INSIGHT

Trial Exam Paper

2010

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 technique best used to identify the presence of more than one isotope of copper in a copper sample is

A. infrared spectroscopy.

B. UV-visible spectroscopy.

C. atomic absorption spectroscopy.

D. **mass spectrometry.**

Answer is D.

Worked solution

- D is correct because mass spectrometry separates particles in a sample according to their mass : charge ratio. These differ for different isotopes of the same element so isotopes will be separated and can be identified.
- A is incorrect because infrared spectroscopy is used to indicate the functional groups or bond types present in an organic compound. It is not used to identify isotopes in a metal.
- B is incorrect because isotopes of copper absorb the same wavelength of UV-visible radiation so cannot be distinguished from each other using UV-visible spectroscopy. It is mainly used for determining the concentration of a substance in a sample.
- C is incorrect because different isotopes of copper absorb the same wavelength of light in AAS in order to promote electrons to higher energy levels. The isotopes cannot be distinguished from each other. AAS is mainly used for determining the concentration of metals in a sample.

Question 2

A mixture containing the compounds 1-chloro-2-methylhexane, 1-chloro-2-methylbutane and 1-chloro-2-methyloctane was analysed using gas chromatography. The molecule expected to have the longest retention time in the chromatography column is

A. 1-chloro-2-methylhexane.

B. 1-chloro-2-methylbutane.

C. **1-chloro-2-methyloctane.**

D. unable to be predicted from the information provided.

Answer is C.

Worked solution

- C is correct because this is the largest molecule with the highest boiling temperature.
- A and B are incorrect because these molecules have the same functional groups as option C, but have shorter hydrocarbon chains, giving them a lower boiling temperature and shorter retention time.
- D is incorrect because relative retention times can be predicted by comparing the structures of these molecules.

Explanatory notes

The molecules with the highest boiling temperature would be expected to move the slowest through the column thus having the longest retention time. All three molecules have a chloro and methyl group, so it is the length of the chain that will contribute to the differences in boiling temperatures. Octane indicates a carbon backbone of eight carbons, which is higher than hexane (6) and butane (4).

Question 3

A mixture of glucose and sucrose was analysed using high-performance liquid chromatography. The chromatogram of the mixture produced the following peak areas.

Compound	Peak area
0.145 mol of glucose	674 units
0.305 mol of sucrose	1205 units

An analysis of a separate sample of glucose under the same conditions gave a peak area of 1205 units. The expected amount of glucose in the second sample is

A. 0.0811
B. 0.145
C. **0.259**
D. 0.305

Answer is C.

Worked solution

- C is correct according to the calculations below.

  0.145 mol of glucose = 674 units

  x mol = 1205 units

  This can be written as an equation and solved for x:

  $$\frac{0.145}{x} = \frac{674}{1205}$$

  $$\frac{x}{0.145} = \frac{1205}{674}$$

  $$x = \frac{1205}{674} \times 0.145$$

  $$= 0.259 \text{ mol}$$

- A, B and D are incorrect because the amount of glucose in the second sample must be calculated using the ratio *amount : peak area* obtained in the first sample. The data given regarding sucrose does not need to be used at all.

Explanatory notes

The peak area of a particular compound is directly proportional to its concentration. The two samples of glucose will have the same retention time and show the same ratio between amount and peak area.

Question 4

Which one of the following compounds is expected to show three peaks in a ^{1}H NMR spectrum and two peaks in a ^{13}C NMR spectrum?

A. chloroethane

B. **ethanol**

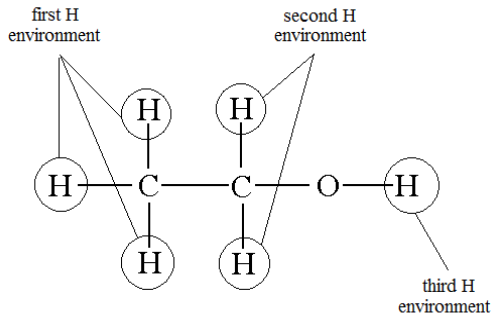
C. ethanoic acid

D. ethyl ethanoate

Answer is B.

Worked solution

- B is correct because a molecule of ethanol has three different hydrogen environments and two different carbon environments.



- A is incorrect because chloroethane has only two different hydrogen environments.
- C is incorrect because ethanoic acid has only two different hydrogen environments.
- D is incorrect because ethyl ethanoate has four different carbon environments.

Explanatory notes

The number of peaks in a ^{1}H NMR spectrum indicates the number of different hydrogen environments in the molecule being analysed, whereas the number of peaks in a ^{13}C NMR spectrum indicates the number of different carbon environments.

Question 5

Spectroscopic techniques involve the analysis of substances based on their absorptions of a range of energies.

Consider the following statements about different spectroscopic techniques.

I Infra-red spectroscopy involves the absorption of infra-red radiation to promote electrons to higher energy levels.

II UV-visible spectroscopy and atomic absorption (AAS) spectroscopy both involve the absorption of light to promote electrons to higher energy levels.

III ^{13}C NMR spectroscopy involves the absorption of radio waves by **all** of the ^{12}C atoms present in a sample of a molecule under analysis.

Which of the statements above are true?

A. I only

B. **II only**

C. I and II only

D. II and III only

Answer is B.

Worked solution

- B is correct because only statement II is correct.
- A is incorrect because statement I is incorrect and statement II is correct.
- C is incorrect because I is an incorrect statement.
- D is incorrect because III is an incorrect statement.

Explanatory notes

Infra-red spectroscopy involves the absorption of infra-red radiation by covalent bonds to promote molecules to higher vibrational levels.

^{13}C NMR spectroscopy involves the absorption of radio waves by only the ^{13}C carbon isotope present in a molecule under analysis because it has an odd number of nucleons (i.e. protons plus neutrons). Most carbon atoms present will be ^{12}C, which do not absorb radio waves as they have an even number of nucleons.

Question 6

A compound is formed by adding together samples of $C_2H_5OH(l)$ and $HCOOH(l)$ in the presence of concentrated sulfuric acid. This compound is then analysed using high resolution ^1H NMR. The number of sets of peaks and the splitting pattern expected for the compound are

A. two sets of peaks; both consisting of a single peak.

B. two sets of peaks; both split into four fine peaks.

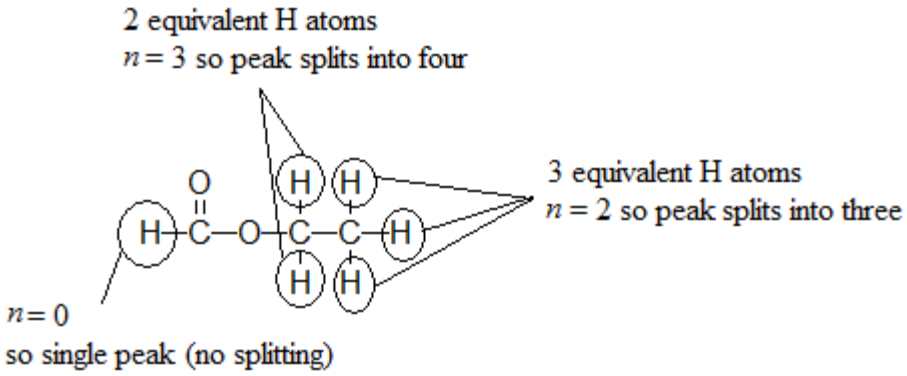
C. **three sets of peaks; one single, one split into three and one split into four fine peaks.**

D. three sets of peaks; one single, one split into two and one split into three fine peaks.

Answer is C.

