INSIGHT

Trial Exam Paper

2011

CHEMISTRY

Written examination 1

Solutions book

This book presents:

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

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SECTION A – Multiple-choice questions

Question 1

20.00 mL of 0.10 M sodium hydroxide is placed in a volumetric flask and titrated with 0.10 M ethanoic acid. The volume of ethanoic acid required to react completely with the sodium hydroxide and the approximate pH at the equivalence point would be closest to

	Volume of ethanoic acid required (mL)	**pH at equivalence point**
A.	less than 20.00 mL	7
B.	less than 20.00 mL	greater than 7
C.	20.00 mL	7
D.	**20.00 mL**	**greater than 7**

Answer is D.

Explanatory notes

- D is correct because sodium hydroxide and ethanoic acid react in a 1 : 1 ratio. They are of equal concentration and so will require equal volumes to react completely; hence, the volume of ethanoic acid required is 20.00 mL. Sodium hydroxide is a strong base whereas ethanoic acid is a weak acid, so the equivalence point will be greater than pH 7.
- A is incorrect because although ethanoic acid is a weak acid and sodium hydroxide is a strong base, they still react in a 1 : 1 ratio. They are of equal concentration, so will require equal volumes to react completely; hence, the volume of ethanoic acid required is 20.00 mL. In addition, the pH at the equivalence point will be greater than pH 7 because sodium hydroxide is a strong base and ethanoic acid is only a weak acid.
- B is incorrect because although ethanoic acid is a weak acid and sodium hydroxide is a strong base, they still react in a 1 : 1 ratio. They are of equal concentration, so will require equal volumes to react completely; hence, the volume of ethanoic acid required is 20.00 mL.
- C is incorrect because the pH at the equivalence point will be higher than pH 7 as this is a titration between a strong base and a weak acid.

Tips

- *Students often mistakenly believe that the strength of an acid or base affects the amount of that acid or base required to react completely with another acid or base.*

Question 2

For which of the following titrations between 0.10 M reactants will phenolphthalein be a suitable choice for indicator?

I $C_2H_5COOH(aq) + NaOH(aq) \rightarrow C_2H_5COONa(aq) + H_2O(l)$
II $NaOH + NH_4^+ \rightarrow Na^+(aq) + NH_3(g) + H_2O(l)$
III $KOH(aq) + HCl(aq) \rightarrow KCl(aq) + H_2O(l)$
IV $NH_4^+(aq) + Cl^-(aq) \rightarrow NH_4Cl(aq)$

A. I and IV only
B. **I and II only**
C. I, II and III
D. III only

Answer is B.

Explanatory notes

- B is correct because the indicator selected for a titration should have an endpoint that is as close as possible to the equivalence point of the reaction. Phenolphthalein has a pH range of 8.3–10.0, so is suitable for titrations that involve a strong base and a weak acid where the equivalence point will be greater than pH 7.
- A is incorrect because although titration II is suitable for the use of phenolphthalein, titration IV is not an acid–base reaction.
- C is incorrect because titration III is between a strong acid and a strong base, so will have an equivalence point at about pH 7, for which phenolphthalein is not suitable.
- D is incorrect because titration III is between a strong acid and a strong base, so will have an equivalence point at about pH 7, for which phenolphthalein is not suitable.

Tips

- *You may point out to students that list of acid-base indicators and the pH range of their endpoints is given on page 11 of the Data Book.*

Question 3

Caffeine, $C_8H_{10}N_4O_2$ (molar mass 194 g mol^{-1}), is the stimulant found in coffee and a number of soft drinks. A 270 mL cup of coffee is found to contain 420 mg of caffeine.
What mass, in g, of nitrogen originating from caffeine, will be present in 1.00 L of coffee?

A. 0.121

B. 0.289

C. 0.450

D. 1.56

Answer is C.

Explanatory notes

- C is correct according to the following steps:

  Step 1: Calculate the mass, in g, of caffeine in 1.00 L of coffee.

  $$m(\text{caffeine) in 1.0 L} = \frac{1.00}{0.270} \times 0.420 = 1556 \text{ mg} = 1.56 \text{ g}$$

  Step 2: Calculate the percentage by mass of nitrogen in caffeine.

  $$\begin{aligned}\%\text{ by mass} &= \frac{\text{mass due to N atoms}}{\text{molar mass of molecule}} \times 100 \\ &= \frac{4 \times 14.0}{8 \times 12.0 + 10 \times 1.0 + 4 \times 14.0 + 2 \times 16.0} \times 100 \\ &= \frac{56.0}{194} \times 100 \\ &= 28.9\%\end{aligned}$$

  Step 3: Calculate the mass of nitrogen in the 1.56 g of caffeine
  28.9% of 1.56 = 0.450 g

- A is incorrect because 0.121 g is the mass of nitrogen in a 270 mL cup of coffee, not 1.00 L of coffee.
- B is incorrect because 28.9 is the percentage by mass of nitrogen in caffeine, not the mass of nitrogen in the 1.56 g sample.
- D is incorrect because 1.56 g is the mass of caffeine in 1.00 L, not the mass of nitrogen in that amount of caffeine.

Tips

- *You may want to remind students to always convert masses to grams for use in mole calculations.*

Question 4

A dipeptide is produced by a reaction between 10.0 g each of the amino acids cysteine (M = 121.2 g mol^{-1}) and glycine (M = 75.1 g mol^{-1}). The mass, in g, of water eliminated in the reaction is

A. 0.0825

B. **1.49**

C. 2.39

D. 2.98

Answer is B.

Explanatory notes

- B is correct according to the following steps:

  Step 1: Determine which amino acid is the limiting reactant.

  $$n(\text{cysteine}) = \frac{m}{M}$$
  $$= \frac{10.0}{121.2}$$
  $$= 0.0825 \text{ mol}$$
  $$n(\text{glycine}) = \frac{m}{M}$$
  $$= \frac{10.0}{75.1}$$
  $$= 0.133 \text{ mol}$$

  The amino acids react in a 1 : 1 ratio to produce a dipeptide, so cysteine is the limiting reactant.

  Step 2: Determine the amount, in mol, of water produced in the reaction.
  One water molecule is eliminated for each pair of amino acids linked together.
  So, $n(H_2O) = n(\text{cysteine}) = 0.0825$ mol

  Step 3: Calculate the mass of water produced.
  $m(H_2O) = n \times M$
  $= 0.0825 \times 18.0$
  $= 1.49$ g

- A is incorrect because 0.0825 is the amount, in mol, of water produced, not the mass.
- C is incorrect because glycine is in excess so its amount, in mol, cannot be used to predict the amount, in mol, of water produced in the reaction.
- D is incorrect because there is only one water molecule produced when two amino acids link together – not two.

