Insight Publications

# *INSIGHT*

***Trial Exam Paper***

# 2008

# CHEMISTRY

# Written examination 1

# *Solutions book*

**This book presents:**

- correct solutions with full working
- explanatory notes
- mark allocations
- tips and guidelines

## SECTION A – Multiple-choice questions

### Question 1

The combination of analytical techniques best suited to the separation and identification of esters used as flavourings in ice-cream is

**A.** UV-visible spectroscopy and nuclear magnetic resonance (NMR) spectroscopy.

**B.** thin-layer chromatography and infra-red (IR) spectroscopy.

**C.** **high-performance liquid chromatography (HPLC) and NMR spectroscopy.**

**D.** gas chromatography (GC) and UV-visible spectroscopy.

***Answer is C.***

**Explanatory notes**

- C is correct. HPLC allows the separation of organic compounds such as esters. NMR spectroscopy allows the estimation of the structure of organic compounds based on their 13C and 1H spectra.
- A is incorrect because neither UV-visible spectroscopy nor NMR spectroscopy allow the separation of compounds.
- B is incorrect because thin-layer chromatography is not precise enough to reliably separate esters for collection. IR spectroscopy will enable the identification of functional groups and can be used as a fingerprint for a structure.
- D is incorrect because UV-visible spectroscopy does not give any information about the structure of the compound being analysed. GC will separate the components if they can be easily vaporised without decomposing.

*Questions 2 and 3 refer to the following information.*

The percentage by mass of sodium ions in the form of sodium chloride in a particular brand of dry biscuit was determined using gravimetric analysis. A 3.65 g sample of the biscuits was ground into a powder, dissolved in water and filtered. Excess silver nitrate was added to the remaining solution to precipitate the chloride ions as silver chloride. The precipitate was collected, washed and dried. Its mass was found to be 0.241 g.

### Question 2

The percentage by mass of sodium ions in the biscuit is closest to

**A.** 0.0387%

**B.** **1.06%**

**C.** 1.47%

**D.** 2.69%

***Answer is B.***

**Explanatory notes**

- B is correct according to the calculations below.

Step 1: Calculate the amount, in mol, of precipitate formed.

$$n(\text{AgCl}) = \frac{m}{M}$$

$$= \frac{0.241}{(107.9 + 35.5)}$$

$$= \frac{0.241}{143.4}$$

$$= 1.17 \times 10^{-3} \text{ mol}$$

Step 2: Write a balanced chemical equation for the reaction between the sodium chloride in the biscuit sample and the silver nitrate that was added.

$$NaCl(aq) + AgNO_3(aq) \rightarrow NaNO_3(aq) + AgCl(s)$$

Step 3: Calculate the amount, in mol, of NaCl in the biscuit sample.

The coefficients in a balanced chemical equation provide the ratio of amounts, in mol, of reactants and products consumed or produced in the reaction.

According to the equation:

$n(\text{NaCl}) : n(\text{AgCl})$

$1 : 1$

So, $n(\text{NaCl}) = \frac{1}{1} \times n(\text{AgCl})$

$= 1.17 \times 10^{-3}$ mol

Step 4: Calculate the amount, in mol, of $Na^+$ ions.

According to the ionic formula there is one $Na^+$ ion in NaCl.

So, $n(Na^+) = n(\text{NaCl})$

$= 1.17 \times 10^{-3}$ mol

Step 5: Calculate the mass of $Na^+$ ions.

$m(Na^+) = nM$

$= 1.17 \times 10^{-3} \times 23.0$

$= 0.0387$ g

Step 6: Calculate the percentage by mass of $Na^+$ ions in the biscuit.

$$\text{Percentage by mass} = \frac{\text{Mass of } Na^+}{\text{Mass of biscuits}} \times 100$$

$$= \frac{0.0387}{3.65} \times 100$$

$$= 1.06\%$$

- A is incorrect because 0.0387 g is the mass of $Na^+$ ions present and must be divided by the mass of the biscuit and multiplied by 100 to determine the percentage by mass.
- C is incorrect because the ratio of $n$(NaCl) : $n$(AgCl) is 1 : 1, not 2 : 1.
- D is incorrect because the percentage by mass of $Na^+$ ions is being calculated, not the percentage by mass of NaCl.

**Tips**

- *Students must know the valencies of common ions and be confident in writing balanced chemical equations. The periodic table is useful for remembering valencies. For example, all ions formed from Group 1 elements have a valency of +1 and ions formed from Group 2 elements have a valency of +2. Ions formed from Group 15 elements have a valency of –3, ions formed from Group 16 elements have a valency of –2, ions formed from Group 17 have a valency of –1 and the Group 18 elements are the noble gases and exist as atoms. Students must also learn polyatomic ions such as NO3–, SO42–, CO32– and OH–.*

**Question 3**

The calculated percentage by mass of sodium chloride is lower than stated on the label on the packaging. This may be due to

**A.** **incomplete precipitation of the chloride ions.**

**B.** inadequate washing of the precipitate.

**C.** the precipitate not being dried to constant mass.

**D.** co-precipitation of another, unknown anion with the silver ions.

***Answer is A.***

**Explanatory notes**

- A is correct because if not all of the chloride ions were precipitated the mass of AgCl would be decreased, resulting in a lower percentage by mass of $Cl^-$ and, therefore, NaCl.
- B is incorrect because any remaining solids would have added to the mass of the filtered precipitate and increased the percentage by mass.
- C is incorrect because any remaining water would contribute to a higher mass of precipitate, hence, an increased percentage by mass.
- D is incorrect because the precipitation of any additional ions would result in a higher mass of precipitate, and increase the percentage by mass.

**Question 4**

100 g of propane gas combusts according to the equation

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

The volume of carbon dioxide produced, in L, at 5.00°C and 0.500 atm is

**A.** 5.59
**B.** 104
**C.** **311**
**D.** $3.15 \times 10^4$

***Answer is C.***

**Explanatory notes**

- C is correct according to the calculations below.

  Step 1: Calculate the amount, in mol, of propane gas undergoing combustion.

$$n(C_3H_8) = \frac{m}{M}$$
$$= \frac{100}{(3\times12.0)+(8\times1.0)}$$
$$= \frac{100}{44.0}$$
$$= 2.27 \text{ mol}$$

  Step 2: Calculate the amount, in mol, of $CO_2$ produced.

  The coefficients in a balanced chemical equation provide the ratio of amounts, in mol, of reactants and products consumed or produced in the reaction.

  According to the equation:

  $n(C_3H_8) : n(CO_2)$

  1 : 3

$$\text{So, } n(CO_2) = \frac{3}{1} \times n(C_3H_8)$$
$$= \frac{3}{1} \times 2.27$$
$$= 6.82 \text{ mol}$$

Step 3: Calculate the volume of $CO_2$ produced at the specified conditions.

Temperature must be expressed in K.

$T$ in K $= T$ in °C + 273

$= 5.0 + 273$

$= 278$ K

Pressure must be expressed in kPa.

1 atm = 101.3 kPa

So, 0.500 atm $= \frac{0.50}{1} \times 101.3$

$= 50.7$ kPa

$PV = nRT$

So, $V(CO_2) = \frac{nRT}{P}$

$= \frac{6.82 \times 8.31 \times 278}{50.7}$

$= 311$ L

- A is incorrect because temperature must be converted to K from °C.
- B is incorrect because the correct ratio $n(C_3H_8) : n(CO_2)$ is 1 : 3, not 1 : 1.
- D is incorrect because pressure must be converted to kPa from atm.

**Question 5**

Consider the equation

$\_\_Al(s) + \_\_Cu^{2+}(aq) \rightarrow \_\_Al^{3+}(aq) + \_\_Cu(s)$

The coefficients required in front of each species to balance the equation are, in order

**A.** 1, 1, 1, 1

**B.** 3, 2, 3, 2

**C.** 1, 3, 2, 1

**D.** **2, 3, 2, 3**

***Answer is D.***

**Explanatory notes**

- D is correct. The two half-equations are:

  $Al(s) \rightarrow Al^{3+}(aq) + 3e^-$ (oxidation because electrons are being lost)

  $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ (reduction because electrons are being gained)

  There are 3 electrons being produced in the oxidation of each Al atom and 2 electrons being gained in the reduction of each copper ion. The electrons lost and gained must be balanced in the overall equation. Each half-equation is multiplied to obtain the lowest common denominator of 6 electrons. All species in the oxidation of Al are multiplied by 3 and all species in the reduction of $Cu^{2+}$ are multiplied by 2. Electrons lost and gained then balance each other.

- A is incorrect because the charge is not correctly balanced.
- B is incorrect because the charge is not correctly balanced.
- C is incorrect because the number and type of atoms are not correctly balanced.

**Tips**

- *Always write the two half-equations before attempting to balance the overall equation of a redox reaction.*

**Question 6**

A volume of 180 mL of 1.0 M HCl is added to 100 mL of 1.0 M NaOH. The pH of the resultant solution is closest to

**A.** 0.3

**B.** 0.4

**C.** **0.5**

**D.** 1.1

***Answer is C.***

**Explanatory notes**

- C is correct according to the steps below.

  Step 1: Calculate the amount, in mol, of both reactants.

  $n(HCl) = cV$

  $= 1.0 \times 0.180$

  $= 0.18$ mol

  $n(NaOH) = cV$

  $= 1.0 \times 0.100$

  $= 0.10$ mol

  Step 2: Write a balanced chemical equation for the reaction occurring. An acid (HCl) reacting with a metal hydroxide (NaOH) produces a salt and water.

  $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

Step 3: Identify the limiting reactant by dividing the amount of each reactant by its coefficient in the chemical equation. The reactant with the lowest answer is the limiting reactant.

$$\text{HCl: } \frac{0.18}{1}$$

$$= 0.18$$

$$\text{NaOH: } \frac{0.10}{1}$$

$$= 0.10$$

NaOH is the limiting reagent and will react completely, leaving behind some excess HCl.

Step 4: Calculate the amount, in mol, of excess HCl.

The coefficients in a balanced chemical equation provide the ratio of amounts, in mol, of reactants and products consumed or produced in the reaction.

According to the equation:

$n(\text{HCl}) : n(\text{NaOH})$

$1 : 1$

And because NaOH is the limiting reagent,

$n(\text{HCl})$ reacted $= n(\text{NaOH})$

$= 0.10$ mol

$n(\text{HCl})$ in excess $= n(\text{HCl})$ added $- n(\text{HCl})$ reacted

$= 0.18 - 0.10$

$= 0.080$ mol

Step 5: Calculate the concentration of HCl in the resultant solution. The total volume of the resultant solution is 150 + 100 = 250 mL.

$$c(\text{HCl}) = \frac{n}{V}$$

$$= \frac{0.080}{0.250}$$

$$= 0.32 \text{ M}$$

Step 6: Calculate $[H_3O^+]$ in solution.

HCl is a monoprotic acid, meaning each acid molecule donates one $H^+$ ion.

