^3$   
 $= 6.770 \times 10^{-29} \text{ m}^3 = 6.770 \times 10^{-23} \text{ cm}^3$  [1]

iii Number of unit cells present within  $1.000 \text{ cm}^3$   
of gold =  $\frac{1.000}{6.770 \times 10^{-23}} = 1.477 \times 10^{22}$  [1]

iv Number of gold atoms present within  $1.000 \text{ cm}^3$   
of gold =  $1.477 \times 10^{22} \times 4 = 5.908 \times 10^{22}$  [1]

c i Mass of one atom of gold =  $\frac{196.97 \text{ g mol}^{-1}}{6.02 \times 10^{23} \text{ mol}^{-1}}$   
 $= 3.27 \times 10^{-22} \text{ g}$  [1]

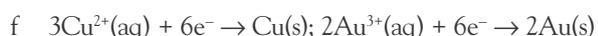
ii Mass of the unit cell of gold =  $3.27 \times 10^{-22} \text{ g} \times 4$   
 $= 1.31 \times 10^{-21} \text{ g}$  [1]

d Density of gold =  $1.470 \times 10^{22} \times 1.31 \times 10^{-21}$   
 $= 19.3 \text{ g cm}^{-3}$  [1]

- e i At low temperatures the positive ions (cations) in the lattice are attracted to a passing electron, distorting the lattice slightly. [1]

A second electron with opposite spin is attracted to this slightly positively charged deformation and a coupling of the electrons occurs (to form Cooper pairs). [1]

- ii Higher catalytic activity; higher stability; some nanocatalysts have charged sites that can help break bonds; increased selectivity. [2]



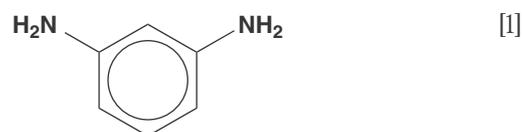
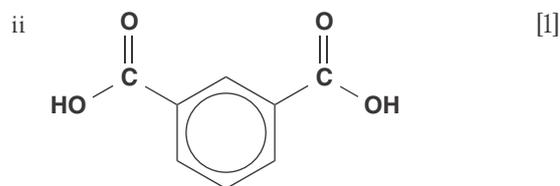
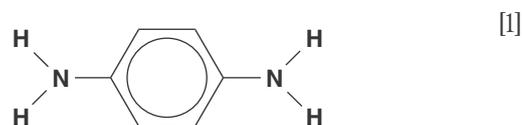
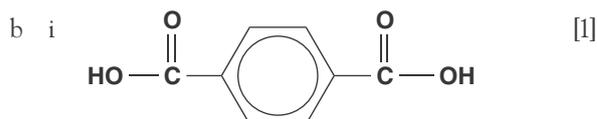
Amount of copper atoms =  $\frac{0.965 \text{ g}}{63.55 \text{ g mol}^{-1}}$   
 $= 0.015 \text{ mol}$

Amount of electrons =  $0.015 \times 2 = 0.030 \text{ mol}$   
(Faradays) [1]

Amount of gold atoms =  $\frac{0.03}{0.3} = 0.01 \text{ mol}$  [1]

Mass of gold atoms =  $0.01 \text{ mol} \times 196.67 \text{ g mol}^{-1}$   
 $= 1.96 \text{ g}$  [1]

- 2 a They contain benzene rings (containing delocalized pi electrons). [1]



- c Hydrogen bonding/hydrogen bonds. [1]

- d Nomex has a lower tensile strength than Kevlar because the chains cannot be aligned as closely for maximizing hydrogen bonding interactions between adjacent chains. [2]

- e The carbonyl groups become protonated (at the nitrogen atoms) due to the sulfuric acid acting as a proton donor; disrupting the hydrogen bonding. [1]

The sulfuric acid molecules then solvate the protonated chains. [1]

- f During addition polymerization, no atoms are lost. [1]

During condensation polymerizations atoms in the form of small molecules are lost. [1]

- g It is composed of long rigid and extended molecules. [1]

- h A composite material is a solid material which consist of a combination of two or more constituents [1], in which the individual components retain their separate identities. [1]

3 a [2]

Compound	Chromium(III) oxide	Cadmium sulfide
Electronegativity difference	1.70	0.90
Average electronegativity	2.55	2.15

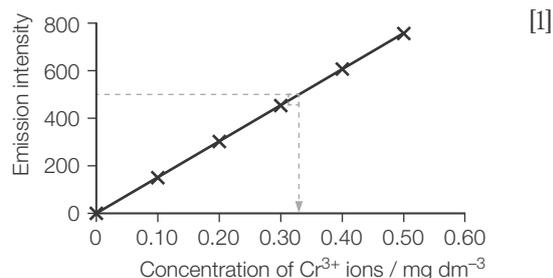
b [2]

Compound	Chromium(III) oxide	Cadmium sulfide
Bond type	Ionic	Polar covalent
%covalent character	15–20	60–58

- c i For example, 1000 cm<sup>3</sup> of the standard solution contains 5.00 mg of Cr<sup>3+</sup> ions, so 2.0 cm<sup>3</sup> contains  $\left(500 \times \frac{2.0}{1000}\right)$  mg = 0.010 mg of Cr<sup>3+</sup> ions; this was diluted in 100 cm<sup>3</sup> so the resulting solution had a concentration of 0.10 mg dm<sup>-3</sup>.