Worked solution

- C is correct because the molecule formed, ethyl methanoate, contains hydrogen atoms in three different environments, producing three sets of peaks in the ^{1}H NMR spectrum. The amount of splitting is determined by the rule that the number of fine peaks produced by splitting equals $n + 1$, where n is the number of non-equivalent H atoms on the neighbouring atom. As seen in the diagram below, one H atom has no neighbouring H atoms so does not split, two H atoms have $n = 3$ so split into four fine peaks and three H atoms have $n = 2$ so split into three fine peaks.



- A is incorrect because the molecule formed in the reaction between ethanol and methanoic acid is ethyl methanoate, not methyl ethanoate. Ethyl methanoate has three different hydrogen environments in the molecule formed, so will have three peak sets in the ^{1}H NMR spectrum.
- B is incorrect because the molecule formed in the reaction between ethanol and methanoic acid is ethyl methanoate, not methyl ethanoate. Ethyl methanoate has three different hydrogen environments in the molecule formed, so will have three peak sets in the ^{1}H NMR spectrum. Also, the amount of splitting is predicted using $n + 1$, where n is the number of H atoms on the neighbouring atom, creating one single peak, one peak split into three and one peak split into four.
- D is incorrect because the amount of splitting is predicted using $n + 1$, where n is the number of H atoms on the neighbouring atom, creating one single peak, one peak split into three and one peak split into four.

Explanatory notes

When an alcohol, such as $C_2H_5OH(l)$, and a carboxylic acid, such as $HCOOH(l)$, are combined in the presence of concentrated sulfuric acid, they react in a condensation or esterification reaction to form an ester; in this case, C_2H_5OOCH or ethyl methanoate.

Question 7

Which of the following correctly represents the coefficients in the following equation when it is correctly balanced?

$\_\_Cr_2O_7^{2-}(aq) + \_\_H^+(aq) + \_\_C_2H_5OH(aq) \rightarrow \_\_Cr^{3+}(aq) + \_\_H_2O(l) + \_\_CH_3COOH(aq)$

A. 1, 14, 1, 2, 7, 1
B. 2, 16, 1, 4, 14, 1
C. **2, 16, 3, 4, 11, 3**
D. 1, 14, 3, 2, 7, 3

Answer is C.

Worked solution

- C is correct according to the following:
  The half-equations are:

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

  $C_2H_5OH(aq) + H_2O(l) \rightarrow CH_3COOH(aq) + 4H^+(aq) + 4e^-$ oxidation

  Writing an overall equation requires the number of electrons produced and consumed to be balanced. In this case, it requires the reduction half-equation to be multiplied by two and the oxidation half-equation to be multiplied by three giving:

  $2Cr_2O_7^{2-}(aq) + 28H^+(aq) + 12e^-(aq) + 3C_2H_5OH(aq) + 3H_2O(l) \rightarrow 4Cr^{3+}(aq) + 14H_2O(l) + 3CH_3COOH(aq) + 12H^+(aq) + 12e^-$

  The electrons, $H_2O(l)$ and $H^+(aq)$ then cancel each other out leaving:

  $2Cr_2O_7^{2-}(aq) + 16H^+(aq) + 3C_2H_5OH(aq) \rightarrow 4Cr^{3+}(aq) + 11H_2O(l) + 3CH_3COOH(aq)$

- A is incorrect because the charge must be balanced as well as the number and type of atoms.
- B is incorrect because the oxidation of ethanol must occur three times for every two times the dichromate ion is reduced. Otherwise, the number of electrons consumed and produced is not balanced.
- D is incorrect because the reduction of dichromate must occur two times for every three times the ethanol is oxidised. Otherwise, the number of electrons consumed and produced is not balanced.

Tips

- *When balancing an overall redox equation it is best to write the half-equations first to ensure the charge is balanced as well as the number and type of atoms.*

Question 8

A sample of a hydrocarbon is burnt in pure oxygen. The only products are 13.2 g of $CO_2(g)$ and 5.40 g of $H_2O(g)$. The name of the hydrocarbon is

A. methane.

B. **ethene.**

C. ethane.

D. propane.

Answer is B.

Worked solution

- B is correct according to the steps below.

Step 1: Calculate the amount, in mol, of CO_2.

$$n(CO_2) = \frac{m}{M} = \frac{13.2}{44} = 0.300\,\text{mol}$$

Step 2: Calculate the amount, in mol, of C (all of which came from the hydrocarbon).

$n(C) = n(CO_2) = 0.300$ mol

Step 3: Calculate the amount, in mol, of H_2O.

$$n(H_2O) = \frac{m}{M} = \frac{5.40}{18} = 0.300\,\text{mol}$$

Step 4: Calculate the amount, in mol, of H (all of which came from the hydrocarbon).

$n(H) = 0.300 \times 2 = 0.600$ mol

Step 5: Determine the ratio of carbon atoms to hydrogen atoms in the hydrocarbon.

$n(C) : n(H)$

0.300 : 0.600

Step 6: Simplify to the smallest whole number ratio.

1 : 2

The hydrocarbon has an empirical formula of CH_2.

The only option with this empirical formula is ethene, C_2H_4.

- A, C and D are incorrect because methane (CH_4), ethane (C_2H_6), and propane (C_3H_8), do not have the empirical formula CH_2 that is required for this hydrocarbon.

Explanatory notes

An empirical formula is the simplest whole number ratio of atoms present in a molecule or compound, whereas a molecular formula is the actual number and type of atoms present.

Questions 9 and 10 refer to the following information.

0.245 g of pure C_3H_7COOH was dissolved in water to a total volume of 25.00 mL and titrated with 0.105 M NaOH solution.

Question 9

The volume of NaOH solution, in mL, required to reach the end point of the titration was closest to

A. less than 26.5

B. **26.5**

C. 53.0

D. 1110

Answer is B.

Worked solution

- B is correct because C_3H_7COOH, a monoprotic acid, will react completely with NaOH, a strong base. The amount, in mol, of NaOH that reacts is calculated by the steps below.