$[H_3O^+] = c(\text{HCl})$

$= 0.32$ M

Step 7: Calculate pH.

pH $= -\log_{10}[H_3O^+]$

$= -\log_{10}(0.32)$

$= 0.495 = 0.5$ (to 1 decimal place)

- A is incorrect because the total volume of the resultant solution is 250 mL, not 150 mL.
- B is incorrect because *n*(HCl) remaining is 0.080 mol and not 0.10 mol, which is the *n*(NaOH) used.
- D is incorrect because 0.080 mol is the *n*(HCl) remaining and not the concentration of HCl or $H_3O^+$.

**Tips**

- *Whenever quantities of both reactants are given, the limiting and excess reactants will need to be determined. If calculations of product are required, the amount, in mol, of the limiting reactant must be used.*

**Question 7**

Different quantities of sulfur trioxide ($SO_3$) are listed below. Which one contains the **greatest** number of molecules?

**A.** $8 \times 10^2$ g

**B.** **8 × 102 L at SLC**

**C.** $8 \times 10^{23}$ molecules

**D.** 8 mol

***Answer is B.***

**Explanatory notes**

- Conversion of all of the quantities to an amount, in mol, allows direct comparison of their numbers of molecules. Amount, in mol, is a convenient way of expressing the number of particles in a substance. Note that 1 mol of a substance contains Avogadro's number, or $6.02 \times 10^{23}$ particles.
- B is correct. Volume at SLC can be converted to amount, in mol, using $n = \frac{V}{V_M}$. The molar volume ($V_M$) is 24.5 L. This is listed in the data booklet.

$$n = \frac{V}{V_M}$$

$$= \frac{8 \times 10^2}{24.5}$$

$= 32.7$ mol

- A is incorrect. Mass can be converted to amount in mol, using $n = \frac{m}{M}$.

$$n = \frac{m}{M}$$

$$= \frac{8 \times 10^2}{32.1 + (3 \times 16.0)}$$

$$= \frac{8 \times 10^2}{80.1}$$

$$= 9.9 \text{ mol}$$

- C is incorrect. The number of molecules can be converted to amount, in mol, using $n = \frac{N}{N_A}$. $N_A$ is Avogadro's constant of $6.02 \times 10^{23}$ mol$^{-1}$. This is listed in the data booklet.

$$n = \frac{N}{N_A}$$

$$= \frac{8 \times 10^{23}}{6.02 \times 10^{23}}$$

$$= 1.3 \text{ mol}$$

**Question 8**

7.33 g of lanthanum (La) combines with oxygen to give 8.60 g of an oxide. The empirical formula of the oxide is

**A.** **$La_2O_3$**
**B.** $LaO_5$
**C.** $LaO_{10}$
**D.** $La_3O_2$

***Answer is A.***

**Explanatory notes**

- A is correct according to the steps below.
The empirical formula of a compound is the simplest whole number ratio of atoms in the compound. It requires the determination of the amount, in mol, of each element present in a particular quantity and conversion of this amount to whole numbers.

Step 1: Calculate the mass of oxygen in the oxide.

$m(\text{O}) = m(\text{oxide}) - m(\text{La})$
$= 8.60 - 7.33$
$= 1.27 \text{ g}$

Step 2: Calculate the amount, in mol, of oxygen in the oxide.

$$n(\text{O}) = \frac{m}{M}$$
$$= \frac{1.27}{16.0}$$
$$= 0.0792 \text{ mol}$$

Step 3: Calculate the amount, in mol, of lanthanum in the oxide.

$$n(\text{La}) = \frac{m}{M}$$
$$= \frac{7.33}{138.9}$$
$$= 0.0528 \text{ mol}$$

Step 4: Determine the simplest whole number ratio of La : O, in terms of mol, by dividing both by the smallest amount.

$n$(La) : $n$(O)

0.0528 : 0.179

So, to determine the simplest ratio, each is divided by 0.0528.

$$\frac{0.0528}{0.0528} : \frac{0.0792}{0.0528}$$

1 : 1.5

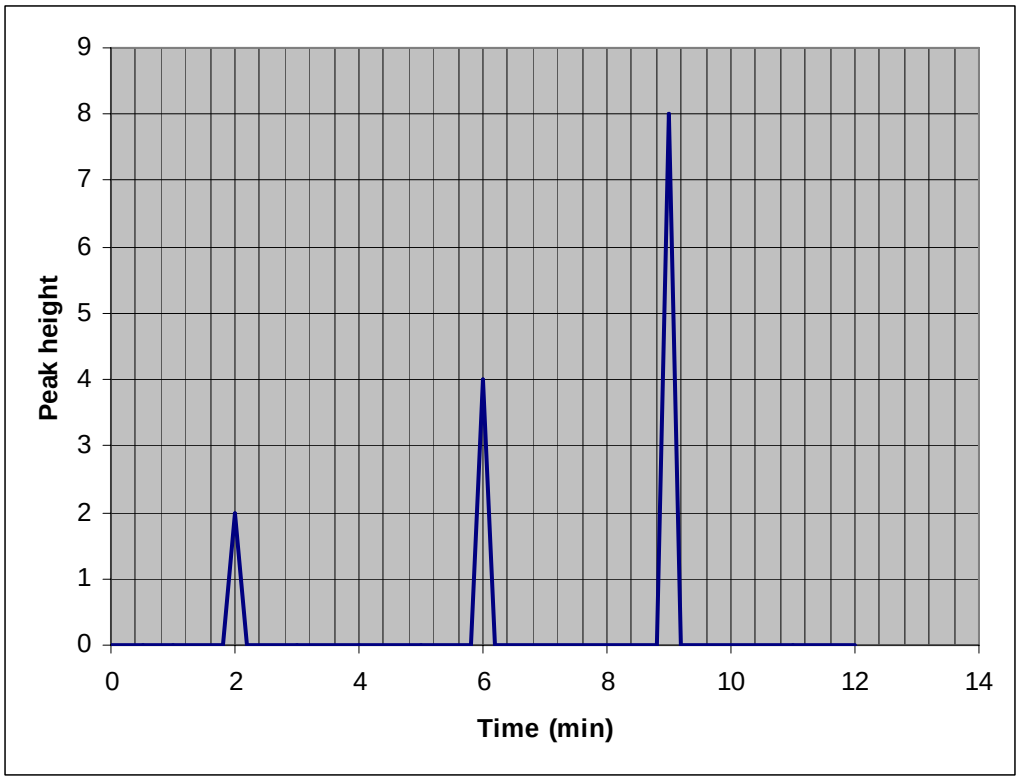
The ratio must be in whole numbers, so converts to

2 : 3

- B is incorrect because the masses of lanthanum and oxygen must be converted to amount, in mol, to obtain the ratio of atoms.
- C is incorrect because 8.60 g is the mass of the oxide. The mass of oxygen is the mass of the oxide minus the mass of lanthanum; i.e. $m$(O) = $m$(oxide) – $m$(La).
- D is incorrect because the molar mass of oxygen is 16.0 g mol$^{-1}$, not 32.0 g mol$^{-1}$.

**Question 9**

A mixture of gases collected from a car exhaust was analysed using gas chromatography. The carrier gas used is also recorded by the detector and known to have a retention time under these conditions of approximately 2 minutes. The following chromatogram was obtained.




Which of the following can be reasonably concluded from the chromatogram?

A. There are at least two components in the mixture of approximately the same amount.

B. **There are at least two components in the mixture with one component present in twice the amount of the other.**

C. There are at least three components in the mixture of approximately the same amount.

D. There are at least three components in the mixture with one present in twice the amount than the others.

***Answer is B.***

**Explanatory notes**

- B is correct because each peak in a chromatogram represents a different component in the sample. They have travelled through the column at different rates and, hence, have different retention times ($R_t$). The peak at 2 minutes is the carrier gas, not a component of the mixture. The area under each peak is an indicator of the quantity of each component. The second peak has approximately twice the area under the peak compared to the first peak, so is present in twice the amount of the other.

- A is incorrect because the components have different areas under the peaks, which indicates they are present in different quantities. The second peak has approximately twice the area under the peak compared to the first peak, so is present in twice the amount of the other.
- C is incorrect because only two components are evident in this chromatogram. The peak at 2 minutes is the carrier gas, not a component of the mixture being analysed. C is incorrect also because the components have different areas under the peaks, indicating they are present in different quantities.
- D is incorrect because only two components are evident in this chromatogram. The peak at 2 minutes is the carrier gas, not a component of the mixture being analysed.

**Question 10**

The structures of 2-chloropropane and propan-2-ol are analysed separately using low resolution nuclear magnetic resonance spectroscopy (NMR). Which of the following statements best describes the $^1$H NMR spectra produced for each of the molecules?

**A.** The spectra for 2-chloropropane and propan-2-ol are identical in appearance.

**B.** The spectra for 2-chloropropane and propan-2-ol each have two main peaks.

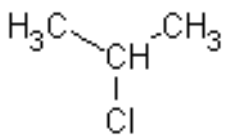
**C.** **The spectrum for 2-chloropropane has two main peaks whereas the spectrum for propan-2-ol has three main peaks.**

**D.** The spectrum for 2-chloropropane has three main peaks whereas the spectrum for propan-2-ol has four main peaks.

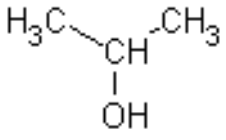
***Answer is C.***

**Explanatory notes**

- C is correct. Proton NMR gives information about the environments of the hydrogen atoms in a molecule. The structures of 2-chloropropane and propan-2-ol are shown below.