The other concentrations are 0.20, 0.30, 0.40 and 0.50 mg dm<sup>-3</sup>. [2]

ii



- iii The concentration is approximately 0.35 mg dm<sup>-3</sup>. [1]

- iv 1000 cm<sup>3</sup> of the waste water would contain  $\left(0.35 \times \frac{1000}{50}\right)$  mg = 7.0 mg of Cr<sup>3+</sup> (aq) ions; concentration = 7.0 mg dm<sup>-3</sup>. [1]

- d  $\text{Ag}_2\text{CrO}_4(\text{s}) \rightleftharpoons 2\text{Ag}^+(\text{aq}) + \text{CrO}_4^{2-}(\text{aq})$ , let  $x$  be the solubility of  $\text{Ag}_2\text{CrO}_4$  in mol dm<sup>-3</sup>  
 $[\text{Ag}^+(\text{aq})] = 2x \text{ mol dm}^{-3}$ ;  $[\text{CrO}_4^{2-}(\text{aq})] = x \text{ mol dm}^{-3}$  [1]  
 $K_{\text{sp}} = [\text{Ag}^+(\text{aq})]^2[\text{CrO}_4^{2-}(\text{aq})] = (2x)^2(x) = 4x^3$   
 $4x^3 = 4 \times 10^{-12}$ ;  $x = 1 \times 10^{-4} \text{ mol dm}^{-3}$  [1]

4 a i Sc: 1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>6</sup> 3s<sup>2</sup> 3p<sup>6</sup> 4s<sup>2</sup> 3d<sup>1</sup> [1]Sc<sup>3+</sup>: 1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>6</sup> 3s<sup>2</sup> 3p<sup>6</sup> [1]

- ii Scandium metal is paramagnetic because of the presence of an unpaired 3d electron. [1]

Scandium(III) compounds are diamagnetic because all the electrons are paired. [1]

iii [(Sc<sup>3+</sup>)<sub>3</sub> C<sub>82</sub><sup>9-</sup>] [1]

- b i Helium is an excellent coolant; and provides an inert and non-oxidizing environment. [1]

- ii Mixture of carbon containing compound and inert dilutant in gas/vapour phase [1] passed over a heated metal catalyst [1].

- iii The C<sub>82</sub> molecule has larger number of atoms and hence a greater number of polarizable electrons available for temporary dipole formation and hence stronger London (dispersion) forces. [2]

c i All sp<sup>2</sup> [1]

- ii There is a poor delocalization of pi electrons within the C<sub>60</sub> molecules because of the curved surface reducing p orbital overlap; these electrons are unable to transfer between adjacent C<sub>60</sub> molecules (high energy band). [1]

There is excellent delocalization of pi electrons within the flat graphene sheet and these electrons readily move when a voltage is applied. [1]

d The particles may be toxic/hazardous/carcinogenic. [1]

The human immune system may not mount a defence against nanoparticles. [1]

e i Silicon and oxygen. [1]

ii  $\text{Sc}_2\text{O}_3(\text{s}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{Sc}(\text{s}) + 3\text{H}_2\text{O}(\text{l})$  [1]

$2\text{Sc}_2\text{O}_3(\text{s}) + 3\text{C}(\text{s}) \rightarrow 2\text{Sc}(\text{s}) + 3\text{CO}_2(\text{g})$  [1]

- iii Higher tensile strength/greater corrosion resistance/ to achieve properties not present in pure metals/alter properties, for example, melting point and malleability. [2]

## 23 Option B Biochemistry

1  $M_r$  of glucose = 180.18 g mol<sup>-1</sup>

Number of moles of glucose per day =  $\frac{135}{180.18}$   
 = 0.75 mol [1]

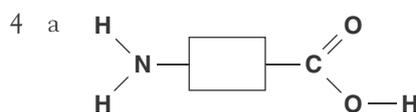
 $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$ 

From equation for respiration: 1 mol of glucose produces 6 mol of carbon dioxide  
 0.75 mol glucose → 4.5 mol CO<sub>2</sub> [1]

Mass of CO<sub>2</sub> = 4.5 × 44.01 = 198.05 g [1]

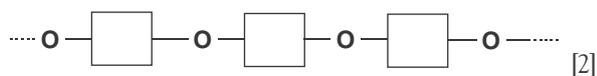
2 Anabolic pathways are metabolic pathways in which compounds are broken down [1], whereas catabolic pathways involve the synthesis of molecules [1].

3 Hydrolysis is the breaking of covalent bonds by a reaction involving the addition of water (H- and -OH) to the breakdown products [1]; in condensation reactions molecules are joined together with the elimination of water as the bonds are made [1].

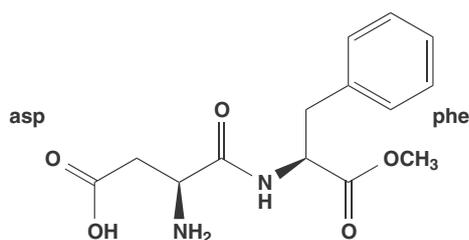


Draw this molecule and a similar one with the box shaded to match one of the examples in the question. [2]

b



- 5 The structure of aspartame is shown here – made up of aspartic acid (asp) as the N terminus of the dipeptide, and phenylalanine (phe) as the C terminus. Note the peptide link in the centre and the fact that the  $-\text{COOH}$  of the phenylalanine has been esterified with methanol (the  $-\text{CH}_3$  group on the right). [3]