Tips

- *You may want to point out to students that the structures of all amino acids are found in pages 8 and 9 of the Data Book.*

Question 5

The initial reaction that occurs when a car airbag is triggered to inflate is

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

When two moles of NaN_3 reacts, the total volume, in L, of gas produced by this reaction, as measured at 32°C and 100 kPa, is closest to

A. 7.98
B. 33.8
C. 50.7
D. **76.0**
Answer is D.

Explanatory notes

- D is correct according to the following steps:
  Step 1: Determine the amount, in mol, of $N_2(g)$ produced using the mole ratio.
  $n(N_2) : n(NaN_3)$
  3 : 2
  So $n(N_2) = \frac{3}{2} \times 2.00$
  $= 3.00$ mol
  Step 2: Determine the volume of gas produced, using the general gas equation.
  $PV = nRT$
  $100 \times V = 3.00 \times 8.31 \times (32 + 273)$
  $V = \frac{7603}{100} = 76.0$ L
- A is incorrect because the temperature must be in Kelvin for use in the general gas equation.
- B is incorrect because the ratio $n(N_2) : n(NaN_3)$ is 3 : 2, not 2 : 3.
- C is incorrect because the ratio $n(N_2) : n(NaN_3)$ is 3 : 2, not 1 : 1.

Tips

- *You may want to remind students that temperature must always be converted to Kelvin using T = t(°C) + 273 for use in the gas equations.*

Question 6

In a particular solvent used for thin-layer chromatography (TLC), compounds A and B have R_f values, as shown in the table below.

Compound	R_f value
A	0.46
B	0.15

In one analysis, compound A travels 3.5 cm from the origin. The origin is marked at 0.7 cm from the bottom of the plate.
The distance, in cm, travelled by compound B from the origin will be

A. 0.91
B. **1.14**
C. 1.84
D. 4.2

Answer is B.

Explanatory notes

- B is correct, as the R_f value is calculated as:
$$\frac{\text{distance travelled by compound from the origin}}{\text{distance travelled by solvent front from the origin}}$$

  The data for compound A enables us to determine the distance travelled by the solvent front from the origin.

  For compound A $0.46 = \dfrac{3.5}{\text{distance travelled by solvent front from the origin}}$

  Distance travelled by solvent front = 7.6 cm

  For compound B $0.15 = \dfrac{\text{distance travelled by compound from the origin}}{\text{distance travelled by solvent front from the origin}}$

  $= \dfrac{\text{distance travelled by compound from the origin}}{7.6}$

  Distance travelled by compound B from the origin = $0.15 \times 7.6 = 1.14$ cm

- A is incorrect because 3.5 cm is the distance travelled by compound A. This is the value used to determine the distance travelled by the solvent front.
- C is incorrect because 1.84 cm is the distance compound B has travelled from the bottom of the plate. The question asks for distance travelled from the origin.
- D is incorrect because 4.2 cm is the distance travelled by compound A from the bottom of the plate. The question asks for the distance travelled by compound B from the origin.

Tips

- *If asked to explain how R_f is calculated, specify that it is the distance travelled by a component* from the origin *divided by the distance travelled by the solvent* from the origin.

Question 7

Which of the following analytical techniques is **least** likely to be used as part of a series of analyses performed to identify an unknown organic compound and determine its concentration in a mixture?

A. gas liquid chromatography

B. mass spectrometry

C. infrared spectroscopy

D. atomic absorption spectroscopy

Answer is D.

Explanatory notes

- D is correct because atomic absorption spectroscopy (AAS) is generally used for the analysis of inorganic substances, such as metals.
- A is incorrect because gas liquid chromatography could be used to perform quantitative analysis of an organic compound. It will allow the concentration to be determined.
- B is incorrect because mass spectrometry will allow the determination of the molar mass of an organic compound, which will assist in its identification.
- C is incorrect because IR spectroscopy will allow for the identification of functional groups in the organic compound, which will assist in its identification.

Question 8

When a sample absorbs radiowaves during NMR spectroscopy

A. electrons in atoms are promoted to higher energy levels.

B. **nucleons are promoted to higher energy spin states.**

C. molecules move to higher vibrational energy levels.

D. molecules are ionised.

Answer is B.

Explanatory notes

- B is correct because when certain nucleons (i.e. protons and neutrons) in an external magnetic field absorb radiowaves, they can move from lower energy spin states to higher energy states. This is the basis for NMR.
- A is incorrect because radiowaves are too low in energy to promote electrons in atoms to higher energy levels. This requires higher energy in the form of light or heat and is the basis for AAS.
- C is incorrect because radiowaves are too low in energy to promote molecules to higher vibrational energy levels. This requires infrared radiation and is the basis for IR spectroscopy.
- D is incorrect because radiowaves do not ionise molecules. Molecules are ionised by a high energy beam of electrons in mass spectroscopy.

Question 9

The concentration of copper ions in ground water is to be analysed using atomic absorption spectroscopy. A sample of the water is sprayed into a flame and a light is passed through.

A. A zinc lamp should be used and the intensity of the light will be greater after passing through the sample in the flame.

B. A zinc lamp should be used and the intensity of the light will reduce after passing through the sample in the flame.

C. A copper lamp should be used and the intensity of the light will be greater after passing through the sample in the flame.

D. **A copper lamp should be used and the intensity of the light will reduce after passing through the sample in the flame.**

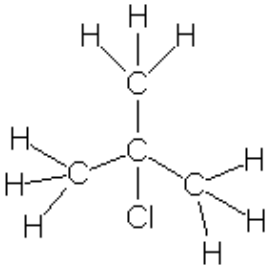
Answer is D.

Explanatory notes

- D is correct because the lamp should be composed of the element of interest, in this case copper, as it will produce the correct wavelength of light required for the analysis. When the light is shone through the sample, some of the light is absorbed to promote electrons to a higher energy level. The intensity of the light will be reduced after passing through the flame.
- A is incorrect because the lamp should be composed of the element of interest, which in this case is copper. Furthermore, when the light is shone through the sample some of it is absorbed to promote electrons to a higher energy level, so its intensity will be reduced after passing through the flame.
- B is incorrect because the lamp should be composed of the element of interest, which in this case is copper.
- C is incorrect because when the light is shone through the sample some if it is absorbed to promote electrons to a higher energy level, so its intensity will be reduced after passing through the flame.

Question 10

What is the correct systematic name for the following compound?



A. 2-methyl-chloropropane

B. 2-methyl-chlorobutane

C. 2-chloro-2-methylpropane

D. 2-chloro-2-methylbutane

Answer is C.

Explanatory notes

- C is correct because this molecule has no double bonds and has three carbon atoms in the longest chain, so is a propane. There is a chloro group on carbon 2 and also a methyl group on carbon 2, giving it the name 2-chloro-2-methylpropane.
- A is incorrect because the number of the carbon that the chloro group is attached to must be specified.
- B is incorrect because this molecule has only three atoms in the longest chain and so it is a propane, not a butane. Furthermore, the number of the carbon that the chloro group is attached to must be specified.
- D is incorrect because this molecule has only three atoms in the longest chain and so is a propane, not a butane.

Question 11

For which of the following molecular formulae are there four possible isomers?

I C_3H_7Cl
II C_4H_9Cl
III $C_3H_6Cl_2$

A. I and II only
B. II only
C. II and III only
D. I, II and III

Answer is C.

Explanatory notes

- C is correct because the four possible structures of formula II are 1-chlorobutane; 2-chlorobutane; 2-chloro-2-methylpropane; and 1-chloro-2-methylpropane. The possible structures of formula III are 1,1-dichloropropane; 1,2-dichloropropane; 2,2-dichloropropane; and 1,3-dichloropropane.
- A is incorrect because formula I has only two possible structures. These are 1-chloropropane and 2-chloropropane. Also, formula III has four possible structures.
- B is incorrect because formula III has four possible structures.
- D is incorrect because formula I has only two possible structures. These are 1-chloropropane and 2-chloropropane.