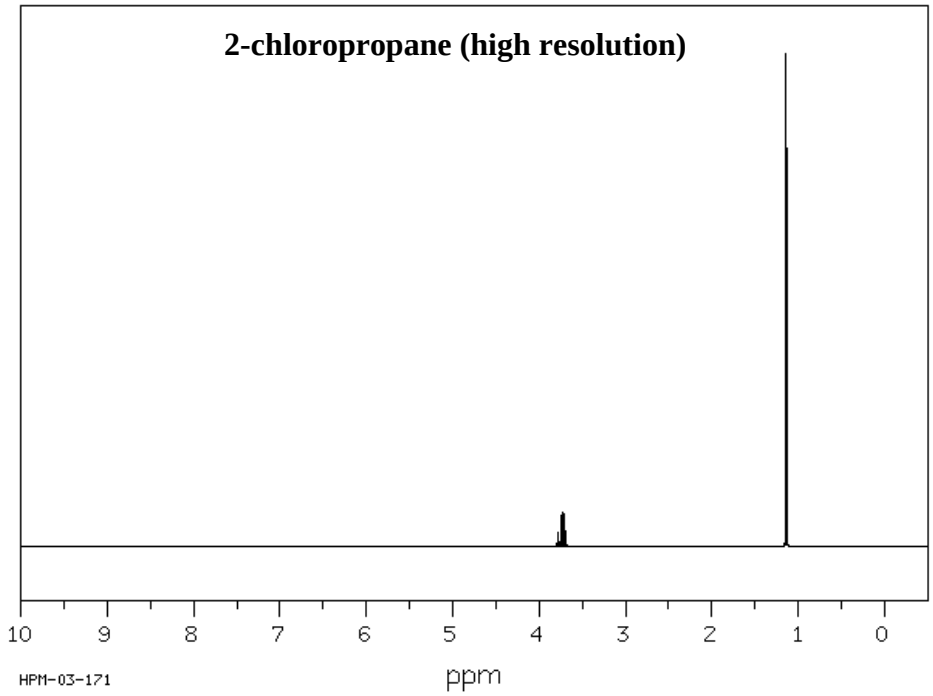



2-chloropropane



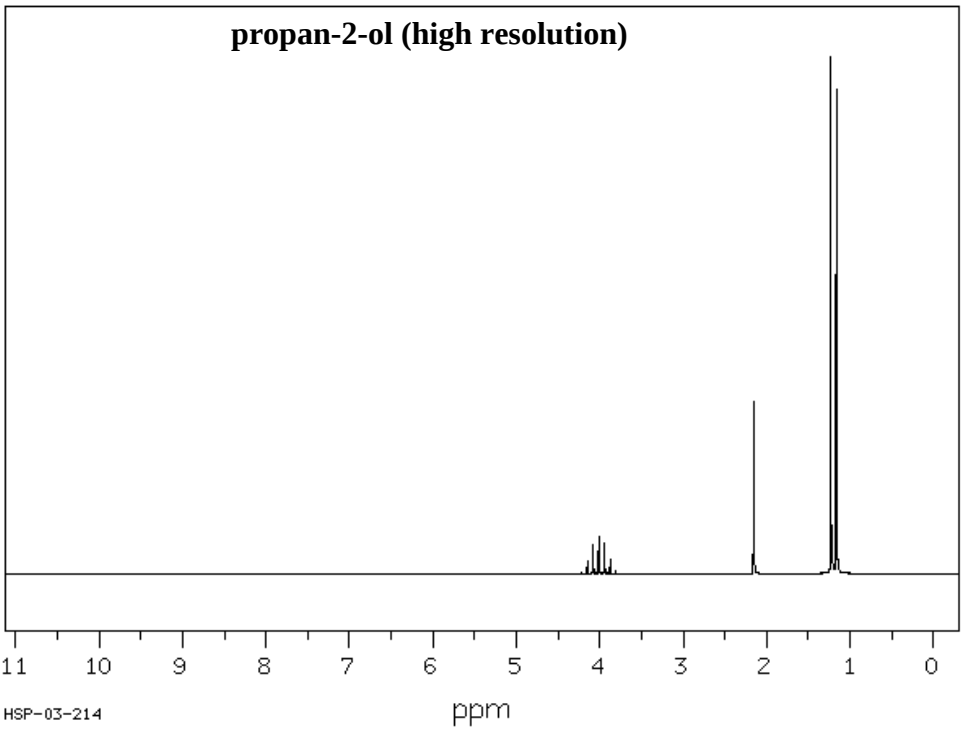

propan-2-ol

In 2-chloropropane, 6 hydrogen atoms are in $–CH_3$ environments, and both $–CH_3$ are bonded to CHCl. One hydrogen atom is in a –CHCl– environment. There will be two main peaks in the low resolution $^1$H NMR spectrum as there are two different environments for hydrogen atoms. The area under each peak is proportional to the number of hydrogen atoms in each environment.




SDBSWeb: http://riodb01.ibase.aist.go.jp/sdbs/ (National Institute of Advanced Industrial Science and Technology, accessed 11/03/2008)

In propan-2-ol, there are 6 hydrogen atoms in a $–CH_3$ environment, 1 hydrogen atom in –CH– and 1 hydrogen in –OH. There are three different environments for hydrogen atoms, so there are three main peaks in the $^1H$ NMR spectrum.




SDBSWeb: http://riodb01.ibase.aist.go.jp/sdbs/ (National Institute of Advanced Industrial Science and Technology, accessed 11/03/2008)

- A is incorrect because the number of peaks on the $^1$H NMR spectrum represents the number of different hydrogen environments in the compound being analysed. 2-Chloropropane and propan-2-ol have different numbers of different hydrogen atom environments and so have different numbers of peaks on the $^1$H NMR spectrum. They are not identical.
- B is incorrect because the number of peaks on the $^1$H NMR spectrum represents the number of different hydrogen environments in the compound being analysed. Propan-2-ol has three different hydrogen environments and so will have three main peaks on the $^1$H NMR spectrum.
- D is incorrect because the number of peaks on the $^1$H NMR spectrum represents the number of different hydrogen environments in the compound being analysed. 2-Chloropropane has three different environments for hydrogen atoms and so there are three peaks on the $^1$H NMR spectrum. Propan-2-ol has three different hydrogen environments and so will have three main peaks on the $^1$H NMR spectrum.

**Tips**

- *Although the data booklet lists a range of characteristic proton chemical shifts, they are not required in answering this question.*

**Question 11**

Which one of the following compounds will include absorption bands in the infra-red spectrum at about 1700 cm$^{-1}$ and 2600 cm$^{-1}$?

**A.** pentane

**B.** pentan-2-ol

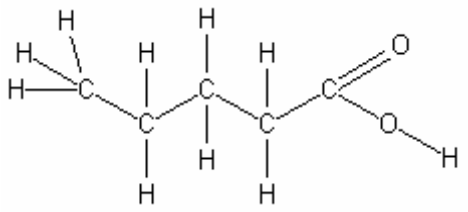
**C.** **pentanoic acid**

**D.** pent-2-ene

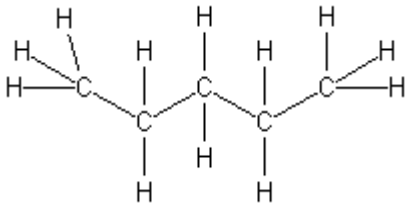
***Answer is C.***

**Explanatory notes**

- C is correct because pentanoic acid contains the bonds C=O and O–H (carboxylic acids), which have characteristic infra-red absorption ranges of 1670–1750 cm$^{-1}$ and 2500–3300 cm$^{-1}$, respectively, so it can account for the absorption bands at 1700 cm$^{-1}$ and 2600 cm$^{-1}$. The structure of pentanoic acid is shown below.

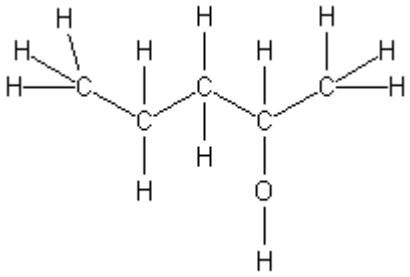


- A is incorrect. The structure of pentane is shown below.



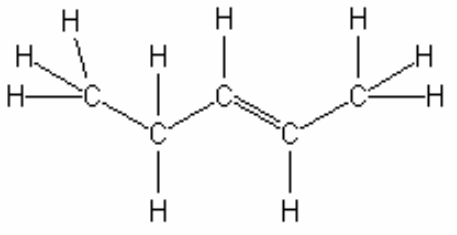
The only bond types present are C–C, which absorbs in the range 750–1100 $cm^{-1}$, and C–H, which absorbs in the range 2850–3300 $cm^{-1}$. Neither can account for the absorption bands at 1700 $cm^{-1}$ and 2600 $cm^{-1}$.

- B is incorrect. The structure of pentan-2-ol is shown below.



The bond types present and their absorption ranges, in $cm^{-1}$, are: C–C at 750–1100, C–H at 2850–3300, C–O at 1000–1300 and O–H (alcohols) at 3200–3550. None of these can account for the absorption bands at 1700 $cm^{-1}$ and 2600 $cm^{-1}$.

- D is incorrect. The structure of pentene is shown below.

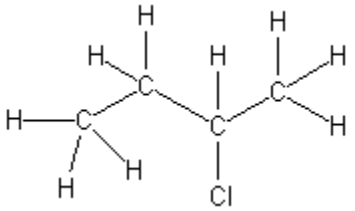


The bond types present and their absorption ranges, in $cm^{-1}$, are: C–C at 750–1100, C–H at 2850–3300 and C=C at 1610–1680. Although the C=C bond absorption range is close to the band at 1700 $cm^{-1}$, none of these can account for the absorption band at 2600 $cm^{-1}$.

**Tips**

- *The data booklet lists the characteristic range for infra-red absorption by a range of common bonds and can be referred to during the examination.*

**Question 12**



The systematic name for the molecule with the structure shown is

**A.** 1-methyl, 2-chloropropane

**B.** 2-chloro, 3-methylpropane

**C.** 3-chlorobutane

**D.** **2-chlorobutane**

***Answer is D.***

**Explanatory notes**

- D is correct because the chloro group (–Cl) is located on the second carbon of a four-carbon chain.
- A is incorrect because the longest unbroken chain contains all of the carbon atoms, making the molecule a type of butane.
- B is incorrect because the longest unbroken chain contains all of the carbon atoms, making the molecule a type of butane.
- C is incorrect because it starts numbering the carbons in the carbon chain from the incorrect end. Numbering must start from the end to which the highest priority group is closest (and, therefore, is assigned the lowest carbon number).

*Questions 13 and 14 refer to the following reactions.*

Reaction 1 $CH_2CH_2(g) + H_2O(g) \rightarrow X$

Reaction 2 $CH_3CH_3(g) + Y \rightarrow CH_3CH_2Cl(g) + HCl(g)$

Reaction 3 $CH_3CH_2CH_2Cl(aq) + OH^-(aq) \rightarrow Z + Cl^-(aq)$

**Question 13**

Which of the following shows the formulas of species X, Y and Z?

| | **Species X** | **Species Y** | **Species Z** |
|---|---|---|---|
| **A** | $CH_2CHOH$ | HCl | $CH_3CHOHCH_3$ |
| **B** | $CH_3CH_2OH$ | HCl | $CH_3CH_2CH_2OH$ |
| **C** | $CH_3CH_2OH$ | $Cl_2$ | $CH_3CH_2CH_2OH$ |
| **D** | $CH_3CH_2OH$ | $Cl_2$ | $CH_3CHOHCH_3$ |

***Answer is C.***

**Explanatory notes**

- C is correct. Reaction 1 is an addition reaction between ethene and water. The double bond between two carbon atoms in ethene breaks and an H is added to one carbon atom and an OH is added to the other.

  The full reaction is $CH_2CH_2(g) + H_2O(g) \rightarrow CH_3CH_2OH(g)$.

  Reaction 2 is a substitution reaction of ethane, producing chloroethane and hydrogen chloride. A hydrogen atom is substituted for a chlorine atom.

  The full reaction is $CH_3CH_3(g) + Cl_2(g) \rightarrow CH_3CH_2Cl(g) + HCl(g)$ and occurs in the presence of UV light.

  Reaction 3 is a substitution reaction of 1-chloropropane. The chlorine atom is substituted for a hydroxy functional group.

  The full reaction is $CH_3CH_2CH_2Cl(aq) + OH^-(aq) \rightarrow CH_3CH_2CH_2OH(aq) + Cl^-(aq)$.