Step 1: Determine the amount, in mol, of C_3H_7COOH present.

$$n(C_3H_7COOH) = \frac{m}{M} = \frac{0.245}{88}$$
$$= 0.002\,78 \text{ mol}$$

Step 2: Write an equation for the reaction with NaOH.

$$C_3H_7COOH(aq) + NaOH(aq) \rightarrow C_3H_7COONa(aq) + H_2O(l)$$

Step 3: Determine the amount, in mol, of NaOH required, using the 1 : 1 ratio given in the equation.

$$n(NaOH) = n(C_3H_7COOH) = 0.002\,78 \text{ mol}$$

Step 4: Determine the volume of 0.105 M NaOH required.

$$V(NaOH) = \frac{n}{c} = \frac{0.002\,78}{0.105}$$
$$= 0.0265 \text{ L} = 26.5 \text{ mL}$$

- A is incorrect because although NaOH is a strong acid and C_3H_7COOH is a weak acid, they still react in a 1 : 1 ratio and the weak acid will react completely with the strong acid.
- C is incorrect because NaOH and C_3H_7COOH react in a 1 : 1 ratio, not a 1 : 2 ratio.
- D is incorrect because the amount, in mol, of C_3H_7COOH is 0.002 78. The concentration of C_3H_7COOH is 0.1288 M, but this does not need to be determined to answer the question. The amount, in mol, of C_3H_7COOH reacts with the NaOH in a 1 : 1 ratio, not the concentration.

Tips

- *It is not always necessary to use every piece of information given in a question. In this question, the 25.00 mL into which the C_3H_7COOH was dissolved is irrelevant. The amount, in mol, of C_3H_7COOH present is important, not its concentration.*

Question 10

Which of the following gives a suitable indicator and the expected colour change for this titration?

	Suitable indicator	Expected colour change
A.	methyl red	red to yellow
B.	methyl red	yellow to red
C.	**phenolphthalein**	**colourless to red**
D.	phenolphthalein	red to colourless

Answer is C.

Worked solution

- C is correct because this reaction is between a strong base, NaOH, and a weak acid, C_3H_7COOH, so the pH of the equivalence point will be greater than 7. The end point of phenolphthalein has a pH range of 8.3–10.0, so is suitable for this analysis. The indicator is placed in the conical flask with the acid, so will start colourless and turn red once the end point is reached (i.e. between pH 8.3 and 10.0).
- A and B are incorrect because the end point for methyl red has a pH range of 4.2–6.3, which is not suitable for this reaction between a strong base and a weak acid.
- D is incorrect because the indicator is placed in the conical flask with the acid, so will start colourless and turn red once the end point is reached.

Tips

- *All carboxylic acids are weak acids.*

Question 11

A sample of propane gas combusts completely in oxygen. A volume of 5.48 L of carbon dioxide is produced when measured at 22.0°C and 1.00 atm. The mass, in g, of propane that combusted was

A. **3.32**
B. 9.41
C. 29.9
D. 401

Answer is A.

Worked solution

- A is correct according to the steps below.

Step 1: Determine the amount, in mol, of carbon dioxide, using the general gas equation.

$$n(CO_2) = \frac{PV}{RT}$$
$$= \frac{(1.00 \times 101.3) \times 5.48}{8.31 \times (22.0 + 273)}$$
$$= \frac{555}{2451} = 0.226 \text{ mol}$$

Step 2: Write a balanced chemical equation for the combustion reaction.

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

Step 3: Determine the amount, in mol, of propane combusted, using the mole ratio.

$$n(C_3H_8) : n(CO_2)$$
$$1 \quad : \quad 3$$

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

$$n(C_3H_8) = \frac{0.226}{3}$$
$$= 0.0755 \text{ mol}$$

Step 4: Determine the mass, in g, of propane.

$$m(C_3H_8) = nM$$
$$= 0.0755 \times (3 \times 12.0 + 8 \times 1.0)$$
$$= 3.32 \text{ g}$$

- B is incorrect because the ratio $n(C_3H_8) : n(CO_2)$ is 1 : 3, not 1 : 1.
- C is incorrect because the ratio $n(C_3H_8) : n(CO_2)$ is 1 : 3, not 3 : 1.
- D is incorrect because temperature must be expressed in K, not °C.

Tips

- *Remember that in the general gas equation the temperature must be in kelvin, pressure in kPa and volume in litres.*

Question 12

Consider the following statements about alkanes.

I Alkanes react with oxygen to produce carbon dioxide and water.

II Alkanes react with hydrogen chloride to produce chloroalkanes.

III Alkanes react with sodium hydroxide to produce alkanols.

Which of the statements above are true?

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

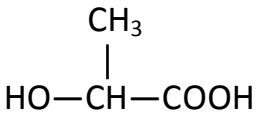
Answer is A.

Worked solution

- A is correct because I is the only correct statement. Alkanes are a hydrocarbon and react with oxygen in a complete combustion reaction to produce carbon dioxide and water.
- B is incorrect because II is an incorrect statement. Alkanes must react with chlorine in a substitution reaction to produce chloroalkanes.
- C is incorrect because III is an incorrect statement. Alkanes react with water in a substitution reaction to produce alkanols.
- D is incorrect because II and III are incorrect statements. Alkanes must react with chlorine in a substitution reaction to produce chloroalkanes and react with water in a substitution reaction to produce alkanols.

Question 13

Lactic acid is an organic substance produced in the body during high levels of activity when the oxygen requirements of the muscles are greater than can be supplied by the blood circulation system. A representation of lactic acid is given below.



Which of the following reagents would you expect lactic acid **not** to react with under the conditions indicated?

A. CH_3OH and H_2SO_4 catalyst
B. $H_2O(l)$ at room temperature
C. **$Br_2(aq)$ at room temperature**
D. $MnO_4^-(aq)$ and $H^+(aq)$

Answer is C.

Worked solution

- C is correct because lactic acid is a saturated molecule, meaning it has no double carbon–carbon bonds, so will not react in an addition reaction with $Br_2(aq)$.
- A is incorrect because the carboxyl functional group in lactic acid **will** react with methanol in the presence of H_2SO_4 catalyst, to produce an ester linkage.
- B is incorrect because the acidic carboxyl functional group in lactic acid **will** react with water in an acid–base reaction by donating a hydrogen ion.
- D is incorrect because the hydroxyl functional group in lactic acid will be oxidised by the permanganate ion in an acidic environment.

Tip

- *The structure for lactic acid is in the VCE Chemistry data book.*

Question 14

Consider the following statements about isomers.

I Isomers share the same molecular formula.

II Isomers share the same physical and chemical properties.

III Isomers share identical infra-red spectrums.

Which of the statements above are true?

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

Answer is A.

Worked solution

- A is correct because I is the only correct statement. Isomers share the same number and type of atoms but in different arrangements.
- B is incorrect because II is an incorrect statement. The differing arrangements of atoms in isomers do affect some of their physical properties; e.g. melting and boiling temperatures.
- C is incorrect because II is an incorrect statement. The differing arrangements of atoms in isomers do affect some of their physical properties; e.g. melting and boiling temperatures.
- D is incorrect because III is an incorrect statement. The different arrangement of atoms in isomers will result in different locations of covalent bonds and hence different absorptions of infra-red radiation and different infra-red spectrums.