Question 12

Which of the following amino acids will have the highest pH when dissolved in solution?

A. aspartic acid
B. histidine
C. lysine
D methionine

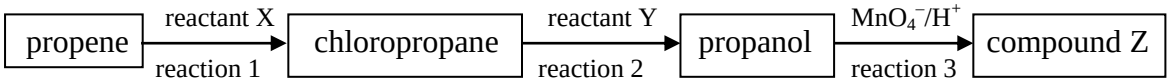
Answer is C.

Explanatory notes

- C is correct because the Z group of lysine contains a basic amine group ($–NH_2$), so when dissolved in water it will have the most basic, or highest, pH.
- A is incorrect because the Z group of aspartic acid contains an acidic carboxyl group (–COOH), so when dissolved in water it will be acidic, or have the lowest pH.
- B is incorrect because the Z group of histidine has neither acidic nor basic groups, so when dissolved in water it will have a neutral pH.
- D is incorrect because the Z group of methionine has neither acidic nor basic groups, so when dissolved in water it will have a neutral pH.

Questions 13 and 14 refer to the following information.

Propene can be converted into other types of carbon compounds according to the following flow chart.



Question 13

What could compounds X, Y and Z be, respectively?

A. Cl_2, NaOH, propanoic acid
B. Cl_2, H_2O, propene
C. **HCl, NaOH, propanoic acid**
D. HCl, H_2O, propene

Answer is C.

Explanatory notes

- C is correct because conversion of an alkene to a chloroalkane requires the addition of HCl across the double bond; the conversion of a chloroalkane to an alkanol requires the substitution of a hydroxide ion; and reaction of an alkanol with a strong oxidising agent in acidic media converts it to a carboxylic acid.
- A is incorrect because conversion of an alkene to a chloroalkane requires the addition of HCl across the double bond.
- B is incorrect because conversion of an alkene to a chloroalkane requires the addition of HCl across the double bond; the conversion of a chloroalkane to an alkanol requires a hydroxide ion, not water; and reaction of an alkanol with a strong oxidising agent in acidic media converts it to a carboxylic acid, not an alkene.
- D is incorrect because conversion of a chloroalkane to an alkanol requires a hydroxide ion, not water; and the reaction of an alkanol with a strong oxidising agent in acidic media converts it to a carboxylic acid, not an alkene.

Question 14

Reactions 1, 2, and 3 can be described, respectively, as

A. **addition, substitution, oxidation.**
B. addition, oxidation, condensation.
C. substitution, condensation, oxidation.
D. substitution, substitution, oxidation.

Answer is A.

Explanatory notes

- A is correct because in reaction 1, an H atom and a Cl atom are added across the double bond; in reaction 2 an –OH functional group replaces the Cl atom; and in reaction 3 an alkanol is oxidised to a carboxylic acid.
- B is incorrect because reaction 2 is a substitution reaction and reaction 3 is an oxidation reaction.
- C is incorrect because reaction 1 is an addition reaction and reaction 2 is a substitution reaction with an –OH group replacing the –Cl.
- D is incorrect because reaction 1 is an addition reaction.

Question 15

Which of the following amino acids is **most** likely to form covalent bonds at the tertiary structure level of a protein?

A. asparagine

B. isoleucine

C. cysteine

D. serine

Answer is C.

Explanatory notes

- C is correct because cysteine contains an –SH on its Z group, allowing it to form covalent disulfide bonds with a cysteine elsewhere in the protein.
- Options A, B and D are incorrect because their Z groups provide no easy way of forming a covalent bond with other amino acids elsewhere in the protein.

Question 16

A tripeptide consists of three different amino acids: A, B and C. What is the maximum number of possible tripepetides that can be formed?

A. 3

B. 4

C. 5

D. 6

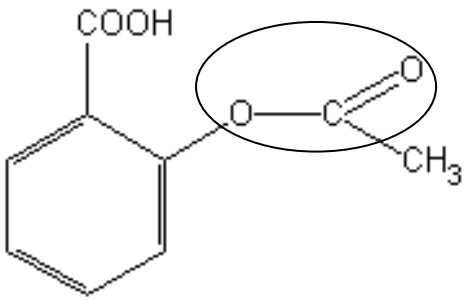
Answer is D.

Explanatory notes

- D is correct because the possible combinations are ABC, ACB, BAC, BCA, CAB and CBA, giving six possibilities.
- Options A, B and C are incorrect as there are six possible tripeptides that could be formed.

Question 17

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



What is the molar mass of aspirin and the name of the circled linkage?

A. 180 g mol^{-1}, ester

B. 176 g mol^{-1}, ester

C. 180 g mol^{-1}, ether

D. 176 g mol^{-1}, ether

Answer is A.

Explanatory notes

- A is correct because the ester linkage is formed by a condensation reaction between a hydroxyl group and a carboxyl group. The molecular formula of aspirin can be worked out to be $C_9H_8O_4$. The molar mass = $9 \times 12.0 + 8 \times 1.0 + 4 \times 16.0 = 180$ g mol^{-1}.
- B is incorrect because the molecular formula of aspirin can be worked out to be $C_9H_8O_4$. There are four H atoms on the benzene ring.
- C is incorrect because the circled linkage is an ester linkage.
- D is incorrect because the circled linkage is an ester linkage and the molar mass is 180 g mol^{-1}.

Questions 18 and 19 refer to the following information.

The percentage by mass of sodium ions in the form of sodium chloride in a particular brand of gravy powder was determined using gravimetric analysis. A 2.67 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 0.187 g.

Question 18

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

A. 0.033%

B. **1.12%**

C. 2.24%

D. 2.85%

Answer is B.

Explanatory notes

- B is correct according to the following calculations:
  Step 1: Calculate the amount, in mol, of precipitate formed.

$$n(\text{AgCl}) = \frac{m}{M}$$
$$= \frac{0.187}{(107.9 + 35.5)}$$
$$= \frac{0.187}{143.4}$$
$$= 1.30 \times 10^{-3} \text{ mol}$$

  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.

$$\text{NaCl(aq)} + \text{AgNO}_3\text{(aq)} \rightarrow \text{NaNO}_3\text{(aq)} + \text{AgCl(s)}$$

  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(NaCl) : n(AgCl)
  1 : 1

$$\text{So } n(\text{NaCl}) = \frac{1}{1} \times n(\text{AgCl})$$
$$= 1.30 \times 10^{-3} \text{ mol}$$

  Step 4: Calculate the amount, in mol, of Na^+ ions.
  According to the ionic formula, there is one Na^+ ion in the NaCl formula.

$$\text{So } n(\text{Na}^+) = n(\text{NaCl})$$
$$= 1.30 \times 10^{-3} \text{ mol}$$

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

$$m(\text{Na}^+) = nM$$
$$= 1.30 \times 10^{-3} \times 23.0$$
$$= 0.0300 \text{ g}$$

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

$$\text{Percentage by mass} = \frac{\text{mass of } Na^+}{\text{mass of biscuits}} \times 100$$
$$= \frac{0.0300}{2.67} \times 100$$
$$= 1.12\%$$

- A is incorrect because 0.0300 g is the mass of sodium 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 sodium ions is being calculated, not the percentage by mass of sodium chloride.