- A is incorrect because reaction 1 is an addition reaction and species X is $CH_3CH_2OH$. Also, species Y is $Cl_2$ and species Z has the hydroxy functional group attached to the wrong carbon, producing propan-2-ol instead of propan-1-ol.
- B is incorrect because species Y is $Cl_2$.
- D is incorrect because species Z has the hydroxy functional group attached to the wrong carbon, producing propan-2-ol instead of propan-1-ol.

**Tips**

- *Students should know all of the general reaction types and the additional reactants, catalysts and conditions required for each.*

**Question 14**

Which of the following correctly identifies each reaction type?

| | **Reaction 1** | **Reaction 2** | **Reaction 3** |
|---|---|---|---|
| **A** | addition | substitution | substitution |
| **B** | addition | condensation | oxidation |
| **C** | addition | substitution | oxidation |
| **D** | substitution | condensation | substitution |

***Answer is A.***

**Explanatory notes**

- A is correct. Reaction 1 is an addition reaction because the double covalent bond in ethene is converted to a single covalent bond during the course of the reaction. Atoms are added onto the molecule without any atoms being removed. Reaction 2 is a substitution reaction because ethane contains only single C–C bonds, so new atoms must be substituted for old atoms. In this case, a chlorine atom is substituted by a hydrogen atom. Reaction 3 is a substitution reaction because 1-chloropropane contains only single covalent bonds. The hydroxyl group is substituted by the chlorine atom.
- B is incorrect because reaction 2 is not a condensation reaction. A condensation reaction involves the elimination of a small molecule. Also, reaction 3 is not an oxidation reaction. The oxidation numbers of the species in the reaction do not change.

- C is incorrect because reaction 3 is not an oxidation reaction. The oxidation numbers of the species in the reaction do not change.
- D is incorrect because reaction 1 is not a substitution reaction. No atoms are substituted out of the ethene molecule.

**Question 15**

Which of the following is not considered a biochemical fuel?

**A.** ethanol

**B.** biodiesel

**C.** vegetable oils

**D.** **natural gas**

***Answer is D.***

**Explanatory notes**

- D is correct because natural gas is not derived from plant materials such as grains, sugarcane or vegetable wastes and oils, and so is not considered a biochemical fuel.
- A is incorrect because ethanol is produced by the fermentation of molasses and grains, and so is considered a biochemical fuel.
- B is incorrect because biodiesel is a mixture of esters produced from vegetable oils, and so is considered a biochemical fuel.
- C is incorrect because vegetable oils can be used as a fuel, and so is considered a biochemical fuel.

**Question 16**

The mass, in grams, of one molecule of ethanol is closest to

**A.** $7.48 \times 10^{-23}$

**B.** $\mathbf{7.64 \times 10^{-23}}$

**C.** 46.0

**D.** $1.31 \times 10^{22}$

***Answer is B.***

**Explanatory notes**

- B is correct according to the following steps:

  Step 1: Determine the molecular formula of ethanol.

  The suffix *-anol* indicates that the molecule is a member of the homologous series of alkanols, and so contains a hydroxy functional group. The prefix *eth-* indicates each molecule contains two carbon atoms. Thus, the formula of the molecule is $C_2H_5OH$.

Step 2: Determine the molar mass of ethanol. This gives the mass of 1 mole of ethanol molecules. The molar mass is the sum of the relative atomic masses of all of the atoms in the molecule.

$M(C_2H_5OH) = (2 \times 12.0) + (5 \times 1.0) + 16.0 + 1.0$

$= 46.0 \text{ g mol}^{-1}$

Step 3: Determine the mass of one molecule of ethanol.

Remembering that 1 mole of any substance contains Avogadro's number of particles,

$$\text{Mass of one molecule} = \frac{\text{Mass of 1 mole of molecules}}{\text{Number of molecules in 1 mole}}$$

$$= \frac{46.0}{6.02 \times 10^{23}}$$

$$= 7.64 \times 10^{-23} \text{ g}$$

A is incorrect because the correct formula of ethanol is $C_2H_5OH$ and its molar mass is 46 g mol$^{-1}$.

- C is incorrect because 46 g is the mass of 1 mole of ethanol, not one molecule.
- D is incorrect because the mass of one molecule of ethanol is calculated by $\frac{46.0}{6.02 \times 10^{23}}$.

**Tips**

- *Read these types of questions very carefully to ensure the correct quantity is calculated; in this case, the mass of one molecule, not 1 mole.*
- *When determining the molar mass of an alkanol, don't forget the hydrogen in the hydroxy functional group.*

**Question 17**

Which of the following statements about the tertiary structure of proteins is **not** correct?

**A.** **Changing the tertiary structure of a protein will always cause a change in its secondary and primary structures.**

**B.** The three-dimensional structure of a protein is determined by its tertiary structure.

**C.** The tertiary structure of a protein is determined by interactions between different Z groups (side chains).

**D.** Changing the tertiary structure of an enzyme will always cause a change in its ability to catalyse a specific chemical reaction.

***Answer is A.***

**Explanatory notes**

- A is the incorrect statement. The primary structure of a protein is the sequence of amino acids that are held together by very strong covalent bonds. Changing the pH or increasing the temperature may interrupt some of the weaker bonds that hold the tertiary structure together without affecting the covalent bonds that hold the primary structure together.

- B is a correct statement. The primary structure is determined by covalent bonding and the secondary structure is determined by hydrogen bonding. Tertiary structure can be determined by hydrogen bonds between polar Z groups (side chains) and covalent cross-links between chains. It can also be determined by ionic interactions and dispersion forces.
- C is a correct statement. The interactions between different Z groups that contribute to tertiary structure include hydrogen bonds, covalent cross-links, ionic interactions and dispersion forces.
- D is a correct statement. Changing the tertiary structure of an enzyme, usually by altering pH or increasing temperature, will change the active site of the enzyme. The ability of an enzyme to catalyse a specific chemical reaction depends on the active site, so it will be affected.

**Question 18**

Which of the following statements is **not** correct in describing the action of enzymes?

**A.** Enzymes generally operate at much lower pressures than inorganic catalysts.

**B.** **Enzymes can catalyse only a small number of reactions each whereas an inorganic catalyst can catalyse a wider range of reactions.**

**C.** Enzyme activity is destroyed at high temperatures whereas many inorganic catalysts require high temperatures to work.

**D.** Enzymes increase the rate of a reaction to a much greater extent than inorganic catalysts.

***Answer is B.***

**Explanatory notes**

- A is a correct statement. Inorganic catalysts require pressures of up to 250 atm whereas enzymes generally operate at normal pressure.
- B is an incorrect statement because enzymes are highly specific and each enzyme can typically catalyse only one reaction.
- C is a correct statement. Inorganic catalysts require temperatures of up to 500°C. High temperatures denature enzymes, changing their active site and destroying their catalytic activity.
- D is a correct statement. Enzymes can increase the rate of a chemical reaction by as much as $10^{10}$ times.

**Question 19**

Electrophoresis is useful for separating fragments of deoxyribonucleic acid (DNA) because all DNA fragments carry a

**A.** **negative charge and, hence, are attracted to the positive electrode, and smaller fragments travel faster than larger fragments.**

**B.** negative charge and, hence, are attracted to the positive electrode, and larger fragments travel faster than smaller fragments.

**C.** positive charge and, hence, are attracted to the negative electrode, and smaller fragments travel faster than larger fragments.

**D.** positive charge and, hence, are attracted to the negative electrode, and larger fragments travel faster than smaller fragments.

***Answer is A.***

**Explanatory notes**

- A is correct. Fragments of DNA chains carry a negative charge due to the phosphate groups and are attracted to the positive electrode. Larger fragments are impeded by the electrophoresis gel more than smaller fragments, so smaller fragments will move faster.
- B is incorrect because larger fragments are impeded by the electrophoresis gel more than smaller fragments, so smaller fragments will move faster.
- C is incorrect because fragments of DNA chains carry a negative charge due to the phosphate groups and are attracted to the positive electrode.
- D is incorrect because fragments of DNA chains carry a negative charge due to the phosphate groups and are attracted to the positive electrode. Also, smaller fragments travel faster than larger fragments.

**Question 20**

When a molecule absorbs radio waves during nuclear magnetic resonance spectroscopy (NMR) this is most likely to lead to

**A.** the molecule moving to a higher vibrational energy level.

**B.** a deflection in the path taken by the molecule when it is travelling at high speeds.

**C.** an electron being promoted from a lower energy level to a higher energy level.

**D.** **a change in the spin state of nucleons.**

***Answer is D.***

**Explanatory notes**

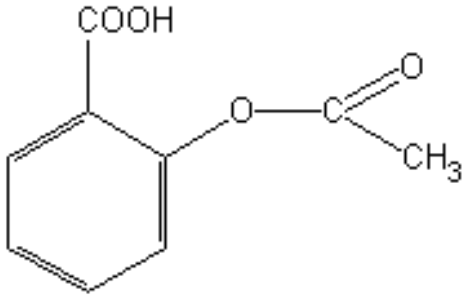
- D is correct. When placed in an external magnetic field, the magnetic field produced by the spinning of nucleons (protons and neutrons) aligns with the field or against the field. Those that align with the field are at a lower spin energy level and can absorb energy from radio waves and be promoted to the higher spin energy level.
- A is incorrect. Molecules move to a higher vibration energy level when they absorb infra-red radiation. This is used for infra-red spectroscopy.
- B is incorrect. Charged particles travelling at high speeds are deflected when they enter a magnetic field in mass spectroscopy.
- C is incorrect. There is not enough energy in radio waves during NMR to promote electrons from lower to higher energy levels. Heat and light can do this in flame tests and atomic absorption spectroscopy.

**END OF SECTION A**

## SECTION B – Short-answer questions

### Question 1

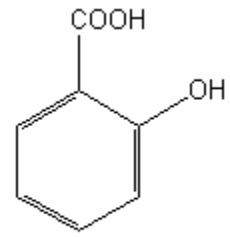
Acetylsalicylic acid, or aspirin, is a drug commonly used as an analgesic (painkiller), to reduce fever and as an anti-inflammatory. The structure of aspirin is shown below.



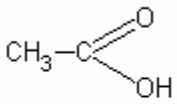

Aspirin can be produced in the laboratory by a number of different synthetic pathways. In one pathway, salicylic acid reacts via a condensation reaction with ethanoic acid to produce aspirin and water.

**1a.** In the space below, draw the structures of salicylic acid and ethanoic acid.

**Solution**




salicyclic acid




ethanoic acid

2 marks

**Mark allocation**

- 1 mark for correct structure of salicylic acid.
- 1 mark for correct structure of ethanoic acid.

**Explanatory notes**

- The reaction between salicylic acid and ethanoic acid to produce aspirin is a condensation reaction between a hydroxy (OH) functional group on the salicylic acid and the carboxy functional group on the ethanoic acid (COOH). When these functional groups react, a water molecule is eliminated and an ester linkage forms in the aspirin.