- 6 a i The amino acids will be in the zwitterion form [1]; but one will have an extra positive charge on the amino group in the side-chain, while another will have an extra negative charge on the R-group because of the ionization of the extra acid group [1].
- Sketch a diagram showing three spots: one will remain at the centre (Val), one will have moved to the right because of the extra negative charge (Asp), and one will have moved to the left because of the extra positive charge (Lys) [1].
- ii At pH 12 two of the amino acids will move together to the right because they have a single negative charge on them (Val and Lys) [1]; the other amino acid (Asp) will move further to the right as it has a double negative charge [1].
- b Amino acids such as valine and isoleucine are non-polar and hydrophobic – the protein will tend to fold so that these amino acids are internal to the structure and away from exposure to water [1]. Amino acids such as glutamic acid and lysine have charged groups in their R-groups, capable of participating in ionic interactions and hydrogen bonding [1] – these will tend to be on the outer ‘surface’ of the protein structure where they can interact with water (they are hydrophilic) [1].
- 7 a The retention factor is the ratio of the distance moved by the sample to the solvent front. [1]
- b 0.4 and 0.7 [1]
- c 0.4, 0.5 and 0.8 [1]
- d Arg, His, Asn, Cys, Pro, Thr, Gly, Glu, Asp, Met, Leu [2]
- e Electrophoresis (or isoelectric focusing, or ion exchange chromatography) [1]
- 8 a See Figures 23.68 and 23.84 for comparison; note that in a triglyceride all three ester links to the central glycerol molecule are taken by long-chain fatty acid molecules whereas in a phospholipid a phosphate group is present. [3]
- b i In a saturated fat all the long-chain fatty acids contain saturated hydrocarbon chains – there are no  $\text{C}=\text{C}$  double bonds; in an unsaturated fat at least one of the long-chain fatty acids has a hydrocarbon chain containing at least one  $\text{C}=\text{C}$  double bond. [1]
- ii A mono-unsaturated fat contains hydrocarbon chains with one  $\text{C}=\text{C}$  double bond. [1]
- iii *Cis-trans* isomerism; octadec-*cis*-9-enoic acid [2]
- 9 a Unsaturated fats in the fish oil /  $\text{C}=\text{C}$  double bonds in the long hydrocarbon chains. [1]
- b Rancid (resulting from oxidative rancidity) [1]
- c Light promotes the formation of oxygen free radicals. [1]
- d The curcumin molecule contains a number of  $\text{C}=\text{C}$  double bonds that absorb the free radicals, acting as an alternative target. [1]
- 10 a The structure contains groups such as  $-\text{NH}_2$ , which can form hydrogen bonds with water molecules; and also carboxylic acid groups ( $-\text{COOH}$ ) which can hydrogen bond and also ionize. [1]
- b i Night-blindness / xerophthalmia (a cause of blindness) [1]
- ii Vitamin A is fat-soluble, and if the intake of fat in the diet is insufficient the vitamin A from the livers cannot be absorbed and used by the body. [1]
- 11 a Atom economy
- $$= \left( \frac{\text{total mass of desired product formed}}{\text{total mass of all products}} \right) \times 100 \quad [1]$$
- Method 1: atom economy =  $\left( \frac{120.16}{620.49} \right) \times 100 = 19.4\%$  [1]
- Method 2: atom economy =  $\left( \frac{120.16}{138.18} \right) \times 100 = 86.8\%$  [1]
- b Consider: the use of highly corrosive chemicals such as sulfuric acid or the ease of availability of any catalyst. [2]
- 12 a  $\text{pK}_a$  glycine = 2.34
- $$\text{pH} = \text{pK}_a + \log_{10} \left( \frac{[\text{base}]}{[\text{acid}]} \right) = 2.34 + \log_{10} \left( \frac{0.20}{0.12} \right)$$
- $$\text{pH} = 2.34 + 0.22 = 2.56 \quad [3]$$
- b  $\text{pH} = \text{pK}_a + \log_{10} \left( \frac{[\text{base}]}{[\text{acid}]} \right) = 2.34 + \log_{10} \left( \frac{0.20}{0.121} \right)$

$$\text{pH} = 2.34 + 0.218 = 2.56 \quad [2]$$

$$\text{c } \text{pH} = \text{p}K_{\text{a}} + \log_{10} \left( \frac{[\text{base}]}{[\text{acid}]} \right) = 2.34 + \log_{10} \left( \frac{0.21}{0.12} \right)$$

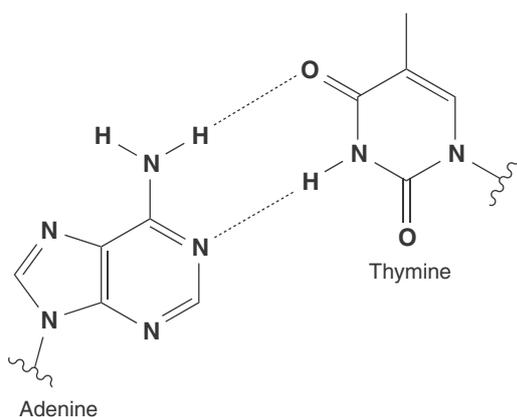
$$\text{pH} = 2.34 + 0.243 = 2.58 \quad [1]$$

13 a The position of the phosphate groups on the inside of the structure would have led to the chains repelling each other [1] as under cellular conditions the phosphate groups would carry negative charges. [1]

b The hydrogen bonds between the nitrogenous bases in the two chains break so that the chains can part. [1]