Tips

- *Students must know the valencies of common ions and be confident with writing balanced chemical equations.*

Question 19

The percentage by mass of sodium chloride calculated by a student is higher than that stated on the label on the gravy powder packaging. This may be due to

I incomplete precipitation of the chloride ions.

II inadequate washing of the precipitate.

III the precipitate was not dried to constant mass.

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

A. I only

B. III and IV only

C. **II, III and IV only**

D. I, II, III, and IV

Answer is C.

Explanatory notes

- C is correct because each of these reasons would result in a precipitate that has greater mass than it should have, resulting in a higher calculated percentage by mass of sodium.
- A is incorrect because if not all of the chloride ions were precipitated, the mass of AgCl would be less, resulting in a lower percentage by mass of Na^+ and therefore NaCl.
- B is incorrect because II will also result in a higher calculated mass. Any remaining solids would add to the mass of the filtered precipitate and increase the percentage by mass.
- D is incorrect because reason I will not result in a higher mass. If not all of the chloride ions were precipitated, the mass of AgCl would be less, resulting in a lower percentage by mass of Na^+ and therefore NaCl.

Question 20

The activity of a particular enzyme is reduced at temperatures above 40°C. Which of the following best describes this observation?

A. Hydrogen bonds in the primary structure are broken.

B. Amide linkages are broken.

C. Covalent bonds in the tertiary structure are broken.

D. Hydrogen bonds in the secondary and tertiary structures are broken.

Answer is D.

Explanatory notes

- D is correct because the temperature is only high enough to disrupt those hydrogen bonds that are found in the secondary and tertiary structures. The active site of the enzyme is disrupted and enzyme activity is reduced.
- A is incorrect because the primary structure has only covalent bonds, not hydrogen bonds.
- B is incorrect because amide linkages are covalent bonds and the temperature is not high enough to break covalent bonds.
- C is incorrect because the temperature is not high enough to break covalent bonds.

END OF SECTION A

SECTION B – Short-answer questions

Question 1

The amount of vitamin C ($C_6H_8O_6$) in a new brand of fruit juice is to be determined.
A 25.00 mL sample of juice is diluted to 250.0 mL with pure water in a volumetric flask.
20.00 mL aliquots of the diluted juice are then placed in a conical flask and titrated against a solution containing 1.80×10^{-4} mol L^{-1} I_3^- ions.

The reaction is

$$C_6H_8O_6(aq) + I_3^-(aq) \rightarrow C_6H_6O_6(aq) + 2H^+(aq) + 3I^-(aq)$$

The half-reaction for the reduction of $I_3^-(aq)$ to $I^-(aq)$ is

$$I_3^-(aq) + 2e^- \rightarrow 3I^-(aq)$$

Four titrations are carried out and the volumes of the I_3^- titres are recorded in the table below.

Titration number	1	2	3	4
Volume of I_3^- solution (mL)	16.87	16.15	17.03	16.93

a. Write a balanced half-equation, including states, for the oxidation of vitamin C.

2 marks

Solution

$C_6H_8O_6(aq) \rightarrow C_6H_6O_6(aq) + 2H^+(aq) + 2e^-$

Mark allocation

- 1 mark for correct species and balanced equation.
- 1 mark for correct states.

Explanatory notes

- Oxidation is the loss of electrons, so electrons must appear on the product side of the equation. Atoms and charge must be balanced in the equation. Two H^+ ions are required to balance the hydrogen atoms and two electrons are needed to balance the charge.

Tips

- *You may tell students to use the acronym KOHES to remember the steps needed to write a redox half-equation in acidic solution.*

K – Balance Key elements	$C_6H_8O_6 \rightarrow C_6H_6O_6$ *not required this time*
O – Balance Oxygen by adding water	$C_6H_8O_6 \rightarrow C_6H_6O_6$ *not required this time*
H – Balance Hydrogen by adding H^+ ions	$C_6H_8O_6 \rightarrow C_6H_6O_6 + 2H^+(aq)$
E – Balance charge by adding Electrons	$C_6H_8O_6 \rightarrow C_6H_6O_6 + 2H^+ + 2e^-$
S – Add States	$C_6H_8O_6(aq) \rightarrow C_6H_6O_6(aq) + 2H^+(aq) + 2e^-$

b. Calculate the average volume, in mL, of the concordant titres of the $I_3^-(aq)$ solution.

1 mark

Solution

Average volume = $\frac{16.87 + 17.03 + 16.93}{3} = 16.94$ mL

Explanatory notes

- The volume of titration number 2 is not concordant with the other titre volumes; hence, it is discarded and not included in the calculation of the average titre.

Tips

- *The key skills in the VCAA study design are examinable and include laboratory work, so make sure you do not neglect this area.*

c. Calculate the amount, in mol, of vitamin C present in each 20.00 mL aliquot.

2 marks

Solution

Step 1: Calculate the amount, in mol, of I_3^- in the average titre.
$n(I_3^-) = cV$
$= 1.80 \times 10^{-4} \times 16.94 \times 10^{-3}$
$= 3.05 \times 10^{-6}$ mol

Step 2: Use the mole ratio to calculate the amount, in mol, of vitamin C in each aliquot.
$n(I_3^-) : n(C_6H_8O_6)$ is 1 : 1.
So $n(C_6H_8O_6) = n(I_3^-) = 3.05 \times 10^{-6}$ mol.

Mark allocation

- 1 mark for $n(I_3^-) = 3.05 \times 10^{-6}$ mol.
- 1 mark for calculating the amount, in mol, of vitamin C as being equal to that of $n(I_3^-)$.

Explanatory notes

- 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.
- Numerical answers should always be expressed with the correct number of significant figures. The answers should always have the same number of significant figures as the least accurate piece of data used in the calculation. In this case, it is the concentration of I_3^- ions that has three significant figures.

Tips

- *It is a common error for students to forget to convert volumes from mL to L for use in calculations. You may want to remind students to do this.*
- *It can be confusing when an analysis question involves a number of different volume amounts. It can be helpful for students to sketch a diagram of the glassware and volumes to make sure they are very clear about the procedure.*
- *Students can earn a consequential mark even if they calculate $n(I_3^-)$ incorrectly provided they use the 1 : 1 ratio correctly to determine $n(C_6H_8O_6)$.*

d. Calculate the concentration, in mol L^{-1}, of vitamin C in the original (i.e., undiluted) sample of fruit juice.

2 marks

Solution

Step 1: Determine the amount, in mol, of vitamin C in the 250.0 mL flask.

$$n(C_6H_8O_6) = \frac{250.0}{20.0} \times 3.05 \times 10^{-6}$$
$$= 3.81 \times 10^{-5} \text{ mol}$$

Step 2: Determine the concentration of vitamin C in the 25.00 mL sample of juice.

$$C(C_6H_8O_6) = \frac{n}{V}$$
$$= \frac{3.81 \times 10^{-5}}{25.00 \times 10^{-3}}$$
$$= 1.53 \times 10^{-3} \text{ M}$$

Mark allocation

- 1 mark for $n(C_6H_8O_6)$ in flask and sample of juice = 3.81×10^{-5} mol.
- 1 mark for calculating concentration of vitamin C correctly.