**Tips**

- *Students should be able to deduce the structures of salicylic acid and ethanoic acid from the structure of aspirin, identify the ester linkage and remember that water is also produced.*

A student wishes to analyse the aspirin content in a particular brand of headache tablets. Five headache tablets are dissolved in 25.00 mL of 1.00 M sodium hydroxide in a 250.0 mL volumetric flask and the mixture is heated. The reaction occurring is:

$CH_3COOC_6H_4COOH(s) + 2NaOH(aq) \rightarrow CH_3COONa(aq) + HOC_6H_4COONa(aq) + H_2O(l)$

The mixture is then made up to 250 mL with water and several 25.00 mL aliquots are transferred to conical flasks and titrated with 0.100 M hydrochloric acid, using phenolphthalein as the indicator. The reaction occurring is:

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

Titre volumes of 6.62 mL, 6.41 mL, 6.38 mL and 6.40 mL are obtained.

**1b.** Calculate the amount, in mol, of hydrochloric acid in the average titre.

**Solution**

Step 1: Calculate the volume of the average titre.

$$\text{Average titre} = \frac{6.41 + 6.38 + 6.40}{3}$$

$$= 6.40 \text{ mL}$$

Step 2: Calculate the amount, in mol, of HCl in the average titre.

$$n(\text{HCl}) = cV$$
$$= 0.100 \times 0.00640$$
$$= 0.000640 \text{ mol}$$
$$= 6.40 \times 10^{-4} \text{ mol}$$

2 marks

**Mark allocation**

- 1 mark for calculating average titre of 6.40 mL.
- 1 mark for $n(\text{HCl}) = 6.40 \times 10^{-4}$ mol.

**Explanatory notes**

- The titre of 6.62 mL is disregarded as it is not concordant with the other titres. Concordant titres will be within 0.05 mL of each other.

**Tips**

- *The equation n = cV requires volume to be expressed in litres (L).*
- *Answers should always be expressed with the correct number of significant figures. The answer should have the same number of significant figures as the least precise piece of data used in the calculation. In this case, both 6.40 mL and 0.100 M have 3 significant figures; hence, the answer is given with 3 significant figures.*

**1c.** Calculate the amount of sodium hydroxide in excess in the volumetric flask after the reaction with aspirin.

**Solution**

Step 1: Calculate the amount, in mol, of NaOH in the 25.00 mL aliquot.

$n$(HCl) : $n$(NaOH)
1 : 1
So, $n$(NaOH) in aliquot = $n$(HCl) in average titre
$= 6.40 \times 10^{-4}$ mol
Step 2: Calculate the amount, in mol, of NaOH in the 250.0 mL flask. A 25.00 mL aliquot was taken from the 250.0 mL flask, so

$$n\text{(NaOH) in excess in flask} = \frac{250}{25.00} \times 6.40 \times 10^{-4}$$
$$= 6.40 \times 10^{-3} \text{ mol}$$

2 marks

**Mark allocation**

- 1 mark for $n$(NaOH) in aliquot = $6.40 \times 10^{-4}$ mol.
- 1 mark for $n$(NaOH) in flask = $6.40 \times 10^{-3}$ mol.

**Tips**

- *The coefficients in a balanced chemical equation give a mole ratio by which the amount, in mol, of any reactant consumed or product produced can be determined from the amount, in mol, of any other.*
- *The NaOH(aq) in the aliquot is a portion of what remained unreacted after the first reaction with aspirin(s). The aliquot is simply a small volume removed from the larger flask – it has exactly the same concentration as the larger flask.*

**1d.** Calculate the amount, in mol, of aspirin in the volumetric flask and, hence, the average mass of aspirin in one headache tablet. Ensure your answer is expressed to the correct number of significant figures.

**Solution**

Step 1: Calculate the amount, in mol, of NaOH initially added to the aspirin.

$n$(NaOH) added = $cV$
$= 0.02500 \times 1.00$
$= 2.50 \times 10^{-2}$ mol
Step 2: Calculate the amount, in mol, of NaOH that reacted with the aspirin.
$n$(NaOH) reacted = $n$(NaOH) added – $n$(NaOH) in excess
$= 2.50 \times 10^{-2} - 6.40 \times 10^{-3}$
$= 0.0186$ mol

Step 3: Calculate the amount, in mol, of aspirin that reacted with the NaOH.

$n$(aspirin) : $n$(NaOH) reacted
1 : 2

So, $n(\text{aspirin}) = \frac{1}{2} \times n(\text{NaOH})$ reacted

$= \frac{1}{2} \times 0.0186$

$= 9.28 \times 10^{-3}$ mol

Step 4: Calculate the mass of aspirin in the five tablets added to the NaOH.

$m$(aspirin) in five tablets = $nM$

$= 9.28 \times 10^{-3} \times 180$

$= 1.67$ g

Step 5: Calculate the average mass of aspirin in one tablet.

$m(\text{aspirin}) \text{ in one tablet} = \frac{1.67}{5}$

$= 0.334$ g

4 marks

**Mark allocation**

- 1 mark for $n$(NaOH) reacting with aspirin = 0.0186 mol.
- 1 mark for $n$(aspirin) in flask = $9.28 \times 10^{-3}$ mol.
- 1 mark for $m$(aspirin) in one tablet = 0.334 g.
- 1 mark for expressing the answer with 3 significant figures.

**Tips**

- *Consequential marks can be awarded if n(aspirin) in flask is calculated incorrectly but subsequent calculations are performed correctly.*
- *This is an example of a back titration. The amount of aspirin cannot be determined by direct titration because it is a weak acid and would not produce a sharp enough colour change in an indicator. Instead, its concentration is determined indirectly by reacting it with a known (but excess) amount of a strong base, NaOH, which is then titrated with a strong acid, HCl, to determine how much remains after the first reaction with the aspirin. The difference between the amount, in mol, of NaOH added initially and the amount, in mol, remaining indicates the amount, in mol, of NaOH that reacted with the aspirin. This is then used to determine the amount and mass of aspirin present in the flask.*

**1e.** Describe a rinsing error that could be made during the experiment that would result in the mass of aspirin in the tablet being calculated as higher than it should be.

**Solution**

One of the following:

Rinsing the volumetric flask with NaOH(aq) instead of water

Rinsing the conical flasks with NaOH(aq) instead of water

Rinsing the burette with water instead of 0.100 M HCl

1 mark

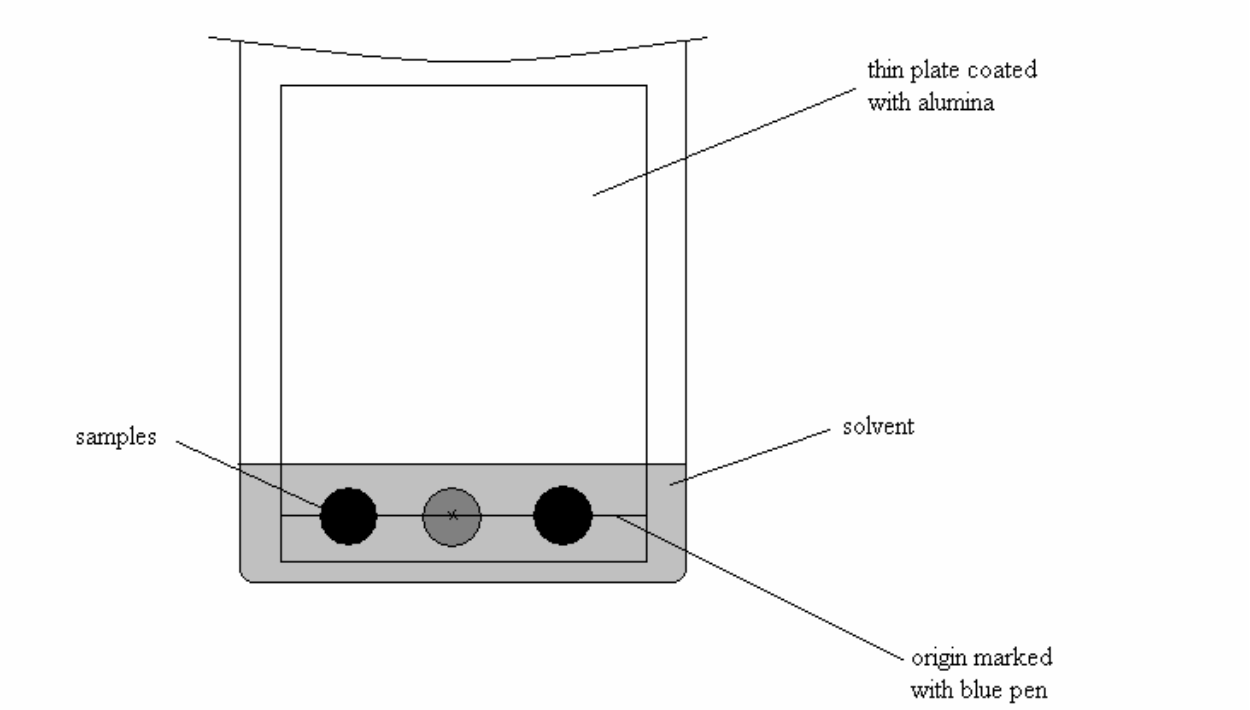
**Explanatory notes**

- A higher mass of aspirin will be calculated if the amount, in mol, of reacted NaOH is more than it should be. This could result from the amount, in mol, of NaOH added being more than it should, or the amount, in mol, of excess NaOH being less than it should.
- Rinsing the volumetric flask with NaOH(aq) instead of water will result in a greater amount, in mol, of NaOH added.
- Rinsing the conical flasks with NaOH(aq) instead of water will result in a greater amount, in mol, of NaOH added.
- Rinsing the burette with water instead of 0.100 M HCl will dilute the HCl and increase the volume of the average titre, making the amount, in mol, of NaOH in each aliquot appear greater than it should.

Total 2 + 2 + 2 + 4 + 1 = 11 marks

**Question 2**

**2a.** Some students use thin-layer chromatography to try to identify an unknown food colouring in a green icy pole. One student uses a blue pen to mark an origin on the plate, applies a large spot of an icy pole sample and two known food colouring standards onto the origin, and places the plate in the solvent, as shown below.




Identify two experimental errors made by this student and describe their likely effect on the experiment.

**Solution**

Two errors from the following:

The solvent level is higher than the origin. This will cause the food colouring to dissolve into the entire solution. It will not separate into clear spots on the chromatogram.

Blue pen was used to mark the origin. The blue ink may dissolve into the solvent and be transported up the plate.

Large spots were used for the samples. The spots from the different samples may merge into each other as they travel up the plate.