14 a Thymine is linked to a hydroxyl group of the sugar, deoxyribose which in turn has a phosphate group attached to another hydroxyl group; a nucleotide consists of a base-sugar-phosphate grouping. [2]

b Thymine is able to hydrogen bond to the base, adenine, in the other chain of the DNA double helix / there is specific recognition, or base pairing, as the AT pairing involves two hydrogen bonds (the alternative pairing GC involves three hydrogen bonds). [3]



c The sequence of the four bases along a strand of DNA provides the message coding for the synthesis of a specific amino acid sequence in a protein chain; each amino acid is coded for by a triplet code of bases; some amino acids have more than one triplet code but there is no ambiguity. [2]

d Restriction enzymes are able to break DNA at very specific places (sequences) and therefore they give rise to very specific fragmentation patterns that are characteristic of an individual's DNA/ the fragmentation patterns can be analysed by gel electrophoresis. [2]

15 a White light is a mixture of colours of varying wavelength / anthocyanin colours the berries blue by absorbing light in the red to green regions of the spectrum thus allowing just the blue region of the spectrum to be seen. [2]

b Low pH and low temperature. [1]

16 a Place an asterisk on the carbon atom at the bottom of the ring structure – see Figure 20.71 in text book. [1]

b The isomers (enantiomers) are optically active / the (+)-form will rotate the plane of plane-polarised light to the right; the (–)-form to the left. [1]

c The R/S convention is based on the priority rules (CIP rules) of Cahn, Ingold and Prelog – see Figure 20.68 – where substituent groups are assigned a priority based on complexity; the structure shown is R-(+)-limonene. [2]

17 a i  $\text{C}_{20}\text{H}_{28}\text{O}$  [1]

ii Add the following to end of the molecule: the aldehyde group –CHO is converted to a primary alcohol grouping –CH<sub>2</sub>OH



iii A C=C double bond. [1]

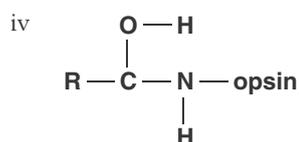
iv Heat [1] alcohol with sodium dichromate(IV) / concentrated sulfuric acid [1] in distillation apparatus so that the aldehyde distils over as soon as formed [1]; use an excess of the alcohol to the oxidising agent [1].

v 5 mol [1]

b i See the structure on the left in Figure 23.264. [1]

ii Primary amine group (–NH<sub>2</sub>) – see Figure 23.267 [1]

iii Condensation reaction [1]



## 24 Option C Energy

1 [3]

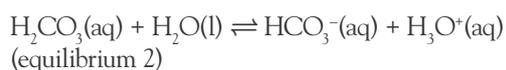
	Advantages	Disadvantages
<b>Coal fires in homes</b>	Coal is widely available and easily stored <i>in situ</i>	Health problems arising from particulate emissions  Very inefficient – lots of heat goes up chimney
<b>Coal for electricity generation</b>	Coal has fewer other uses (i.e. oil can be used for manufacturing plastics, rather than as fuel)  Less pollution in populated areas – easier to process emissions in large scale plants  More efficient way of extracting maximum energy from coal	Emission of CO <sub>2</sub> (greenhouse gas)  Emission of SO <sub>2</sub> (from sulfur impurities; acid rain)  Electricity infrastructure is required – not always available in poorer countries

- 2 a  $47.6 \text{ MJ kg}^{-1}$  [2]  
 b  $476\,500 \text{ MJ}$  ( $4.76 \times 10^{12} \text{ J}$ ) [2]
- 3 a  $10\text{C(s)} + 11\text{H}_2\text{(g)} \rightarrow \text{C}_{10}\text{H}_{22}\text{(l)}$  [2]  
 b  $21\text{H}_2\text{(g)} + 10\text{CO(g)} \rightarrow \text{C}_{10}\text{H}_{22}\text{(l)} + 10\text{H}_2\text{O(l)}$  [3]
- 4 a  $^{235}_{92}\text{U} + ^1_0\text{n} \rightarrow ^{137}_{54}\text{Xe} + ^{99}_{38}\text{Sr}$ ; Strontium-99 [2]  
 b  $^{137}_{54}\text{Xe} \rightarrow ^0_{-1}\beta + ^{137}_{55}\text{Cs}$ ;  $^{137}_{55}\text{Cs} \rightarrow ^0_{-1}\beta + ^{137}_{56}\text{Ba}$  [2]  
 c 1.6% [2]  
 d High solubility makes it likely to enter ground water; solubility means it is likely to be taken up by organisms (plants and animals). [2]
- 5 a Alpha – beta – beta – alpha – alpha [5]  
 b 3715 years [2]  
 c Gases are likely to be breathed in. Alpha sources have a very short range in air but are very dangerous if they enter the body. [2]
- 6 a Advantages: (i) lower net greenhouse emissions than fossil fuels (as the plants absorb  $\text{CO}_2$  when they grow); use of biofuels preserves fossil fuel reserves for other uses (e.g. plastics manufacture); existing infrastructure and car designs can be used with minimal modification.  
 Disadvantages: production of biofuels is energy intensive (high embodied energy); commercial production of biofuels impacts on biodiversity; commercial production of biofuels might displace necessary food production. [4]  
 b [3]

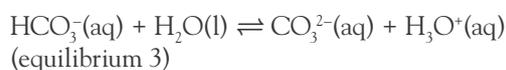
	Advantages	Disadvantages
<b>Ethanol</b>	Easily mixed with gasoline and usable in engines without modification	Lower specific energy Absorbs moisture so might damage engines
<b>Palm oil biodiesel</b>	Higher specific energy	Requires processing (transesterification) to lower viscosity