Tips

- *Students can earn a consequential mark even if they forget to allow for the taking of the aliquot from the flask provided they correctly use* $c = \frac{n}{V}$ *to calculate the concentration of vitamin C.*

e. Express your answer to **part d** in g L^{-1}.

2 marks

Solution

Step 1: Determine the molar mass of vitamin C.

$$M(C_6H_8O_6) = 6 \times 12.0 + 8 \times 1.0 + 6 \times 16.0$$
$$= 176 \text{ g mol}^{-1}$$

Step 2: Determine the mass of vitamin C present in 1.0 L of juice.

$$m(C_6H_8O_6) = nM$$
$$= 1.53 \times 10^{-3} \times 176$$
$$= 0.269 \text{ g}$$

Step 3: Express as a concentration.

0.269 g L^{-1}

Mark allocation

- 1 mark for molar mass of vitamin C = 176 g mol^{-1}.
- 1 mark for concentration = 0.269 g L^{-1}.

Tips

- *Students can earn a consequential mark even if their molar mass for vitamin C is incorrect provided they use it correctly to determine the mass of vitamin C.*

Total 2 + 1 + 2 + 2 + 2 = 9 marks

Question 2

A molecule with the formula $C_3H_6O_2$ is thought to have one of the following structures.

molecule A **or** **molecule B**

The molecule is first subjected to infrared (IR) spectroscopy.

a. Explain how this analysis will help in identifying which of these is the correct structure.

2 marks

Solution
Although both molecules have C–H, C–O and C=O covalent bonds, only molecule A has an O–H (acids) bond, which should produce an absorption peak in the range 2500–3300 cm^{-1} in the IR spectrum. Molecule B should not produce a major peak at this point.

Mark allocation
- 1 mark for identifying the significant difference in terms of covalent bonds is the O–H (acids) bond in molecule A.
- 1 mark for indicating this bond will produce a peak at 2500–3300 cm^{-1} in the IR spectrum.

Tips
- *Students' answers should be specific to the question asked and not just general in nature. Page 7 of the Data Book lists infrared absorption data and should be referenced in the answer to this question.*

The molecule is subjected to further analysis using nuclear magnetic resonance (NMR) spectroscopy.

b. How many different carbon environments are present in each molecule?

2 marks

Solution
Molecule A has 3.
Molecule B has 3.

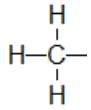
Mark allocation
- 1 mark for each correct molecule.

Explanatory notes
- Each of the three carbon atoms in both molecules are in different environments because they are each bonded to different types of atoms. None of the carbon atoms are equivalent.

c. The ^{1}H NMR spectrum of the analysed molecule shows three peaks in addition to the TMS calibration peak. The peaks have relative areas of 1, 2 and 3. Draw the grouping of atoms in molecule A that could give rise to the peak with a relative area of 3.

1 mark

Solution



Explanatory notes

- There are three hydrogen atoms in this environment, compared to two and one in the other hydrogen environments, respectively. These three hydrogen atoms are responsible for the largest peak.

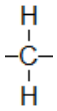
d. The peaks in the ^{1}H NMR spectrum have distinctive splitting patterns. One peak is a singlet, one is a triplet and another is a quartet. Draw the groupings of atoms in molecule B that would give rise to the singlet and quartet splitting patterns.

2 marks

Solution

singlet

quartet

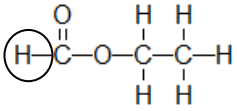


Mark allocation

- 1 mark for each grouping of atoms.

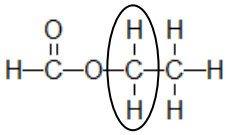
Explanatory notes

- A peak will show a splitting pattern according to the formula $n + 1$, where n is the number of non-equivalent hydrogen atoms on the neighbouring carbon atom. The H atom circled below



has zero H atoms on the neighbouring carbon atom, so its peak splits into $0 + 1 = 1$, forming a singlet in the ^{1}H NMR spectrum.

The H atoms circled here



have three H atoms on the neighbouring carbon atom, so their peak splits into $3 + 1 = 4$, forming a quartet in the ^{1}H NMR spectrum.

e. A further test showed that the molecule being tested reacted with a base. Identify whether the molecule is A or B and give the name of the molecule.

2 marks

Solution
Molecule A, propanoic acid

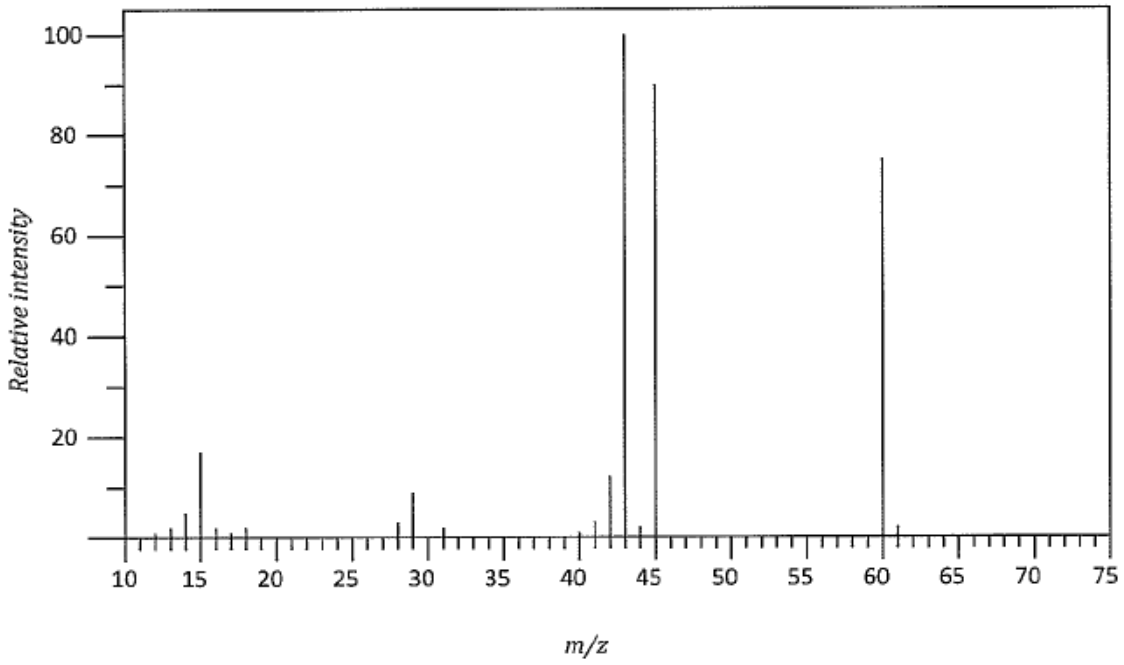
Mark allocation
- 1 mark for molecule A.
- 1 mark for propanoic acid.

Explanatory notes
- Only molecule A has the carboxyl acid group (–COOH), which means it will react with a base. Molecule B has an ester functional group, which will not react with a base.