2 marks

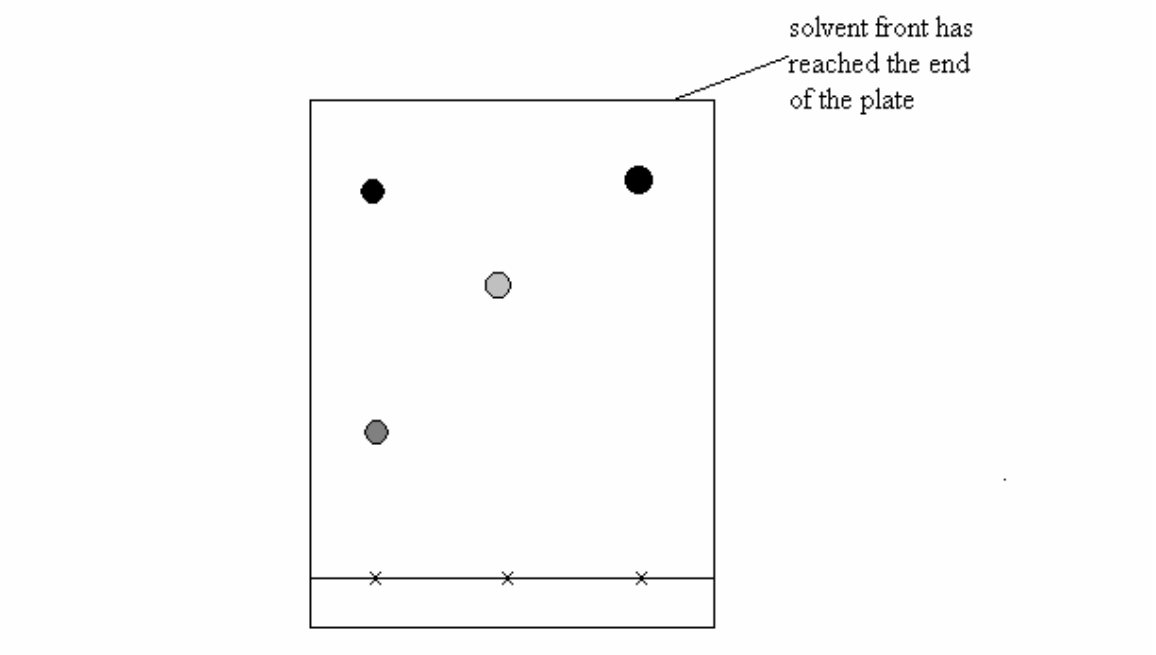
**Mark allocation**

- 1 mark for first error and description.
- 1 mark for second error and description.
- An error without a description does not receive any marks.

**Explanatory notes**

- Thin-layer chromatography allows the separation of components of a mixture. Correct laboratory technique is essential. The origin is drawn with grey lead pencil, samples are placed on the origin as very small spots, and the plate sits in the solvent so that the level of the solvent is below the origin.

**2b.** A second student begins the experiment with a correct initial set-up and allows the solvent to move up the plate. The diagram below shows the appearance of the plate after it was removed from the solvent.




Explain why this student is unable to calculate accurate $R_f$ values for the components in the mixture.

**Solution**

The distance travelled by the solvent front from the origin cannot be determined.

1 mark

**Explanatory notes**

$$R_f = \frac{\text{Distance travelled by component from the origin}}{\text{Distance travelled by solvent front from the origin}}$$

**2c.** Briefly explain why the components of a mixture separate in thin-layer chromatography.

**Solution**

As the solvent (mobile phase) travels up the plate, the components in the sample dissolve in the solvent and travel with it. As they travel up the plate with the solvent the components continually adsorb and desorb to the alumina (stationary phase). Different components adsorb and desorb at different rates, so separation occurs.

2 marks

**Mark allocation**

- 1 mark for explaining components adsorb and desorb to the stationary phase.
- 1 mark for explaining components do so at different rates.

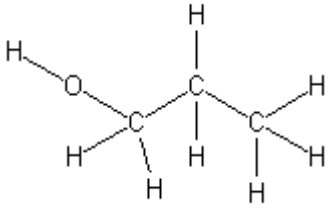
**Explanatory notes**

- Adsorption is the forming of bonds and desorption is the breaking of bonds. A component that adsorbs strongly to the stationary phase will travel more slowly than those that adsorb more weakly. The strength of adsorption depends on properties of the components. Varying solubility in the solvent will also effect the rate at which a component travels; however, a solvent that dissolves the components well is usually selected, which reduces this effect. If a component is unable to dissolve in the mobile phase it will not move from the origin.

Total 2 + 1 + 2 = 5 marks

## Question 3

**3a.** Consider the compound represented by the structure shown below.



Give the name of this compound.

**Solution**

propan-1-ol or 1-propanol

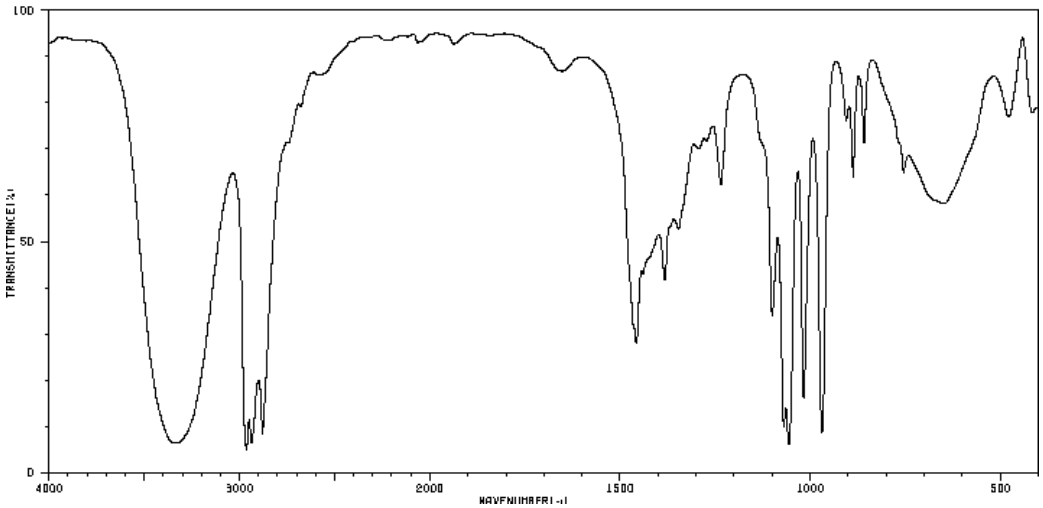
1 mark

**Explanatory notes**

- The compound contains an unbroken 3-carbon chain; hence, it has the prefix *prop*-. The presence of the hydroxy (OH) group indicates that it is an alkanol; hence, it has the suffix *-anol*. The location of the hydroxy group must be specified. It is on the first carbon, so the compound is propan-1-ol.
- Naming the compound simply propanol does not receive any marks.

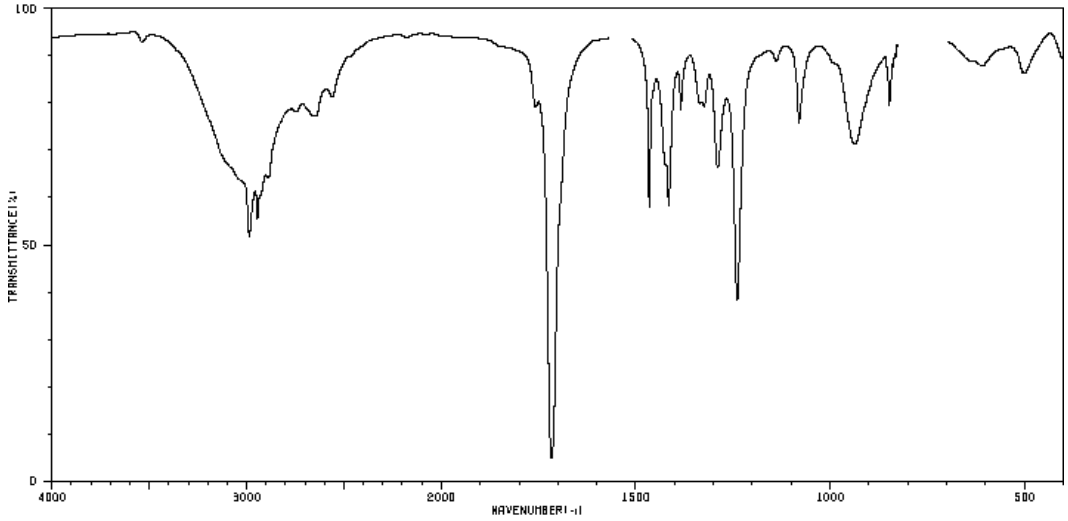
**i.** Consider the two infra-red spectra below.

Spectrum A




SDBSWeb: http://riodb01.ibase.aist.go.jp/sdbs/ (National Institute of Advanced Industrial Science and Technology, accessed 11/03/2008)

Spectrum B




SDBSWeb: http://riodb01.ibase.aist.go.jp/sdbs/ (National Institute of Advanced Industrial Science and Technology, accessed 11/03/2008)

Which of the spectra, A or B, is most likely to be the spectrum of the compound with the structural formula shown above? Explain how you arrived at your answer.

**Solution**

Answer is A.

The O–H bond in the alkanols causes infra-red absorption in the range 3200–3550 $cm^{-1}$, which is evident in spectrum A.

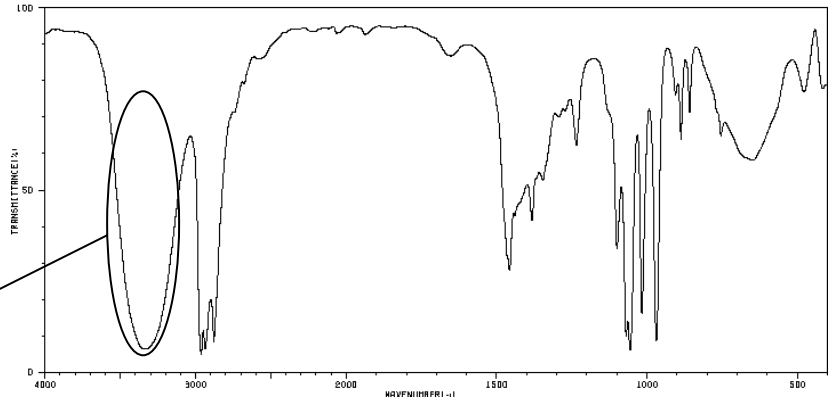
2 marks

**Mark allocation**

- 1 mark for correctly answering spectrum A.
- 1 mark for explaining that absorption due to O–H bond is evident in spectrum A.

**Explanatory notes**

- Infra-red absorption provides information about the functional groups present in a compound. The structure given in this question is an alkanol and contains the hydroxyl (–OH) functional group. It absorbs radiation over a typical narrow range of wavelengths, which will be evident on an infra-red spectrum of the compound. It is circled on the spectrum below.



**Tips**

- *The infra-red absorption data referred to in the solution is included in the data booklet.*

**3c.** How many peaks, in addition to the TMS signal, would you expect to see in the $^{13}C$ NMR spectrum of this compound? Give a reason for your answer.

**Solution**

Three peaks

There are three different carbon environments in the molecule.