Question 15

The melting temperature of a piece of double-stranded DNA is the temperature at which 50% of the strand separates into single strands. Two fragments of DNA of equal length have different melting temperatures. The melting temperature of fragment A is higher than that of fragment B. This is best explained by

A. Fragment A has a greater percentage of adenine bases than fragment B.

B. Fragment B has a greater percentage of cytosine bases than fragment A.

C. Fragment A has a higher number of disulfide cross-links than fragment B.

D. **Fragment A has a greater percentage of guanine bases than fragment B**.

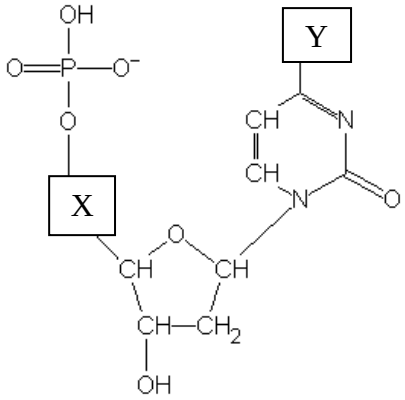
Answer is D.

Worked solution

- D is correct because the greater percentage of guanine bases in strand A means a greater percentage of guanine–cytosine base pairs. These hold the DNA strands together with three hydrogen bonds and so will confer a higher melting temperature, as it takes more energy to separate the strands.
- A is incorrect because a greater percentage of adenine bases would result in a lower melting temperature. Adenine in one strand bonds with thymine in the other by two hydrogen bonds, whereas cytosine and guanine bond with three hydrogen bonds. The smaller number of hydrogen bonds in an A–T pair means it is easier to separate them and 'melt' the strand.
- B is incorrect because a greater percentage of cytosine bases in strand B would give strand B a higher melting temperature. Cytosine–guanine base pairs are held together with three hydrogen bonds and so will confer a higher melting temperature, as it takes more energy to separate the strands.
- C is incorrect because the two strands of DNA are held together by hydrogen bonds between the A–T and G–C base pairs, not by disulfide cross-links.

Question 16

Part of the structure of a nucleotide is represented in the diagram below.



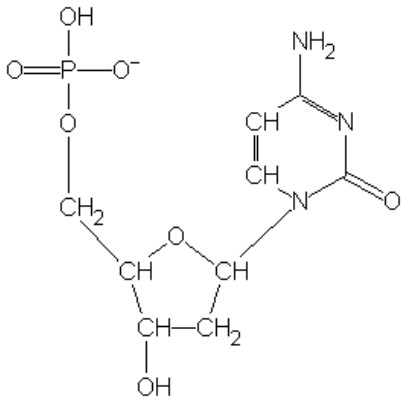
The formulas of the atom or groups of atoms represented by X and Y are

	X	**Y**
A.	NH	NH_2
B.	**CH_2**	**NH_2**
C.	NH	CH_3
D.	CH_2	CH_3

Answer is B.

Worked solution

- B is correct because the full structure of the nucleotide is



X is CH_2, part of the original deoxyribose, and Y is NH_2, part of the base cytosine.

- A is incorrect because X is CH_2, part of the original deoxyribose.
- C is incorrect because X is CH_2, part of the original deoxyribose, and Y is NH_2, part of the base cytosine.
- D is incorrect because Y is NH_2, part of the base cytosine.

Tips

- *The structures for deoxyribose, phosphate, adenine, guanine, cytosine and thymine can all be found in the data booklet. It is useful to practise drawing a single nucleotide from the components, as represented in the data booklet.*

Question 17

The amino acid sequence of a small polypeptide molecule is shown below.

Ala – Gly – Asn – Pro – Ala – Val

The number of amide (peptide) functional groups in this polypeptide, and the expected pH of the polypeptide when dissolved in water is

	–CONH	**pH**
A.	**5**	**basic**
B.	5	neutral
C.	6	neutral
D.	6	acidic

Answer is A.

Worked solution

- A is correct because there is an amide functional group between each of the linked amino acids. Six amino acids will require five amide functional groups to be linked together. The pH of the solution formed when this polypeptide is dissolved in water is basic due to the presence of the amino acid asparagine (Asn), which includes a basic amine functional group in its Z group. This will accept a proton when added to water. The remaining amino acids in the polypeptide chain are neutral.
- B is incorrect because this polypeptide will produce a basic solution when dissolved in water.
- C and D are incorrect because six amino acids will require five functional groups to be linked together. Also, this polypeptide will produce a basic solution when dissolved in water.

Question 18

Biochemical fuels are best defined as

A. fuels derived from plant materials.

B. fuels produced by the anaerobic decay of wastes.

C. fuels that do not produce carbon dioxide when combusted.

D. fuels used by living things to provide energy.

Answer is A.

Worked solution

- A is correct because all biochemical fuels are derived from plants. For example, ethanol is derived from glucose extracted from starch in plants and biodiesel is produced from carboxylic acids derived from vegetable oils extracted from plants. Other organisms, such as cattle, can supply animal fat which can be converted into biodiesel.
- B is incorrect because although biogas is produced from the decay of wastes, ethanol, biodiesel and other biochemical fuels are not produced this way.
- C is incorrect because all organic fuels produce carbon dioxide when combusted. The combustion of biochemical fuels can be regarded as carbon neutral because all of the carbon dioxide released was once absorbed by the plants from which the fuel was derived.
- D is incorrect because a range of fuels are used by living things to provide energy, not just biochemical ones.

Question 19

Consider the following reactions.

I Production of a nucleotide from deoxyribose, phosphate and adenine

II Production of polyethene from ethene

III Production of a disaccharide from monosaccharides

Which of these reactions could **not** be classified as a condensation reaction?

A. I only

B. **II only**

C. I and II only

D. I and III only

Answer is B.

Worked solution

- B is correct because the production of polythene from ethene is an addition polymerisation reaction, which is made possible because ethene contains a carbon–carbon double bond.
- A is incorrect because during the production of a nucleotide, water molecules are eliminated, making it a condensation reaction. Also, reaction II is **not** a condensation reaction.
- C is incorrect because reaction I is a condensation reaction because during the production of a nucleotide, water molecules are eliminated.
- D is incorrect because reaction III is a condensation reaction. A reaction between two hydroxyl (–OH) functional groups on different monosaccharides results in an ether linkage
  (–O–) and the elimination of a water molecule.

Question 20

The ester ethyl ethanoate is prepared by reacting ethanol with ethanoic acid in the presence of concentrated sulfuric acid. The boiling points of these three compounds and water are shown below.

$CH_3COOCH_2CH_3$	57°C
CH_3CH_2OH	78°C
H_2O	100°C
CH_3COOH	118°C

Fractional distillation can be used to extract pure ethyl ethanoate from the reaction mixture. The best way to achieve this is to

A. heat the reaction mixture in a distillation flask until the temperature at the top of the fractionating column is 118°C, and collect the fraction that condenses at this temperature.

B. **heat the reaction mixture in a distillation flask until the temperature at the top of the fractionating column is 57°C, and collect the fraction that condenses at this temperature.**

C. heat the reaction mixture in a distillation flask until the temperature at the top of the fractionating column is 57°C, and collect the fraction that remains in the flask at this temperature.

D. heat the reaction mixture in a distillation flask until the temperature at the top of the fractionating column is 118°C, and collect the fraction that remains in the flask at this temperature.

Answer is B.