Total 2 + 2 + 1 + 2 + 2 = 9 marks

Question 3

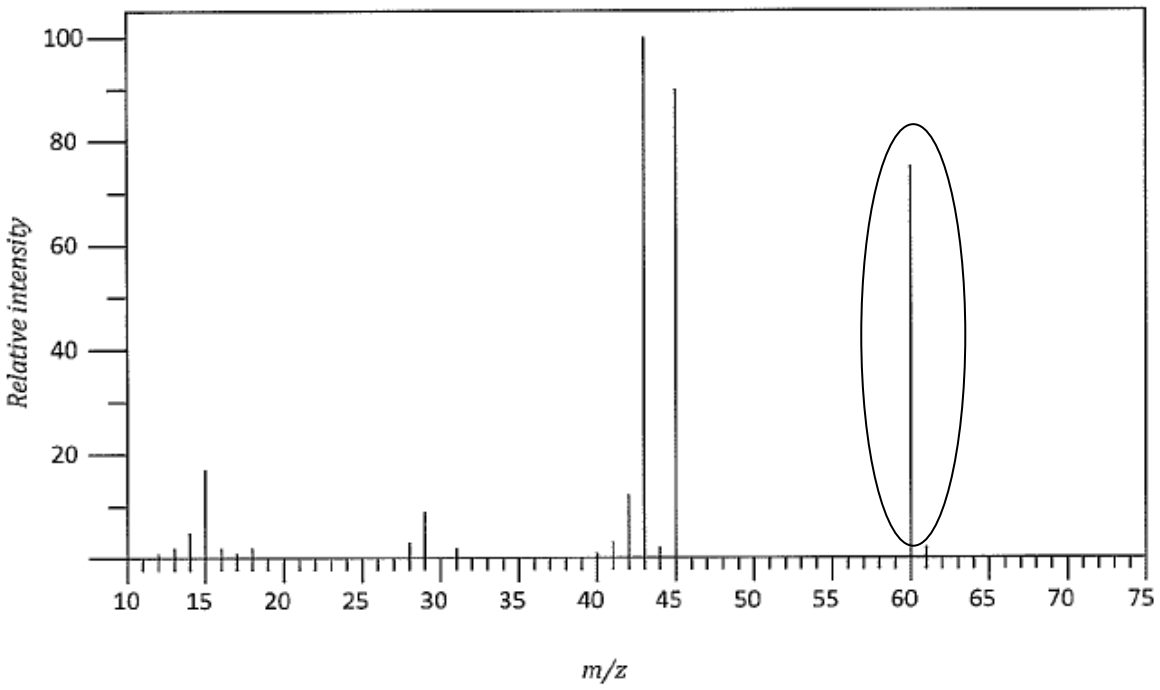
The mass spectrum of ethanoic acid is shown below.



a. **i.** On the spectrum above, circle the peak that is caused by the parent molecular ion.

1 mark

Solution



Explanatory notes

- The parent molecular ion is the ion formed from the parent molecule before any fragmentation occurs. This molecule is ethanoic acid, so the parent ion has a molar mass of 60 g mol^{-1}.

Tips

- *Students may get confused between the **parent molecular ion**, which has the highest molar mass, and the **base peak**, which has the highest relative abundance (assigned 100 on the relative intensity axis).*

ii. Write an equation showing the formation of the parent ion in the mass spectrometer.

1 mark

Solution

$CH_3COOH + e^- \rightarrow CH_3COOH^+ + 2e^-$

Explanatory notes

- In the mass spectrometer, a high energy electron beam is used to knock an electron from the parent molecule CH_3COOH to form a positive ion, CH_3COOH^+.

b. What fragment must have been lost from ethanoic acid to account for the peak at m/z 45?

1 mark

Solution

CH_3

Explanatory notes

- The molar mass of ethanoic acid is 60 g mol^{-1} and the remaining fragment is 45 g mol^{-1}, so the lost fragment must have a mass of 60 – 45 = 15 g mol^{-1}. The CH_3 end of the molecule has a molar mass of 15 g mol^{-1}. The molecular ion causing the peak is $COOH^+$.

Tips

- The lost fragment will always be uncharged. When a molecular ion splits, only one of the products is charged, being the fragment that will show a peak in the mass spectrometer. The uncharged fragment does not show an equivalent peak.

c. Write an equation showing the formation of the fragment at m/z 15 from the parent ion.

1 mark

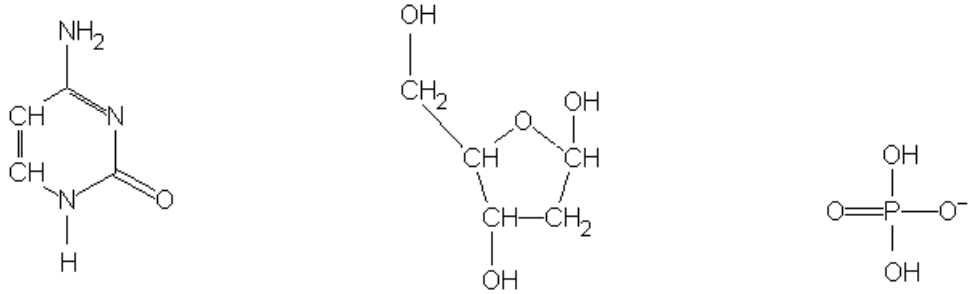
Solution

$CH_3COOH^+ \rightarrow CH_3^+ + COOH$

Total 2 + 1 + 1 = 4 marks

Question 4

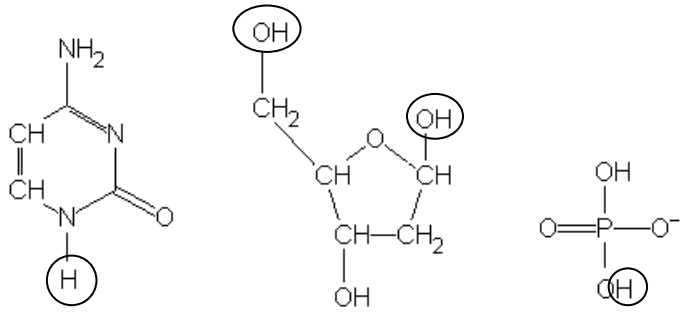
Shown below are some of the components of a nucleotide that is the building block of a single strand of DNA.



a. i. Circle only the atoms on the components that will form bonds with the other components to form a single nucleotide.

2 marks

Solution



Note that circling the top OH on the phosphate and the bottom H on the sugar would also be accepted.

Mark allocation

- 1 mark for circling the H on the base and the corresponding OH on the sugar.
- 1 mark for circling the H on the phosphate and the corresponding OH group on the sugar.
- A water molecule must be produced by the atoms circled, that is, if the entire OH on both the phosphate and the sugar are circled, the mark will not be awarded.

Explanatory notes

- The first molecule is the base cytosine, the second molecule is the sugar deoxyribose and the third molecule is phosphate. The phosphate and the base both bond to the deoxyribose sugar.

ii. Name the type of bonding that holds the three components of the nucleotide together.

1 mark

Solution
Covalent

Explanatory notes

- The base and phosphate each bond to the sugar in a condensation reaction that eliminates a water molecule and forms a covalent bond.

b. Strand A is a segment of double-stranded DNA in which 35% of the bases are of the type given in **part a.** Strand B is a segment of double-stranded DNA in which only 10% of the bases are of this type. Which strand would be **least** readily separated by heating? Give an explanation for your answer.