2 marks

**Mark allocation**

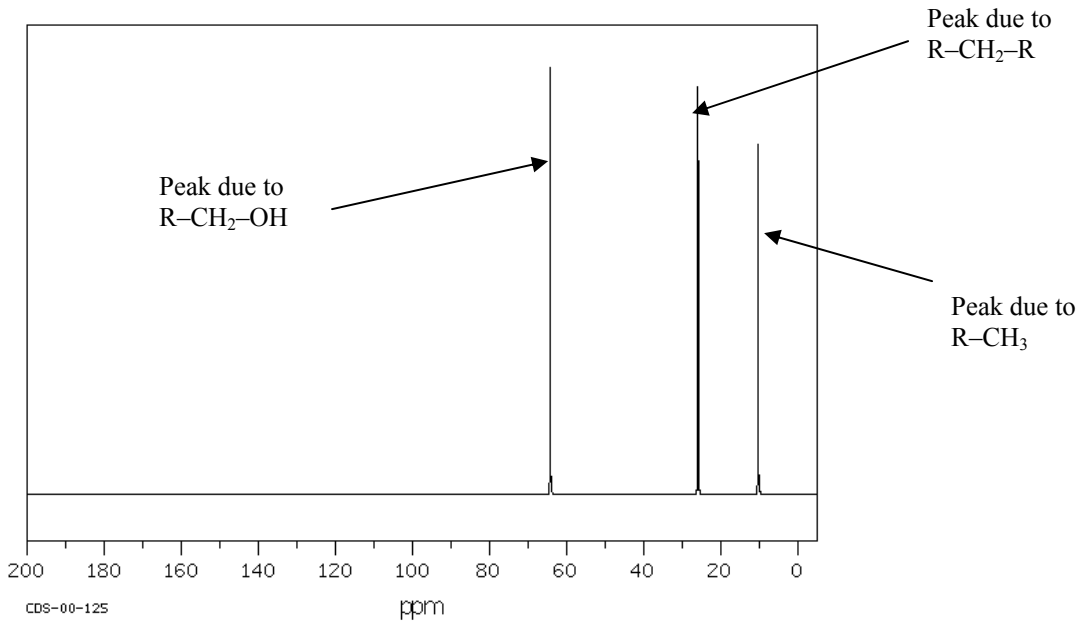
- 1 mark for correctly answering three peaks.
- 1 mark for explaining that there are three different carbon environments.

**Explanatory notes**

$^{13}C$ NMR gives information about the different environments of the carbon atoms in a molecule. This molecule has three different carbon environments:

- $R–CH_2–OH$, which has a chemical shift of 50–90 ppm.
- $R–CH_2–R$, which has a chemical shift of 20–45 ppm.
- $R–CH_3$, which has a chemical shift of 8–25 ppm.

Each carbon atom produces a different peak in the $^{13}NMR$ spectrum:




SDBSWeb: http://riodb01.ibase.aist.go.jp/sdbs/ (National Institute of Advanced Industrial Science and Technology, accessed 11/03/2008)

**Tips**

- *The chemical shift data referred to in the solution is included in the data booklet.*

**3d.** All types of spectroscopy use a part of the electromagnetic spectrum. One spectroscopic technique is used in the analysis of sodium chloride in potato chips. This technique uses radiation from the visible part of the electromagnetic spectrum to give quantitative information.

**i.** Name the spectroscopic technique used in this analysis.

**Solution**

Atomic absorption spectroscopy

1 mark

**Explanatory notes**

- Atomic absorption spectroscopy, flame tests, atomic emission spectroscopy and general colorimetry are the only spectroscopic techniques that use radiation from the visible part of the electromagnetic spectrum. However, flame tests and atomic emission spectroscopy provide only qualitative information about the material being analysed. Only atomic absorption spectroscopy can quantitatively analyse metal atoms present, such as when sodium chloride is sprayed into the flame and visible light of the correct wavelength passes through the excited sodium atoms. The other spectroscopic techniques (e.g. UV-visible, IR and NMR) use radiation in the part of the spectrum that is not visible.

**ii.** Identify the type of lamp that should be used in this analysis. Give a reason for your answer.

**Solution**

A sodium lamp.

It will emit the particular wavelength required to excite sodium atoms.

2 marks

**Mark allocation**

- 1 mark for sodium lamp.
- 1 mark for emits the particular wavelength required to excite sodium atoms.

Total 1 + 2 + 2 + 3 = 8 marks

**Question 4**

Consider the reactions below.

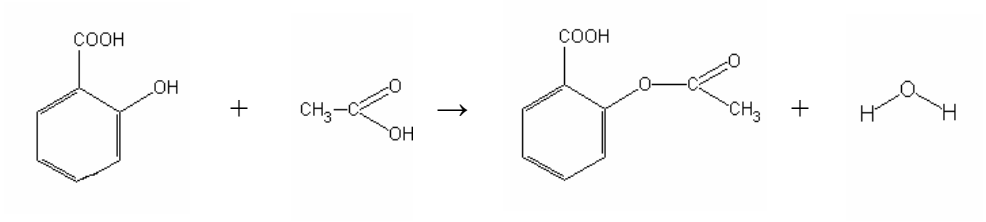
A $C_6H_{12}O_6(aq) \rightarrow 2CH_3CH_2OH(aq) + 2CO_2(g)$

B $C_3H_8O_3(aq) + 3C_{18}H_{36}O_2(aq) \rightarrow C_{57}H_{110}O_6(aq) + 3H_2O(l)$

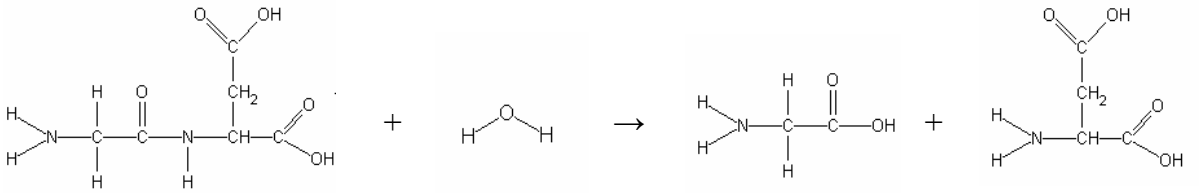
C $C_3H_8O_3(aq) + 3C_{18}H_{34}O_2(aq) \rightarrow C_{57}H_{104}O_6(aq) + 3H_2O(l)$

D $CH_2CH_2(g) + H_2O(g) \rightarrow CH_3CH_2OH$

E



F



G $4C_6H_{12}O_6(aq) \rightarrow 2C_{12}H_{22}O_{10}(aq) + 2H_2O(l)$

H $CH_3CH_2CH_2Br(aq) + NH_3(g) \rightarrow CH_3CH_2CH_2NH_2(aq) + HBr(g)$

Using the letters A–H, indicate which one or more of the reactions represented by the equations above fits the descriptions below. The equations can appear more than once.

**4a.** An addition reaction

**Solution**

Answer is reaction D.

1 mark

**Explanatory notes**

- An addition reaction is one during which a reactant molecule is added to an unsaturated hydrocarbon across the C=C double bond.
- Reaction D is an addition reaction. Water is added to the unsaturated ethene to produce ethanol.
- Reaction A is the fermentation of glucose to ethanol and carbon dioxide.
- Reaction B is a condensation reaction between glycerol and three fatty acids to produce a triglyceride and water.

- Reaction C is also a condensation reaction between glycerol and three fatty acids, producing a triglyceride and water.
- Reaction E is a condensation reaction between salicylic acid and ethanoic acid to produce acetylsalicylic acid (aspirin) and water.
- Reaction F is a hydrolysis reaction during which a dipeptide reacts with water to produce two amino acids.
- Reaction G is a condensation reaction between glucose molecules, producing sucrose and water.
- Reaction H is a substitution reaction during which the bromo group on 1-bromopropane is replaced with an amino group, producing the amine 1-aminopropane.

**4b.** Involves a reaction between hydroxy and carboxy functional groups

**Solution**

Reactions B, C and E.

1 mark

**Explanatory notes**

- The reaction between hydroxy and carboxy functional groups is a condensation reaction, resulting in an ester linkage. Water will be a product.
- Reaction B is a condensation reaction between three hydroxy groups on a glycerol molecule and the carboxy groups on three fatty acids, producing a triglyceride and water.
- Reaction C also is a condensation reaction between three hydroxy groups on a glycerol molecule and the carboxy groups on three fatty acids, producing a triglyceride and water.
- Reaction E is a condensation reaction between a hydroxy group on the salicylic acid and a carboxy group on the ethanoic acid to produce aspirin and water.

**4c.** Is catalysed by enzymes in yeast

**Solution**

Answer is reaction A.

1 mark

**Explanatory notes**

Reaction A is the fermentation of glucose to ethanol and carbon dioxide. It is an anaerobic process catalysed by enzymes in yeast.

**4d.** Involves an unsaturated fatty acid

**Solution**

Reactions B and C.

1 mark

**Explanatory notes**

- $C_{18}H_{36}O_2$ and $C_{18}H_{34}O_2$ are both unsaturated fatty acids, meaning that they each contain a C=C double bond. Saturated fatty acids can be considered to have the molecular formula $C_nH_{2n+2}O_2$. The fatty acid with formula $C_{18}H_{36}O_2$ has two fewer H atoms than a saturated fatty acid, giving it one C=C double bond and making it monounsaturated, whereas the fatty acid with formula $C_{18}H_{34}O_2$ has four fewer H atoms, giving it two C=C double bonds and making it polyunsaturated.

**4e.** A condensation reaction

**Solution**

Reactions B, C, E and G.

1 mark

**Explanatory notes**

- A condensation reaction is a reaction between two molecules, which therefore eliminates a small molecule such as water.
- Reaction B is a condensation reaction because the reaction between glycerol and three fatty acids to produce a triglyceride eliminates water.
- Reaction C is a condensation reaction because the reaction between glycerol and three fatty acids to produce a triglyceride eliminates water.
- Reaction E is a condensation reaction because the reaction between salicylic acid and ethanoic acid to produce acetylsalicylic acid (aspirin) eliminates water.
- Reaction G is a condensation reaction because the reaction between glucose molecules to produce sucrose eliminates water.

**4f.** A substitution reaction

**Solution**

Reaction H

1 mark

**Explanatory notes**

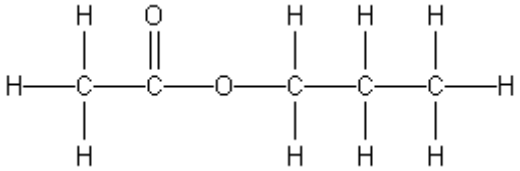
- A substitution reaction involves the replacement of an atom or group of atoms by another atom or group of atoms.
- In Reaction H, a bromine atom is replaced by an amino group.

Total 1 + 1 + 1 + 1 + 1 + 1 = 6 marks

**Question 5**

**5a.** Draw the structural formula for propyl ethanoate. Clearly show all bonds.

**Solution**



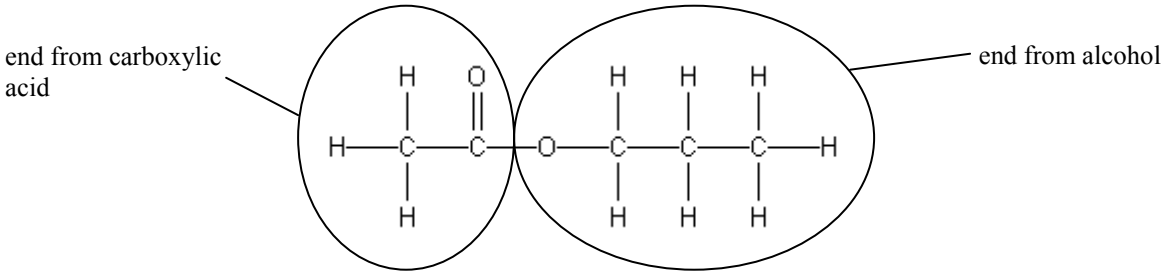
1 mark

**Mark allocation**

- 1 mark for the correct structure. It must be fully expanded and show all atoms.