Worked solution

- B is correct because in fractional distillation the fraction with the lowest boiling temperature is collected first. Ethyl ethanoate has the lowest boiling temperature so is the most volatile in the mixture and will be the most concentrated at the top of a column heated to 57°C.
- A is incorrect because if the flask is heated to 118°C, the temperature is above the boiling points of all of the components so all will have a high concentration in the fraction collected at the top of the column.
- C is incorrect because once the flask is heated to 57°C, it is the components with a boiling temperature above this, i.e. the ethanol and ethanoic acid, will remain in the flask. Ethyl ethanoate will be most concentrated in the fraction at the top of the column.
- D is incorrect because once the flask is heated to 118°C, the temperature is above the boiling points of all of the components so all will have a high concentration in the fraction at the top of the column. There will be very little of the mixture remaining in the flask at this time.

END OF SECTION A

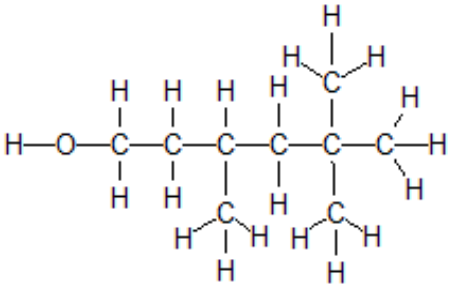
SECTION B – Short-answer questions

Question 1

3,5,5-trimethylhexan-1-ol is a compound used in perfumes.

a. Draw the structural formula of 3,5,5-trimethylhexan-1-ol, clearly showing all bonds.

Solution



1 mark

Explanatory notes

- The '3,5,5-trimethyl' part of the name indicates there are three methyl groups present, with one located on carbon 3 and two located on carbon 5.
- The 'hexan-1-ol' part of the name indicates the carbon chain backbone is six carbons long, has all single bonds and has a hydroxyl functional group on carbon 1.
- Numbering of carbon atoms in the longest chain is always consistent, starting at the end where the hydroxyl functional group is located.

Tips

- *Ensure that all covalent bonds are drawn in the structure, including those in the hydroxyl and methyl groups.*

b. Name the part of the structure of 3,5,5-trimethylhexan-1-ol that enables it to dissolve in water.

Solution

The hydroxyl (functional) group.

1 mark

Explanatory notes

- The hydroxyl functional group is a polar group, so is able to bond with polar water molecules and dissolve.

Tips

- *It is useful to remember that, in general, 'like dissolves like' so polar substances can dissolve in water, which is also polar, and non-polar substances do not. This assumes there are sufficient polar regions on the molecule compared with non-polar regions.*

c. Give the name of an analytical technique that could be used to quantitatively analyse a solution containing 3,5,5-trimethylhexan-1-ol.

Solution

Gas chromatography; high-performance liquid chromatography (HPLC) also acceptable.

1 mark

Explanatory notes

- Chromatography is used for the analysis of organic compounds. The area under the peak created by the sample would be compared with a calibration curve to determine the amount present. This compound has a small molar mass and is easily vaporised (it is used in a perfume), so would be suitable for gas chromatography. HPLC would also be a suitable technique.

Total 1 + 1 + 1 = 3 marks

Question 2

A student wishes to accurately determine the concentration of a solution of sodium hydroxide in a titration against a standard solution of nitric acid, HNO_3.

A solution of 0.100 M HNO_3 is required for the analysis. However, the only stock solution of HNO_3 available to the student is 1.00 M.

a. Describe, in detail, the steps the student must follow to accurately obtain a 500 mL solution of 0.100 M HNO_3.

Solution

Use a 50.00 mL pipette to transfer 50.00 mL of stock solution to a 500 mL volumetric flask. Add distilled water until the calibration line is reached. Stopper and carefully mix the solution.

3 marks

Mark allocation

- 1 mark for add 50.00 mL.
- 1 mark for use a 50.00 mL pipette.
- 1 mark for making upto 500 mL in a volumetric flask.

Explanatory notes

Relevant calculations:

$$c_1V_1 = c_2V_2$$
$$1.00 \times V_1 = 0.100 \times 0.500$$
$$V_1 = 0.0500 \text{ L}$$

Tips

- *Always refer to specific glassware when describing a specific laboratory procedure in detail.*
- *Pipette should be rinsed with the solution it is about to contain – in this case stock solution of HNO_3.*

The student then adds the diluted nitric acid to the burette for the analysis of sodium hydroxide. However, instead of previously cleaning the burette by rinsing it with the diluted nitric acid solution, the student rinses it with the 1.00 M stock solution. The concentration of sodium hydroxide is then determined.

b. Will the calculated concentration of sodium hydroxide be higher or lower than the true value? Explain your answer.

Solution

Concentration of NaOH will be lower.

Since the nitric acid solution will be more concentrated, less nitric acid solution will be required to neutralise the sodium hydroxide, making it appear less concentrated than it actually is.

2 marks

Mark allocation

- 1 mark for lower concentration.
- 1 mark for correct explanation.

The student repeats the titration another three times. One of these titre amounts was determined to be discrepant. The three volumes are shown below.

Titre	Volume (mL)
1	24.55
2	24.90
3	24.60

c. Give two errors the student may have made that would have caused the discrepant titre.

Solution

Two errors, which may include:

- The student overshot the end point.
- The conical flask used in the second titre had been rinsed with sodium hydroxide.
- Some water was mistakenly added to the burette before the second titre.
- The student forgot to add indicator until after the end point had been reached.
- The pipette was over-filled to above the calibration line.

2 marks

Mark allocation

- 1 mark for each correct error.

Tips

- *Errors must be specific things the student may have done. A general comment (e.g. there was too much sodium hydroxide in the flask) is not specific enough to answer this question.*

Total 3 + 2 + 2 = 7 marks

Question 3

Acetylsalicylic acid, or aspirin, is a drug commonly used as an analgesic (painkiller), to reduce fever and also as an anti-inflammatory. Aspirin can be produced in the laboratory by a number of different synthetic pathways. In one pathway, one molecule of salicylic acid reacts with one molecule of ethanoic acid to produce one molecule of aspirin and a water molecule.

A sample of aspirin (molar mass 180 g mol^{-1}) was prepared by reacting 3.65 g of salicylic acid (molar mass 138 g mol^{-1}) with 8.40 mL of ethanoic acid, in a conical flask. After the reaction was complete, the precipitated white crystals were collected, dried to constant mass and weighed.

The results below were obtained.

mass of salicylic acid	3.65 g
volume of ethanoic acid	8.40 mL
mass of product	4.50 g
density of ethanoic acid	1.05 g mL^{-1}

a. **i.** Calculate the initial amount, in moles, of ethanoic acid used.

Solution

m(ethanoic acid)= $d \times V$

$= 1.05 \times 8.40$

$= 8.82$ g

$$n\text{(ethanoic acid)} = \frac{m}{M} = \frac{8.82}{60}$$

$= 0.147$ mol

2 marks

Mark allocation

- 1 mark for determining mass of 8.82 g.
- 1 mark for correctly using n(ethanoic acid) = $\frac{m}{M}$.

Explanatory notes

The formula for ethanoic acid is CH_3COOH, giving a molar mass of $(2 \times 12.0) + (4 \times 1.0) + (2 \times 16.0) = 60.0$ g mol^{-1}.