2 marks

Solution
Strand A because it has a greater proportion of C–G base pairs, which are held together by three hydrogen bonds and so will be harder to separate than A–T base pairs, which are only held together by two hydrogen bonds.

Mark allocation

- 1 mark for stating strand A.
- 1 mark for explaining that C–G base pairs have three hydrogen bonds holding them together.

Tips

- *You may point out to students that the names and structures of all the bases are on page 10 of the Data Book.*

Total 3 + 2= 5 marks

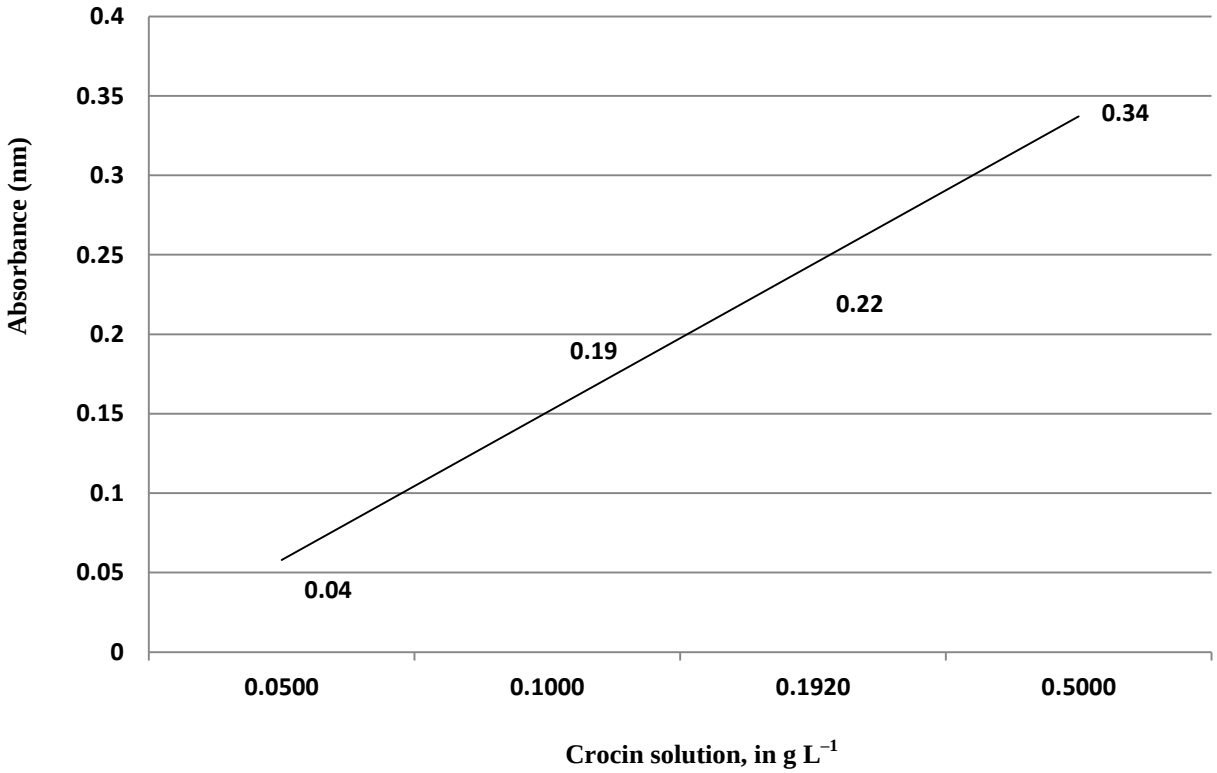
Question 5

Saffron is a spice that is highly valued for its colour and aroma. The chemical responsible for its rich golden colour is crocin ($C_{44}H_{64}O_{24}$; molar mass = 977 g mol^{-1}). UV-visible spectroscopy is used to analyse the crocin content of a batch of saffron.

A stock solution of crocin is prepared by dissolving 0.500 g of crocin in 250.0 mL of water. The stock solution is then diluted to make the following three standard solutions.

Standard solution	Crocin solution, in g L^{-1}
standard 1	1.00×10^{-2}
standard 2	5.00×10^{-2}
standard 3	1.00×10^{-1}

The absorbances of the standard solutions are measured at an appropriate wavelength and the following calibration line is obtained.



Crocin solution, in g L^{-1} (*x*-axis)	Absorbance (*y*-axis)
0.0500	0.04
0.100	0.19
0.192	0.22
0.500	0.34

a. Calculate the concentration, in mol L^{-1}, of crocin in the stock solution.

2 marks

Solution

$$n(\text{crocin}) = \frac{m}{M}$$
$$= \frac{0.500}{977}$$
$$= 5.12 \times 10^{-4} \text{ mol}$$
$$c(\text{crocin}) = \frac{n}{V}$$
$$= \frac{5.12 \times 10^{-4}}{0.250}$$
$$= 2.05 \times 10^{-3} \text{ M}$$

Mark allocation

- 1 mark for calculating $n(\text{crocin}) = 5.12 \times 10^{-4}$ mol.
- 1 mark for calculating $c(\text{crocin}) = 2.05 \times 10^{-3}$ M.

b. The crocin in a dried 4.875 g sample of saffron is extracted into solution. The solution is filtered and made up to 100 mL in a volumetric flask. 10.0 mL of this solution is then further diluted to 250 mL. The absorbance of the diluted solution at the same wavelength as that used in the calibration was found to be 0.22.

i. Calculate the crocin content of the diluted solution, in g L^{-1}.

1 mark

Solution
0.192

Explanatory notes

- The absorbance is used to read the concentration in g L^{-1} straight off the calibration graph.

ii. Calculate the percentage by mass of crocin in the saffron sample.

2 marks

Solution

$$c(\text{crocin}) \text{ in undiluted solution} = \frac{250}{10.0} \times 0.192$$
$$= 4.80 \text{ g L}^{-1}$$
$$m(\text{crocin}) \text{ in sample} = 0.100 \times 4.80$$
$$= 0.480$$
$$\% \text{ by mass} = \frac{0.480}{4.875} \times 100$$
$$= 9.85\%$$

Mark allocation

- 1 mark for determining the $c(\text{crocin})$ in undiluted solution = 4.8 g L^{-1}.
- 1 mark for determining the percentage by mass using calculated $m(\text{crocin})$.

Explanatory notes

- The original solution is diluted from 10 mL to 250 mL, which has to be taken into account. Furthermore, the sample size is 100 mL, not 1.0 L, so this must also be taken into account.

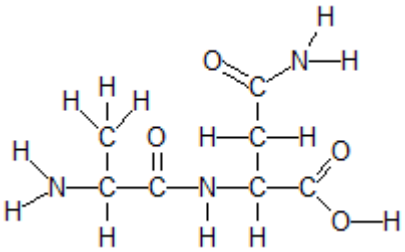
Total 2 + 3 = 5 marks

Question 6

a. Draw the structure of one dipeptide that could result from the linking of asparagine and alanine.