- c Vegetable oils are too viscous (especially at lower temperatures) so they need pre-warming or additional processing (transesterification) to make them usable. [2]  
 d Transesterification involves reacting the triglyceride (oil) with methanol or ethanol, producing three molecules of methyl or ethyl esters and glycerol. This mixture has a similar energy density to the original oil but lower viscosity and lower boiling point. [2]  
 e  $(\text{C}_{17}\text{H}_{33}\text{COO})_3\text{CH}(\text{CH}_2)_2 + 3\text{CH}_3\text{OH} \rightleftharpoons 3\text{C}_{17}\text{H}_{33}\text{COOCH}_3 + \text{CH}_2\text{OHCHOHCH}_2\text{OH}$  [2]
- 7 As carbon dioxide dissolves in the oceans it forms carbonic acid,  $\text{H}_2\text{CO}_3$ ,  
 $\text{CO}_2\text{(aq)} + \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_2\text{CO}_3\text{(aq)}$  (equilibrium 1)

Carbonic acid is a weak diprotic acid, which dissociates to form first hydrogen carbonate ions ( $\text{HCO}_3^-$ )



The hydrogen carbonate ion then dissociates (to a smaller extent) to form carbonate ions ( $\text{CO}_3^{2-}$ )



Both these reactions generate  $\text{H}_3\text{O}^+$ . The solution becomes more acidic and the pH falls.

An increase in the concentration of dissolved carbon dioxide will lead to an increased concentration of carbonic acid in equilibrium (1). Increasing the concentration of carbonic acid in equilibrium (2) leads to a shift to the right and therefore more hydrogen carbonate and oxonium ( $\text{H}_3\text{O}^+$ ) ions. More hydrogen carbonate ions in equilibrium (3) causes a shift towards more oxonium ions again.

Increased carbon dioxide concentrations in the atmosphere will lead to more carbon dioxide in the oceans and an increase in the oceans' acidity. This may kill sea creatures with calcium carbonate shells, an effect which will then move through the entire food chain. In addition, the larvae or eggs of sea creatures may be unable to survive.

A further effect may be the loss of coral. As the pH of the ocean falls, the loss of calcium carbonate may occur more quickly than the corals can replace. [5]

- 8 a Visible light, (near) infrared, (near) ultraviolet [3]  
 b This radiation is absorbed by the Earth's surface, warming it. The surface emits infrared radiation which warms the atmosphere. [2]  
 c Infrared radiation is absorbed by carbon dioxide as its frequencies match the vibrational frequencies of the molecule. The molecules then re-radiate infrared, with some of it radiated downwards towards the surface. [3]  
 d GWP is a factor which combines the abundance of a gas in the atmosphere, their ability to absorb radiation, and their lifetime in the atmosphere before chemical processes remove them. [4]  
 e Methane has much lower abundance than carbon dioxide, but it absorbs infrared much more efficiently. [2]  
 f Outcomes might include: ocean acidification, drought, flooding, sea-level rise, glacier retreat, changing patterns of agriculture. [4]
- 9 a i The platinum catalyst on the anode splits the hydrogen molecules into hydrogen ions and electrons. The platinum on the cathode catalyses the reaction of oxygen gas and water forming hydroxide ions.

- ii The electrolyte completes the electrical circuit. The sodium hydroxide electrolyte reacts with the hydrogen ions carrying out a neutralisation reaction forming water. [4]
- b The polymer membrane allows the use of much less platinum. The polymer membrane has a lower resistance than the liquid electrolyte. [1]
- c Anode:  $\text{H}_2(\text{g}) \rightarrow 2\text{H}^+(\text{aq}) + 2\text{e}^-$  (oxidation) – negative terminal  
Cathode:  $\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$  (reduction) – positive terminal [4]
- d Hydrogen is not readily available (it must be extracted, for example, from seawater). Hydrogen is a gas and must be stored under pressure. [1]
- 10 a A secondary cell is a voltaic cell in which the cell reaction can be reversed by passing a current through it. [1]
- b [4]

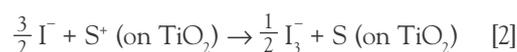
	Nature of electrolyte	Charge carrier
Lithium-ion battery	Polymer film	Lithium ion
Nickel–cadmium battery	Potassium hydroxide paste	Hydroxide ion

- c Lithium-ion battery half-equations:  
Anode:  $2\text{Li}(\text{graphite}) \rightarrow 2\text{Li}^+(\text{electrolyte}) + 2\text{e}^-$   
Cathode:  $2\text{CoO}_2(\text{s}) + 2\text{e}^- + 2\text{Li}^+(\text{electrolyte}) \rightarrow \text{Co}_2\text{O}_3(\text{s}) + \text{Li}_2\text{O}(\text{s})$   
Nickel–cadmium battery half-equations:  
Anode:  $\text{Cd}(\text{s}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Cd}(\text{OH})_2(\text{s}) + 2\text{e}^-$   
Cathode:  $2\text{Ni}(\text{OH})_3(\text{s}) + 2\text{e}^- \rightarrow 2\text{Ni}(\text{OH})_2(\text{s}) + 2\text{OH}^-(\text{aq})$  [8]
- d Lithium-ion battery advantages: High energy density – lithium-ion batteries are light and powerful; Minimal memory effect – lithium-ion batteries are more tolerant of incomplete charge–discharge cycles.  
Nickel–cadmium battery advantages: High number of charge–discharge cycles possible (thousands); Long storage time – can retain a charge ‘on the shelf’ for months. [4]
- 11 a Methanol has higher energy density than hydrogen; methanol is a liquid and is more easily stored. [2]
- b i –2 [1]  
ii +4 [1]  
iii  $\text{CH}_3\text{OH}(\text{l}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{CO}_2(\text{g}) + 6\text{H}^+(\text{aq}) + 6\text{e}^-$  [2]  
iv  $\text{O}_2(\text{g}) + 2\text{e}^- + 2\text{H}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$  [2]
- c Carbon in ethanol: –2;  $\text{CH}_3\text{CH}_2\text{OH}(\text{l}) + 3\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{CO}_2(\text{g}) + 12\text{H}^+(\text{aq}) + 12\text{e}^-$  [3]