Tips

- *The formula for determining density is useful to remember:* $d = \frac{m}{V}$.

ii. Calculate the initial amount, in moles, of salicylic acid used.

Solution

$$n(\text{salicylic acid}) = \frac{m}{M} = \frac{3.65}{138}$$

$$= 0.0264 \text{ mol}$$

1 mark

iii. Calculate the maximum mass of aspirin that can be theoretically produced from these starting amounts.

Solution

n(aspirin) : n(salicylic acid)

1 : 1

n(aspirin) = 0.0264 mol

m(aspirin) = $n \times M$

$= 0.0264 \times 180$

$= 4.75$ g

2 marks

Mark allocation

- 1 mark for n(aspirin) = 0.0264 mol.
- 1 mark for correct use of m(aspirin) = $n \times M$.

Explanatory notes

Although there is no written equation, it is stated in the question that one molecule of salicylic acid reacts with one molecule of ethanoic acid to produce one molecule of aspirin; i.e. that there is a 1 : 1 mole ratio. There is a higher amount of ethanoic acid than salicylic acid, so the ethanoic acid will be in excess and the salicylic acid is the limiting reactant and must be used for the prediction of aspirin produced.

iv. Calculate the percentage yield of aspirin in this preparation.

Solution

Actual mass produced = 4.50 g

Theoretical mass produced = 4.75 g

$$\text{Percentage yield} = \frac{4.50}{4.75} \times \frac{100}{1}$$

$= 94.7\%$

1 mark

b. A second pathway for preparing aspirin is one in which salicylic acid reacts with ethanoic anhydride. Give two reasons why this pathway is preferred over the one used in part **a**.

Solution

It is faster.

It gives a higher yield.

2 marks

Mark allocation

- 1 mark for each reason.

Total 6 + 2 = 8 marks

Question 4

In a 1.00 L vessel, 600 mL of chlorine gas, Cl_2, is added to 400 mL of a saturated hydrocarbon that contains two carbon atoms. The vessel is then subjected to UV light for a period of time.

a. Write a chemical equation for the first reaction between chlorine gas and the hydrocarbon.

Solution

$$C_2H_6(g) + Cl_2(g) \xrightarrow{UV} C_2H_5Cl(g) + HCl(g)$$

1 mark

Explanatory notes

- The hydrocarbon is saturated, indicating it is an alkane, and contains two carbon atoms, indicating it is ethane. Alkanes react with chlorine gas in a substitution reaction, in the presence of a UV light source.

Tips

- *Always include states in chemical equations.*

b. Assuming constant temperature and pressure, what volume is produced of the largest product?

Solution

$n(C_2H_6) : n(Cl_2)$

1 : 1

So C_2H_6 is the limiting reagent.

$n(C_2H_6) : n(C_2H_5Cl)$

1 : 1

As all of the species in the equation are all gases, then

$V(C_2H_6) : V(C_2H_5Cl)$

1 : 1

So $V(C_2H_5Cl) = 400$ mL

2 marks

Mark allocation

- 1 mark for determining that ethane is the limiting reactant.
- 1 mark for determining $V(C_2H_5Cl) = 400$ mL.

c. What will be the total volume, in L, of gases present once the reaction has finished.

Solution

1.0 L

1 mark

Explanatory notes

- The same amount of different types of gases will occupy the same volumes. In this reaction there are two gaseous reactants and two gaseous products. The total number of gas particles, and hence the total volume of gases, will be conserved. The total volume will be
  600 mL + 400 mL = 1.00 L

Tips

- *Since gases always expand to fill the volume of their container, regardless of the amount, in mol, of gas present, they will always occupy the largest possible volume, which in this case is 1.00 L.*

d. Write a chemical equation for a possible subsequent reaction in the vessel in which the largest product formed in part **a** is a reactant.

Solution

$$C_2H_5Cl(g) + Cl_2(g) \xrightarrow{UV} C_2H_4Cl_2(g) + HCl(g)$$

1 mark

Total 1 + 2 + 1 + 1 = 5 marks

Question 5

The IR and ^{13}C NMR spectra of a particular organic compound revealed the data below.

IR spectrum

Significant peak	Wavelength (cm^{-1})
1	1300
2	1700
3	3400 (broad)

^{13}C NMR spectrum

Peak	Chemical shift (ppm)
1	8.9
2	27.6
3	181.6

a. What type of information does the IR spectrum give you about the structure of a molecule?

Solution

Presence of functional groups; bond types present.

1 mark

b. In the list given below, circle the part of the molecule that absorbs energy in order to produce the IR spectrum as shown.

electrons nucleons covalent bonds dispersion forces

Solution

electrons nucleons (covalent bonds) dispersion forces

1 mark

c. What type of information does the ^{13}C NMR spectrum give you about the structure of a molecule?

Solution

The number of different carbon environments; chemical environment of ^{13}C atoms.

1 mark

d. In the list given below, circle the part of the molecule that absorbs energy in order to produce the ^{13}C NMR spectrum as shown.

electrons nucleons covalent bonds dispersion forces

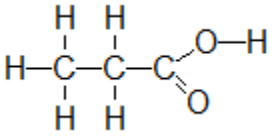
Solution

electrons (nucleons) covalent bonds dispersion forces

1 mark

e. Draw the structural formula and give the name of the organic compound that causes this spectral data to be produced.

Solution



propanoic acid

2 marks

Mark allocation

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

Explanatory notes

The IR spectrum indicates bonds in the molecule of:

Significant peak	Wavelength (cm^{-1})	Bond
1	1300	C–O
2	1700	C=O
3	3400 (broad)	O–H (alcohols)

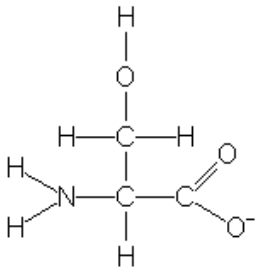
The ^{13}C NMR spectrum indicates types of carbons:

Peak	Chemical shift (ppm)	Type of carbon
1	8.9	$R–CH_3$
2	27.6	$R–CH_2–R$
3	181.6	R–COOH

Total 1 + 1 + 1 + 1 + 2 = 6 marks

Question 6

Consider the amino acid as represented by the structure below.



a. From the list below, circle the pH of the solution this amino acid would be dissolved in for it to exist as the structure given above.

pH 3 pH 5 pH 7 pH 9

Solution

pH 3 pH 5 pH 7 (pH 9)

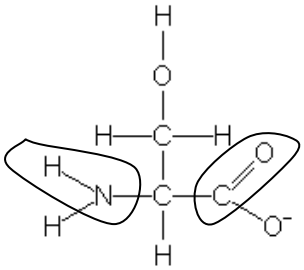
1 mark

Explanatory notes

The structure drawn shows the amino acid acting as an acid and donating the proton on the carboxyl group. It will do this when dissolved in a basic solution.

b. On the structure above, circle the part(s) of the molecule that would contribute to the secondary structure of a polypeptide using this amino acid.