**Explanatory notes**

Propyl ethanoate is the name of an ester. The first part of the name (propyl) indicates the alkanol from which it formed (i.e. propenol); hence, the end connected to the –O– in the ester linkage has 3 carbon atoms. The second part of the name (ethanoate) indicates the carboxylic acid from which it formed (i.e. ethanoic acid); hence, the end connected to the  in the ester linkage has 2 carbon atoms.




**Tips**

- *When asked to show all bonds, the structure must be fully expanded and include all atoms, including hydrogen atoms.*

**5b.** Design a reaction pathway for the synthesis of propyl ethanoate from propane and ethene. Include all relevant chemical equations.

**Solution**

Step 1: Production of propanol from propane via chloropropane.

$$\underset{\text{propane}}{CH_3CH_2CH_3(g)} + Cl_2(g) \xrightarrow{\text{heat or light}} \underset{\text{chloropropane}}{CH_3CH_2CH_2Cl(g)} + HCl(g)$$

$$\underset{\text{chloropropane}}{CH_3CH_2CH_2Cl} + H_2O(l) \xrightarrow{\text{catalyst}} \underset{\text{propanol}}{CH_3CH_2CH_2OH(aq)} + HCl(aq)$$

Step 2: Production of ethanoic acid from ethene via ethanol.

$$\underset{\text{ethene}}{CH_2CH_2(g)} + H_2O(l) \xrightarrow[300°C]{H_3PO_4 \text{ catalyst}} \underset{\text{ethanol}}{CH_3CH_2OH(aq)}$$

$$\underset{\text{ethanol}}{CH_3CH_2OH(aq)} \xrightarrow[H^+(aq)]{MnO_4^-(aq) \text{ or } Cr_2O_7^{2-}(aq)} \underset{\text{ethanoic acid}}{CH_3COOH}$$

Step 3: Synthesis of propyl ethanoate from propanol and ethanoic acid.

$$\underset{\text{propanol}}{CH_3CH_2CH_2OH(aq)} + \underset{\text{ethanoic acid}}{CH_3COOH(aq)} \xrightarrow{H_2SO_4} \underset{\text{propyl ethanoate}}{CH_3COOCH_3CH_2CH_2OH(aq)}$$

6 marks

**Mark allocation**

- 1 mark for identification of pathway of propane → chloropropane → propenol.
- 1 mark for correct formulas and catalysts in the two equations of the propane → chloropropane → propanol pathway.
- 1 mark for identification of pathway ethene → ethanol → ethanoic acid.
- 1 mark for correct formulas and catalysts in the two equations of the ethene → ethanol → ethanoic acid pathway.
- 1 mark for balanced equation of $CH_3CH_2CH_2OH(aq) + CH_3COOH(aq) \rightarrow CH_3COOCH_3CH_2CH_2OH(aq)$.
- 1 mark for $H_2SO_4(l)$ catalyst for the esterification reaction.

**5c.** Fractional distillation can be used to separate different organic compounds and hydrocarbons.

**i.** State the physical property used to separate different components in fractional distillation.

**Solution**

Boiling temperature

1 mark

**Explanatory notes**

- Fractional distillation is based on the different boiling points of components in a mixture. The mixture is heated and vapours rise up a fractionating column. A process of evaporation and condensation is repeated throughout the column, increasing the concentration of the components with the lowest boiling points in the vapour.

**ii.** Describe one structural feature of hydrocarbons that influence their separation using fractional distillation.

**Solution**

One of:

The size of the molecules

The branching of the molecules

Presence of double bonds

1 mark

**Explanatory notes**

- The boiling temperature of a hydrocarbon is an indication of the energy required to separate the molecules from each other.
- Hydrocarbons are non-polar molecules so the only intermolecular attraction present is dispersion forces. The size of dispersion forces increase as molecular size increases; hence, more energy is required to separate larger molecules from each other and a higher boiling temperature is required.
- Branching of hydrocarbon chains influences how easily they pack together. Unbranched hydrocarbon chains pack together more closely than branched hydrocarbons and so require more energy; hence, a higher boiling temperature is required for their separation.
- Double bonds also prevent hydrocarbon molecules from packing together as closely; hence, their presence lowers the boiling temperature.

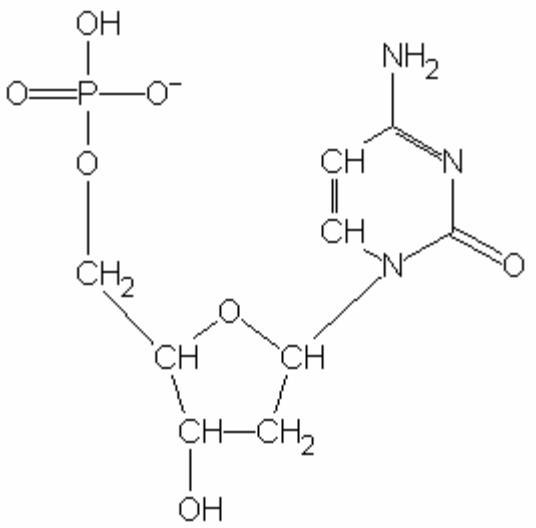
Total 1 + 6 + 2 = 9 marks

**Question 6**

Deoxyribonucleic acid (DNA) provides the genetic code for all living things. Its structure codes for particular sequences of amino acids, which link together to form proteins.

**6a.** Draw the structure of a single nucleotide that includes the base cytosine.

**Solution**




2 marks

**Mark allocation**

- 1 mark for the phosphate and deoxyribose groups.
- 1 mark for the cytosine group.

**Explanatory notes**

- A nucleotide consists of a phosphate group, a deoxyribose sugar and a base; in this case, cytosine. There are four different nucleotides that differ according to the type of base they contain. The four bases are adenine (A), cytosine (C), guanine (G) and thymine (T).

**Tips**

- *The structures of the deoxyribose sugar and all four of the bases (i.e. A, C, T and G) are in the data booklet.*

**6b.** Describe the secondary structure of a DNA polymer.

**Solution**

The secondary structure is a pair of DNA strands held together by hydrogen bonding. The bases adenine and thymine always pair as do the bases cytosine and guanine. The paired structure twists to form a double helix.

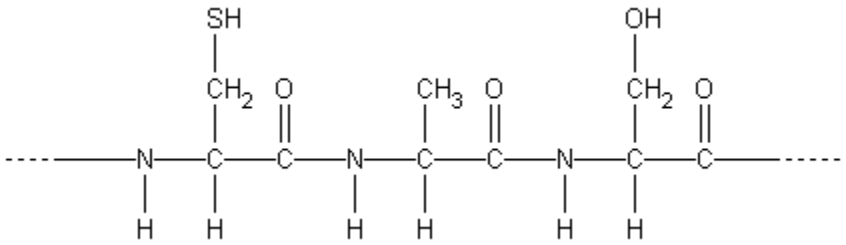
2 marks

**Mark allocation**

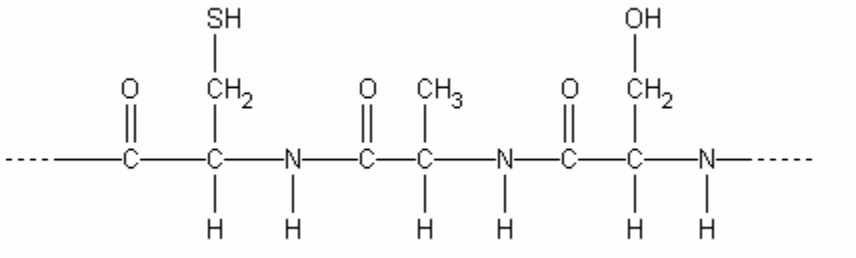
- 1 mark for hydrogen bonding between bases A–T and C–G.
- 1 mark for double helix.

**6c.** A section of one strand of DNA codes for a protein that includes the amino acids cysteine, alanine and serine, in that order. Draw the structure of this section of the protein.

**Solution**



or



1 mark

**Explanatory notes**

- Amino acids link together to form a protein through condensation reactions between the carboxy functional group on one amino acid and the amino group on another. Two structures are possible for this section of the protein, depending on which carboxy and amino groups react.

**6d.** Describe how the Z group of cysteine may contribute to the tertiary structure of the protein.

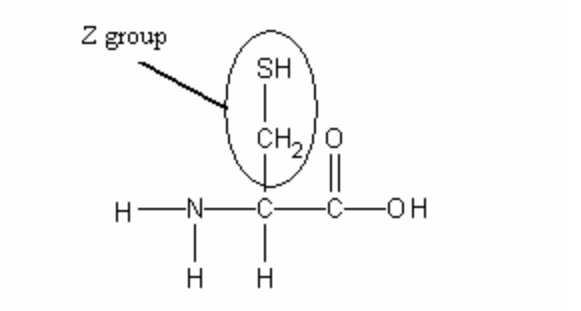
**Solution**

Covalent disulfide bonds may form between two cysteine amino acids/sulfur atoms on different amino acids.

1 mark

**Explanatory notes**

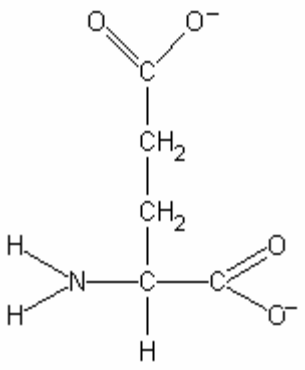
- The structure of cysteine with the Z group circled is shown below.




- Tertiary structure is the overall 3D shape of a protein and is determined by interactions between the Z groups on different amino acids. The types of interactions can include hydrogen bonds, covalent cross-links, ionic interactions and dispersion force. The sulfur atom on the cysteine Z group would be able to take part in a covalent cross-link with a sulfur atom on the Z group of another cysteine amino acid.

**6e.** Draw the structure of glutamic acid as it would appear in a solution of pH 12.

**Solution**




1 mark

**Explanatory notes**

- A solution of pH 12 is a basic solution. The amino acid will act as a buffer and donate all $H^+$ ions from the acidic groups to the solution. For glutamic acid, this includes the $H^+$ ions on each of the two carboxyl groups, one of which forms part of the Z group/side-chain.

**Tips**

- *The structure of glutamic acid is given in the data booklet.*

**6f.** Give one example of how the presence of a protein can be used as a marker for disease.

**Solution**

- There are many potential examples. Several are given below.
- Detection of specific antibodies produced in response to a specific disease.
- Detection of a specific protein known to be produced by damaged or diseased body organs.
- Detection of increased levels of enzymes produced during a heart attack.

1 mark

Total 2 + 2 + 1 + 1 + 1 + 1 = 8 marks

**END OF SOLUTIONS BOOK**