- 12 a  $\Delta G = -872 \text{ kJ mol}^{-1}$ ;  $\Delta H = -874 \text{ kJ mol}^{-1}$ ; efficiency = 99.8%. [2]
- b They produce useful energy from a waste product; they help to clean up waste water by removing organic pollutants; they decrease the demand for expensive catalysts such as platinum. [2]
- 13 a i Fission; 0.18614 amu; 169.2 MeV  
ii Fusion; 0.01894 amu; 17.6 MeV  
iii Fission;  $5.14 \times 10^{-3}$  amu; 4.79 MeV  
iv Fission; 0.22194 amu; 206.7 MeV [12]
- b  $1.673 \times 10^{10} \text{ kJ mol}^{-1}$ ; very high value (a million times larger than a typical enthalpy of combustion of a fuel). [3]
- 14 a The graph has a very steep upwards curve, levelling off to Fe (mass = 56) and then a shallow slope across to heavy transuranic elements (250+ amu). [3]
- b The binding energy depends on the difference between two forces: the strong nuclear force and the electrostatic repulsion within the nucleus. For light elements (up to around  $^{16}\text{O}$ ) the increase in nuclear size causes a large increase in the strong nuclear force, but a relatively small increase in the electrostatic repulsion of the protons within the nucleus. During the approximately horizontal portion of the graph the increase in strong nuclear force is balanced by the increase in the electrostatic repulsion. For the heavier elements (beyond  $^{56}\text{Fe}$ ) the increase in electrostatic repulsion exceeds the increase in the strong nuclear force. [3]
- c For small elements undergoing fusion, the binding energy of the fusion product (in this case, helium) is greater than the binding energy of the hydrogen nuclei, so there is an energy output during fusion. [2]
- d For heavier elements, the total binding energy of the smaller nuclei produced during fission (barium and krypton) is greater than the binding energy of the uranium nucleus which undergoes fission. [2]
- 15 a Naturally occurring uranium contains insufficient fissionable nuclei to sustain a chain reaction. [1]
- b i  $\text{UO}_2 + 4\text{HF} \rightarrow \text{UF}_4 + 2\text{H}_2\text{O}$ ; neutralization reaction [3]  
ii  $\text{UF}_4 + \text{F}_2 \rightarrow \text{UF}_6$ ; oxidation reaction [3]  
iii Enrichment by effusion or centrifugation relies on the uranium compound being in the gas state.  $\text{UF}_6$  is a gas whereas  $\text{UO}_2$  is a solid. [2]
- c i  $1.004$  ( $^{235}\text{UF}_6$  effuses at 1.004 times the rate of  $^{238}\text{UF}_6$ ) [2]  
ii  $0.7 \times (1.004)^x = 90$ ; 1217 stages [2]  
iii  $0.7 \times (1.3)^x = 90$ ; 19 stages [1]

- 16 a  $\text{H}_2\text{O} + \text{HO}^\bullet \rightarrow \text{HO}^\bullet + \text{H}_2\text{O}$  [1]
- b i  $\text{H}^\bullet + \text{O}_2 \rightarrow \text{HOO}^\bullet$  [2]
- ii  $\text{H}-\ddot{\text{O}}-\ddot{\text{O}}^\bullet$  [1]
- c  $\ddot{\text{O}}:\ddot{\text{O}}^\bullet$  [1]
- d Radicals can collide and react with DNA molecules causing mutations. [2]
- 17 a i Neptunium-237 [1]
- ii Use  $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$
- $$\lambda = \frac{0.693}{432} = 1.605 \times 10^{-3} \text{ y}^{-1};$$
- Use  $N = N_0 e^{-\lambda t}$
- $$N_0 = 0.29 \mu\text{g}; t = 20 \text{ y}; N = 0.28 \mu\text{g}$$
- [3]
- b i  $\lambda = \frac{0.693}{23400 \text{ y}} = 2.962 \times 10^{-5} \text{ y}^{-1}$  [2]
- ii Use  $t_{\frac{1}{2}} = t \frac{\ln 2}{\ln\left(\frac{N_0}{N}\right)}$
- $$\frac{N_0}{N} = \left(\frac{1 \text{ g}}{1 \text{ mg}}\right) = 0.001;$$
- $$t = 23400 \times \left(\frac{\ln(1000)}{\ln 2}\right) = 233200 \text{ y}$$
- [2]
- c i Praseodymium-144 [1]
- ii Use  $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$
- $$\lambda = \frac{0.693}{285} = 2.432 \times 10^{-3} \text{ d}^{-1}$$
- Use  $\frac{N}{N_0} = e^{-\lambda t}$
- $$\frac{N}{N_0} = e^{-2.432 \times 10^{-3} \times 84} = 0.82$$
- 81% of the cerium remains untransmuted so 19% has transmuted. [2]
- 18 a A conjugated series of double and single bonds. [1]
- b i The titanium dioxide is a semi-conductor that transfers electrons from the dye to the external circuit. [1]
- ii To maximise the area of the dye exposed to light. [2]
- c i The iodide / triiodide electrolyte gains an electron (which has come from oxidation of the dye):
- $$\frac{1}{2} \text{I}_3^- + e^- \rightarrow \frac{3}{2} \text{I}^-$$
- [2]