Solution



1 mark

Explanatory notes

The amide linkages in a polypeptide molecule are responsible for the secondary structure of the molecule through hydrogen bonding. It is the N–H bond from the amino and the C=O bond from the carboxyl functional groups on the amino acid that will form the amide linkages in the polypeptide.

c. Give the name of the main type of bonding this amino acid might use to contribute to the tertiary structure of a polypeptide of which this amino acid was a part.

Solution

hydrogen bonding

1 mark

Explanatory notes

The Z group of this molecule contains a hydroxyl functional group that may be able to hydrogen bond to a Z group in another part of the polypeptide.

d. **i.** This amino acid links with glycine and threonine to form a tripeptide. How many possible different tripeptides could be produced?

Solution

Six

1 mark

Explanatory notes

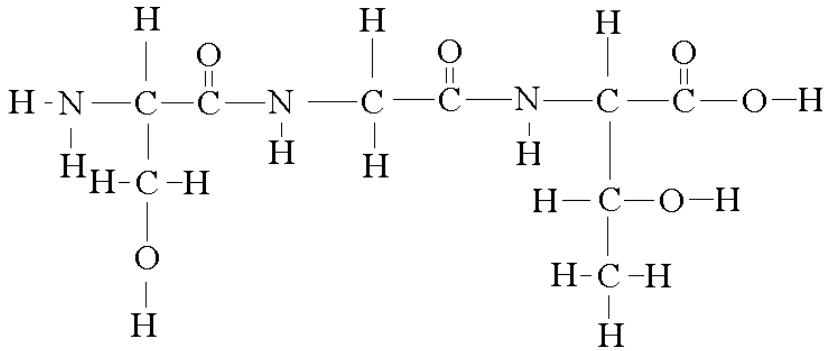
The possible tripeptides are:

ser–gly–thr ser–thr–gly gly–ser–thr gly–thr–ser thr–ser–gly thr–gly–ser

ii. Draw the structure of one of the possible tripeptides that could result.

Solution

For example, the ser–gly–thr will look like:

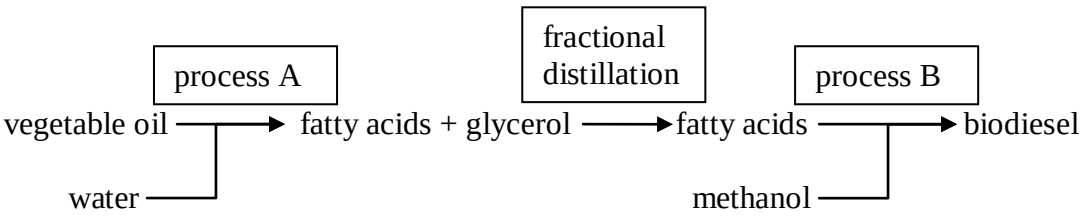


1 mark

Total 1 + 1 + 1 + 2 = 5 marks

Question 7

Consider the flow chart below, showing the production of biodiesel, a biochemical fuel.



a. What type of reaction is process A?

Solution

hydrolysis

1 mark

Explanatory notes

The vegetable oil consists of triglycerides. Water reacts with the triglycerides in a hydrolysis reaction that splits up the triglyceride into its constituents glycerol and fatty acids.

b. What type of reaction is process B?

Solution

condensation or esterification

1 mark

Explanatory notes

- The carboxyl group on the fatty acid reacts with the hydroxyl group on the methanol, forming an ester. Water is eliminated.

c. Write a balanced chemical equation for a reaction that could occur at process B.

Solution

$C_{15}H_{31}COOH(l) + CH_3OH(l) \xrightarrow{acid} C_{15}H_{31}COOCH_3(l) + H_2O(l)$

Note: this is an example of a correct equation using palmitic acid. Any correct reaction in which a fatty acid reacts with methanol in the presence of an acid catalyst would be accepted.

2 marks

Mark allocation

- 1 mark for correct formulas of a fatty acid and methanol.
- 1 mark for the fully balanced equation, including acid catalyst above arrow.

Tips

- *Formulas of many fatty acids are listed in the data booklet.*

d. Give two advantages of biodiesel over diesel as a fuel for vehicles.

Solution

Any two of:

- more carbon neutral (no biofuel is 100% carbon neutral)
- renewable/sustainable
- re-uses a waste product
- produces less CO_2 emissions.

2 marks

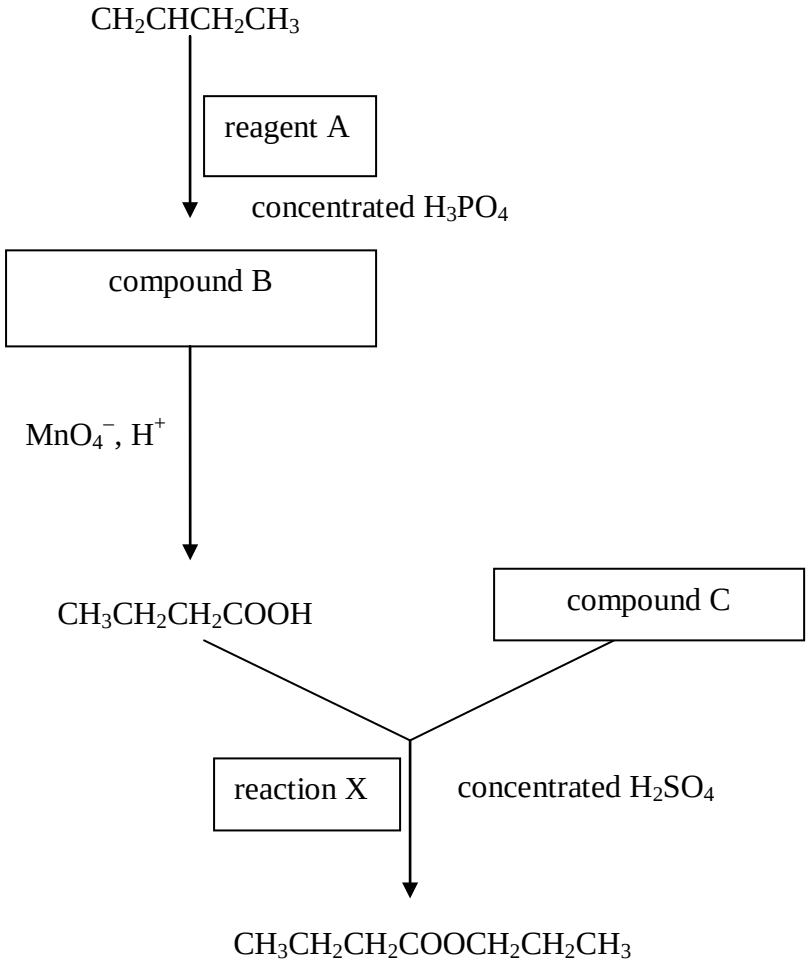
Mark allocation

- 1 mark for each advantage.

Total 1 + 1 + 2 + 2 = 6 marks

Question 8

Consider the partly completed reaction pathway shown below.



a. What is the formula of reagent A?

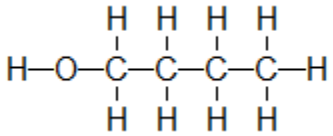
Solution

H_2O

1 mark

b. Draw a structure of compound B.