2 marks

Solution



Mark allocation

- 1 mark for dipeptide link drawn correctly.
- 1 mark for correct structures of asparagine and alanine.
- The alternative dipeptide in which alanine's amino group and asparagine's carboxyl group are used in the amide linkage will also be accepted.

b. Would you expect a solution of the dipeptide you drew in **part a** dissolved in water to be acidic, basic or neutral? Give a reason for your answer.

2 marks

Solution

Basic because asparagine contains a basic NH_2 functional group.

Mark allocation

- 1 mark for stating basic.
- 1 mark for an explanation that includes reference to the NH_2 group on asparagine.

Total 2 + 2 = 4 marks

Question 7

a. Ethanol can be added to petrol to reduce our reliance on fossil fuels as the energy source for vehicles. It is produced primarily by the fermentation of glucose in plant grains.

i. Write a balanced chemical equation to show how glucose is produced by plants.

1 mark

Solution

$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$

Explanatory notes

- This is the photosynthesis reaction. It occurs in the green leaves of plants in the presence of sunlight.

Tips

- *You may remind students to include state symbols in all of their reactions.*

ii. Write a balanced chemical equation to show the fermentation of glucose to ethanol.

1 mark

Solution

$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$

iii. Write a balanced chemical equation to show the combustion of ethanol for the release of energy.

1 mark

Solution

$C_2H_5OH(aq) + 2O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$

Explanatory notes

- Complete combustion of an organic compound, such as ethanol, is always a reaction with oxygen that produces carbon dioxide and water.

b. Biodiesel is another biochemical fuel that can be produced by a reaction between methanol and the fatty acids obtained from triglycerides in plant oils.

i. Name the type of organic molecule that would result from the reaction between methanol and a fatty acid.

1 mark

Solution

(Methyl) ester

Explanatory notes

- In a condensation reaction, the –OH group on the methanol molecule reacts with the –OH group on a fatty acid, resulting in an ester linkage and a water molecule being eliminated.

ii. Give the formula of the other molecule that would be produced in this reaction.

1 mark

Solution
H_2O

iii. One type of biodiesel that is produced from fatty acids has the formula $C_{15}H_{29}COOH$. How many double bonds does this molecule have?

1 mark

Solution
One

Explanatory notes

- If this was a saturated fatty acid, the number of hydrogen atoms would be equal to $2n + 1$, where n is the number of carbon atoms in the hydrocarbon chain. Therefore, for the formula given, this would be 31. As there are two hydrogen atoms less than this number, this is equivalent to one double bond.

Total 3 + 3 = 6 marks

Question 8

A low molecular mass unbranched alkane is subjected to the sequence of chemical reactions below.

- The alkane is added to a sample of chlorine gas and placed under ultraviolet light. Two compounds, A and B, are formed, each with a molar mass of 92.5 g mol^{-1}.
- One of these compounds is isolated and allowed to react with sodium hydroxide to form compound C, which is then heated with a solution containing acidified dichromate ions and reacted completely to form compound D.
- Compound D is reacted with sodium carbonate crystals to produce a gas.

a. Give the systematic names of compounds A and B.

2 marks

Solution
Compound A – 1-chlorobutane
Compound B – 2-chlorobutane

Mark allocation

- 1 mark for each correct name.

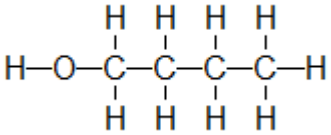
Explanatory notes

- Alkanes are saturated and the first reaction is a substitution reaction in which a hydrogen atom in the alkane is replaced with a chlorine atom. The formula must be $C_nH_{2n+1}Cl$. The molar mass of 92.5 g mol^{-1} corresponds to C_4H_9Cl. We are told the alkane is unbranched, so two isomers must exist.

b. Draw the structure of compound C below and give the systematic name of the compound.

2 marks

Solution
1-butanol



Mark allocation

- 1 mark for the correct structure.
- 1 mark for the correct name of the drawn structure.

Explanatory notes

- Compound C is produced in a substitution reaction in which the –Cl atom is replaced by an –OH group. We know it is 1-butanol and not 2-butanol because it goes on to be converted to a carboxylic acid, which reacts with sodium carbonate in an acid–base reaction, and therefore must have its functional group on the end of the chain.

c. Write redox half-equations for the reaction that produces compound D. The dichromate ions, $Cr_2O_7^{2-}$, are converted to Cr^{3+} ions.

2 marks

Solution
Oxidation reaction:
$CH_3CH_2CH_2CH_2OH(aq) + H_2O(l) \rightarrow CH_3CH_2CH_2COOH(aq) + 4H^+(aq) + 4e^-$

Reduction reaction:
$Cr_2O_7^{2-} + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$

Explanatory notes

- The half-equations can be written by following the KOHES steps for writing redox half-equations in acidic media. Alcohols undergo oxidation when they are converted to carboxylic acids. The oxidising agent, $Cr_2O_7^{2-}$, is reduced.

Total 2 + 2 + 2 = 6 marks

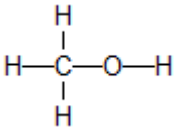
Question 9

Methanol and ethanol can both form solutions by dissolving in water.

a. i. Draw the structure of a methanol molecule.

1 mark

Solution



Explanatory notes

- The prefix meth- indicates there is one carbon atom in the molecule. The suffix –anol indicates the molecule is an alkanol, so contains an –OH group.

Tips

- *Students should show all bonds in drawn structures. This includes showing the bond between the oxygen and hydrogen in a hydroxyl group.*

ii. Explain how methanol is able to form bonds with and dissolve in water.

2 marks

Solution

The polar hydroxyl functional group enables methanol to form hydrogen bonds with polar water molecules.

Mark allocation

- 1 mark for referring to the importance of a hydroxyl functional group.
- 1 mark for reference to the hydrogen bonds formed with polar water.

b. The different boiling points of methanol, ethanol and water are listed in the table below.

Molecule	Boiling point (°C)
methanol	64.5
ethanol	78.3
water	100.0

i. Explain, in terms of intermolecular forces, why the boiling point of ethanol is higher than that of methanol.

1 mark

Solution

Ethanol is a larger molecule, so the number of dispersion forces between molecules is greater.

Explanatory notes

- Both molecules are alkanols, so each contains a hydroxyl group that enables them to form hydrogen bonds with each other. The difference between the two is simply size; methanol is CH_3OH and ethanol is C_2H_5OH, and molecular size affects the size of the dispersion forces.

ii. Give the name of the process that could be carried out to separate and collect the methanol and ethanol from the water, based on their different boiling points.

1 mark

Solution
Fractional distillation

iii. Briefly describe how you would obtain a pure sample of methanol from the mixture using this process.

2 marks

Solution
Gently heat the mixture in some distillation apparatus until the temperature reaches about 65°C. The fraction collected at the top of the column will consist almost entirely of methanol.

Mark allocation

- 1 mark for gentle heating to a temperature above 64.5°C but below 78.3°C.
- 1 mark for collecting the first fraction at the top of the column.

c. Give the name of the process that could be used to determine the concentration of methanol and ethanol in the water.

1 mark

Solution
Gas chromatography

Explanatory notes

- Methanol and ethanol are small, volatile, organic compounds and so are well suited to gas chromatography.

Total 3 + 4 + 1 = 8 marks

END OF SOLUTIONS BOOK