- ii The dye (S) is reduced by electrons from the iodide ions:



- d A homemade DSSC is likely to use finely divided  $\text{TiO}_2$  powder. The best DSSCs use  $\text{TiO}_2$  nanoparticles which have a much larger surface area for dyes and more pathways for electron flow.

A homemade DSSC uses fruit juice or plant dyes to absorb light. The best DSSCs use specially-designed dyes which optimise the absorption of light. [3]

## 25 Option D Medicinal chemistry

- 1 a An antibiotic is a synthetic or semi-synthetic substance that kills bacteria. [1]
- b Prevents deactivation by stomach acid/more resistant to stomach acid. [1]
- Prevents deactivation by the enzyme penicillinase (produced by bacteria) increases resistance/tolerance to penicillinase. [1]
- c Broad spectrum – effective against many types/strains of bacteria; narrow spectrum – effective only for certain type of bacteria. [1]
- d Penicillin interferes with the cell wall formation. [1]
- Cells can expand/burst/disintegrate/bacteria die. [1]
- e Makes penicillin less effective; destroys useful/beneficial bacteria; allows resistant population to build up. [1]
- f Failure to complete a course of antibiotics favours the selection of antibiotic-resistant bacteria. [1]
- g The strain within the four-membered ring structure increases the reactivity of the amide. [1]
- The ring structure opens so that the penicillin becomes covalently bonded to the enzyme [1] that synthesizes the bacterial cell walls (blocking its action). [1]
- h Pharmaceuticals, for example, penicillins and cephalosporins; analgesics, for example, codeine; anticonvulsants; beta-blockers, X-ray media and chemotherapy drugs and anabolic steroids. [3]
- 2 a Esterification or condensation. [1]
- b *Difference:* aspirin shows two strong peaks in the carbonyl ( $>\text{C}=\text{O}$ ) stretching region ( $1700\text{--}1800 \text{ cm}^{-1}$ ) since it has two carbonyl groups; the higher frequency peak at about  $1750 \text{ cm}^{-1}$  can be assigned to the acetyl ( $-\text{O}-(\text{C}=\text{O})-\text{CH}_3$ ) group. [1]
- Similarity:* A strong peak near  $1700 \text{ cm}^{-1}$  due to the stretching of the  $>\text{C}=\text{O}$  bond of the carboxylic

- acid group; peaks near  $1605\text{ cm}^{-1}$  due to a skeletal vibration of the benzene ring; both have strong peaks from  $1050\text{--}1410\text{ cm}^{-1}$  for C–O in alcohol/phenol; both have broad peaks (because of hydrogen bonding) from  $2500\text{--}3000\text{ cm}^{-1}$  for –OH in carboxylic acid. [1]
- c Three peaks in a ratio of 4:3:1. [1]  
All singlets. [1]
- d Reaction with potassium hydroxide produces an ionic salt:  