Solution



1 mark

Explanatory notes

When H_2O is reacted with an alkene, the water adds across the double bond to produce an alkanol. The possible products from the addition of water to but-1-ene are 1-butanol and 2-butanol. Compound B must be 1-butanol because it is then oxidised to butanoic acid in the next step of the reaction pathway.

c. What is the name of compound C?

Solution

1-propanol

1 mark

Explanatory notes

- Concentrated H_2SO_4 is a catalyst for an esterification reaction between an alkanol and a carboxylic acid. The ester is propyl butanoate, so has been created from the butanoic acid and the alkanol, 1-propanol.

d. Write a balanced chemical equation for reaction X.

Solution

$$CH_3CH_2CH_2COOH(l) + CH_3CH_2CH_2OH(l) \xrightarrow{H_2SO_4} CH_3CH_2CH_2COOCH_2CH_2CH_3(l) + H_2O(l)$$

1 mark

Tips

- *Remember to include water as the other product in this and other condensation reactions.*

Total 1 + 1 + 1 + 1 = 4 marks

Question 9

a. Describe the difference between the primary and secondary structures of DNA.

Solution

The primary structure is the sequence of nucleotides and the secondary structure is the double helix.

2 marks

Mark allocation

- 1 mark for correct description of primary structure.
- 1 mark for correct description of secondary structure.

b. DNA sequences are used to code for amino acid sequences in proteins, such as enzymes. Explain how a change in the primary structure of an enzyme can affect the ability of the enzyme to catalyse a reaction.

Solution

A change in the primary structure of an enzyme may change the secondary and tertiary structures, which can affect the shape of the active site so the enzyme no longer functions as a catalyst.

2 marks

Mark allocation

- 1 mark for indicating a change in primary structure may change secondary and tertiary structures.
- 1 mark for indicating the shape of the active site may be affected.

c. Name one method/change, other than altering the primary structure, which can alter an enzyme's catalytic ability.

Solution

Increasing the temperature or altering the pH.

1 mark

Explanatory notes

- Simply writing altering the temperature is not acceptable. It must be specified that it is an increase in temperature that affects the enzyme's catalytic ability.

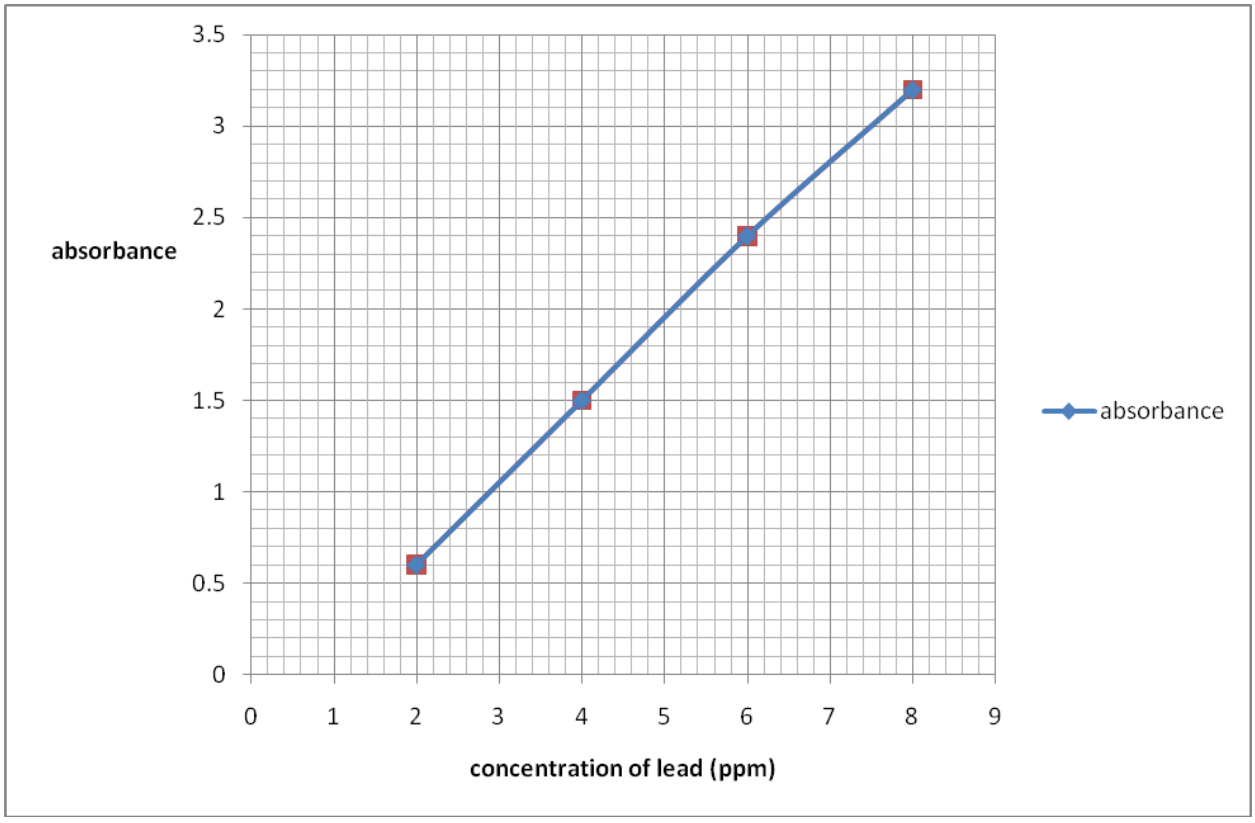
Total 2 + 2 + 1 = 5 marks

Question 10

An experiment was carried out to determine the percentage of lead in a particular batch of shellfish. One of the shellfish was removed from its shell and chopped finely. A 2.30 g sample was heated with 10 mL of nitric acid. The mixture was then filtered and made up to a volume of 1.00 L. A 25.00 mL aliquot of this solution was then further diluted to 100.0 mL in a flask. This solution was then analysed using atomic absorption spectroscopy and found to have an absorbance of 1.20.

The absorbances of a series of standard solutions of lead (II) ions were also measured and a calibration graph drawn.

Calibration graph



a. What is the concentration, in ppm, of lead (II) ions in the 100 mL volumetric flask?

Solution

3.3–3.4 ppm

1 mark

b. Calculate the mass, in mg, of lead in the 1.00 L shellfish sample.

Solution

c(lead) in diluted sample in flask = 3.3 ppm

So *c*(lead) in undiluted sample = $\frac{100}{25} \times 3.3 = 13$ ppm

1 ppm = 1 mg L^{-1}

So, 13 ppm = 13 mg L^{-1}

The mass, in mg, of lead in the 1.00 L sample is 13 mg.

2 marks

Mark allocation

- 1 mark for using the dilution factor correctly.
- 1 mark for correct calculation of mass, in mg.

c. Calculate the percentage, by mass, of lead in the shellfish sample.

Solution

13 mg = 0.013 g

The mass of the shellfish sample was 2.30 g.

The percentage, by mass, of lead = $\frac{0.013}{2.30} \times \frac{100}{1}$

= 0.57%

1 mark

Total 1 + 2 + 1 = 4 marks

END OF SOLUTIONS BOOK