$$\text{C}_6\text{H}_4(\text{OH})(\text{COOH}) + \text{KOH} \rightarrow \text{C}_6\text{H}_4(\text{OH})(\text{COOK}) + \text{H}_2\text{O}$$
 [1]  
 Increases aqueous solubility for transport/uptake. [1]  
 Higher proportion of drug/dosage reaches target region/cells. [1]
- e Any one of the following beneficial effects: used to treat mini-strokes; prevents heart attacks / reduces risk of heart attack / thins the blood / anticoagulant; relieves symptoms of rheumatologic diseases / anti-inflammatory; reduces fever. [1]  
 Any one of the following side effects: stomach bleeding; allergic reaction; Reye's syndrome; hearing loss; tinnitus (ringing in the ears); gastrointestinal irritation (e.g. heartburn, nausea). [1]
- f Prostaglandins are involved in the transmission of pain impulses to the brain; when the enzyme controlled production of prostaglandins is suppressed, the pain impulses are reduced or do not reach the brain. [1]
- 3 a Mild analgesics intercept pain at the source/interfere with the production of substances that cause pain. [1]  
 Strong analgesics bond to receptor sites in the brain/prevent the transmission of pain impulses. [1]
- b Amide [1]  
 Tertiary (amine) [1]
- c –OH/alcohol/phenol/hydroxyl [1]  
 Esterification/condensation [1]  
 Water/ $\text{H}_2\text{O}$  [1]
- d i Ether/alkene (carbon–carbon double bond); (tertiary) amine [2]  
 ii *Main effect*: relief from strong pain. [1]  
*Side effect*: constipation. [1]
- e i  $\text{LD}_{50}$  is the drug dosage that kills half the population of test animals. [1]  
 ii Heroin [1]
- f  $\text{TD}_{50}$  is the dose at which toxicity occurs in 50% of humans in a test sample of a drug. [1]
- The  $\text{ED}_{50}$  of a drug is the dose required to produce the desired effect in 50% of test animals or patients. [1]
- g The ionic salt structure increases the drugs solubility in water due to the formation of strong ion–dipole interactions and therefore increase the drugs distribution in the body. [2]
- 4 a  $\text{Mg}(\text{OH})_2 + 2\text{HCl} \rightarrow \text{MgCl}_2 + 2\text{H}_2\text{O}$   
 $\text{Al}(\text{OH})_3 + 3\text{HCl} \rightarrow \text{AlCl}_3 + 3\text{H}_2\text{O}$  [2]
- b Aluminium hydroxide,  $\text{Al}(\text{OH})_3$  [1]
- c Corrosive to body/tissue / strong base/alkali. [1]
- d Heartburn occurs when gastric juice from the stomach rises into the esophagus/gullet. [1]
- e Dimethicone is added as an anti-foaming agent to prevent flatulence (passing of wind) and hence reduce pain. [1]  
 Provide a neutralizing layer on top of the stomach contents/to prevent acid rising up the esophagus/to prevent heart burn. [1]
- f Production of carbon dioxide gas,  $\text{CO}_2$  [1]
- g  $\frac{[\text{H}^+(\text{aq})]}{[\text{HCl}(\text{aq})]} = 10^{-2} = 0.1\text{ mol dm}^{-3}$   
 Mass of HCl in  $1\text{ dm}^3 = 0.1\text{ mol dm}^{-3} \times 36.46\text{ g mol}^{-1} = 3.646\text{ g}$   
 Mass of HCl in  $1.000\text{ cm}^3 = 3.646 \times 10^{-3}\text{ g} = 3.646\text{ mg}$  [2]
- h Amount of  $\text{NH}_4\text{Cl} = \frac{4.28\text{ g}}{53.50\text{ g mol}^{-1}} = 0.08\text{ mol}$   
 Concentration of  $\text{NH}_4\text{Cl} = 0.08\text{ mol} \times \left(\frac{[1000]}{[250]}\right) = 0.32\text{ mol dm}^{-3}$  [1]  
 $\text{pOH} = \text{p}K_b - \log_{10}\left(\frac{[\text{base}]}{[\text{salt}]}\right)$   
 $= 4.75 - \log_{10}\left(\frac{[0.50]}{[0.32]}\right) = 4.56$   
 $\text{pH} = 14.00 - 4.56 = 9.44$  [1]
- i  $4.5 = 4.76 - \log_{10}\left(\frac{0.1}{x}\right)$ , where  $x$  = concentration of  $\text{CH}_3\text{COONa}$   
 $x = 0.055\text{ mol dm}^{-3}$ ;  $x = 0.055\text{ mol dm}^{-3} \times 82.03\text{ g mol}^{-1} = 4.512\text{ g dm}^{-3}$  [1]  
 Mass of  $\text{CH}_3\text{COONa}$  required  $= \frac{500}{1000} \times 4.512\text{ g dm}^{-3} = 2.256\text{ g}$  [1]
- j Molecules of ranitidine (Zantac) bind to the histamine receptors/ $\text{H}_2$ -histamine receptors of the parietal cells in the gastric lining reducing hydrochloric acid secretion. [1]  
 Molecules of omeprazole reduce hydrochloric acid production by binding and inhibiting the gastric

- proton pump/ $H^+K^+$  ATPase pump located on the surface of gastric parietal cells. [1]
- 5 a Alcohol, ether, primary amine, amide and alkene. [2]  
The  $-OH$  groups allow it to hydrogen bond with water molecules. [1]
- b Intramuscular: into the muscles; intravenous: into veins; subcutaneous: into fat; anal: via the anus and inhalation. [1]  
Intravenous since the drug is circulated and transported quickly via the bloodstream (to various parts of the body). [1]
- c Placebo [1]
- d A side effect is an effect produced as well as the one intended and is an unwanted or undesired effect. [1]
- e A synergistic effect is a cumulative effect of two drugs which together is greater than the sum of each drug's individual effect. [1]
- f The therapeutic window is an index for an estimation of drug dosage which can treat disease effectively while remaining within the safe dosage range. [1]  
The use of this index can help to avoid most of the potential side effects of drug usage. [1]
- g Viruses undergo rapid mutation; viruses are not affected by antibiotics; it is difficult to destroy viruses without damaging cells; there are only a limited number of metabolic functions that can be targeted by antivirals. [1]
- h Viruses are acellular and hence have no ribosomes, cytoplasm or cell wall and cell membrane; viruses are smaller than bacteria and are not motile (able to move). [1]  
Bacteria replicate via asexually via binary division. This occurs outside cells. Virus particles are synthesized and assembled within the host cells. [1]
- 6 a Oxidizing agent/accepts electrons [1]  
Orange to green [1]
- b Gas-liquid chromatography and infrared spectroscopy [2]
- c Stomach bleeding [1]
- d A sample of blood, hair or urine is injected into a GC or HPLC column; the components are separated according to their volatility (GC) or solubility (HPLC) and affinity to the stationary phase. [1]  
The presence of an anabolic steroid in the body can be detected by its retention time and confirmed by mass spectroscopy; the sample with the substance is vaporized and ionized to form cations. [1]  
The cations are accelerated by an electric field and deflected by a magnetic field according to their mass to charge ratios. [1]  
Each substance produces a unique pattern of fragment ions, which can be detected and compared (by a computer search) with a library of known anabolic steroids (and their degradation products). [1]