LEARNING MATERIALS

Victorian Certificate of Education
Trial Examination

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

STUDENT NUMBER | | | | | | | | | Letter |

2023 CHEMISTRY

Written trial examination – Units 3/4

Reading time: (15 minutes)

Writing time: (2 hours 30 minutes)

QUESTION AND ANSWER BOOK

Structure of book

Section	*Number of questions*	*Number of questions to be answered*	*Number of marks*
A	30	30	30
B	8	8	90
			120

- Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners, rulers and one scientific calculator.
- Students are NOT permitted to bring into the examination room: blank sheets of paper and/or correction fluid/tape.

Materials supplied

- Question and answer book
- Data book
- Answer sheet for multiple-choice questions

Instructions

- Write your **student number** in the space provided above on this page.
- Check that your **name** and **student number** as printed on your answer sheet for multiple-choice questions are correct, and sign your name in the space provided to verify this.
- Unless otherwise indicated, the diagrams in this book are not drawn to scale.
- All written responses must be in English.

At the end of the examination

- Place the answer sheet for multiple-choice questions inside the front cover of this book.
- You may keep the data book.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

VCAA Chemistry Data Book download: https://bit.ly/ChemDataBook

SECTION A – Multiple-choice questions

Instructions for Section A

Answer **all** questions in pencil on the answer sheet provided for multiple-choice questions.
Choose the response that is **correct** or that **best answers** the question.
A correct answer scores 1; an incorrect answer scores 0.
Marks will **not** be deducted for incorrect answers.
No marks will be given if more than one answer is completed for any question.
Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1

The arrangement of connecting atoms to a chiral centre is most likely to be

A. linear.
B. V-shaped.
C. trigonal planar.
D. tetrahedral.

Question 2

In an investigation to determine the concentration of ethanoic acid in a commercial vinegar, two students used identical equipment, and followed the same procedure, which involved the titration of a diluted sample of the vinegar with an aqueous solution of sodium hydroxide of known concentration.

The equation for the titration reaction was

$CH_3COOH(aq) + OH^-(aq) \rightarrow CH_3COO^-(aq) + H_2O(l)$

The students were able to select the indicator they wished to use.

Student A chose methyl orange and recorded titres of 18.2 mL, 18.3 mL and 18.4 mL.

Student B chose phenolphthalein and recorded titres of 19.3 mL, 19.7 mL and 19.5 mL.

The procedures followed by both students were closely monitored and no discrepancies in technique were observed. Both accurately judged the endpoint colour for the indicator chosen.

Based on the information provided, it might be concluded that compared to Student B, the data recorded by Student A was

A. more precise but less accurate.
B. less precise but more accurate.
C. more precise and more accurate.
D. less precise and less accurate.

Question 3

When a particular alkene reacts with steam, two isomeric compounds are formed with one far more abundant than the other. Both isomers react with acidified dichromate, one to produce two different products and the other to produce one product. All three products show four signals on their ^{13}C NMR spectrum.

The alkene was

A. *cis*-but-2-ene.

B. *trans*-but-2-ene.

C. but-1-ene.

D. 2-methylprop-1-ene.

Question 4

A 5.25 g gaseous sample of a hydrocarbon occupied a volume of 3.42 L at 77 ºC and 102 kPa. What volume of carbon dioxide, in L, measured at the same temperature and pressure, would be produced by the complete combustion of the sample?

A. 3.42 L

B. 6.84 L

C. 10.3 L

D. 14.0 L

Question 5

The rate-time graphs shown below are related to the impact of a change imposed at time t on a system at equilibrium.

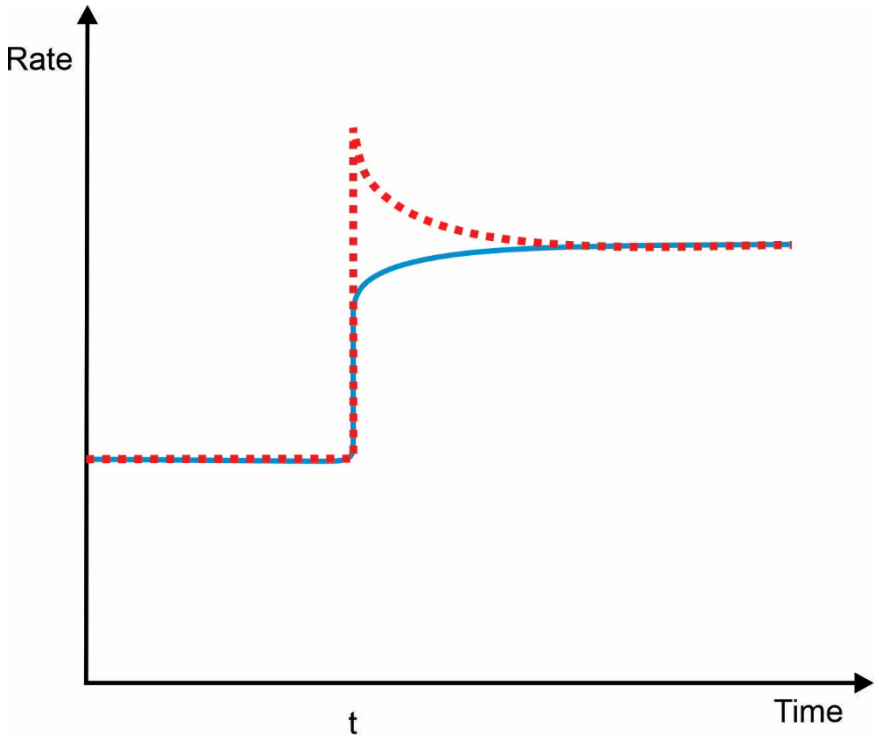

Figure 1

Which of the following equilibria is most likely to be consistent with the response to the imposed change indicated on the graphs?

A. $H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(aq)$

B. $CH_3COOH(l) + CH_3CH_2OH(l) \rightleftharpoons CH_3COOCH_2CH_3(l) + H_2O(l)$

C. $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

D. $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$

Question 6

The boiling points of the two main forms of vitamin D, ergocalciferol and cholecalciferol are 496 °C and 406 °C respectively.

Both forms are part of the diet, ergocalciferol from plant material and fungi such as mushrooms, and cholecalciferol mainly from animal sources including oily fish such as salmon, tuna and herring.

A HPLC chromatographic analysis of a mixture of vitamin D_2 and vitamin D_3 produced the chromatogram represented in **Figure 2**.

https://www.sigmaaldrich.com/AU/en/technical-documents/protocol/analytical-chemistry/small-molecule-hplc/hplc-analysis-of-vitamin-d2-and-vitamin-d3-g005614 5 August 2023)

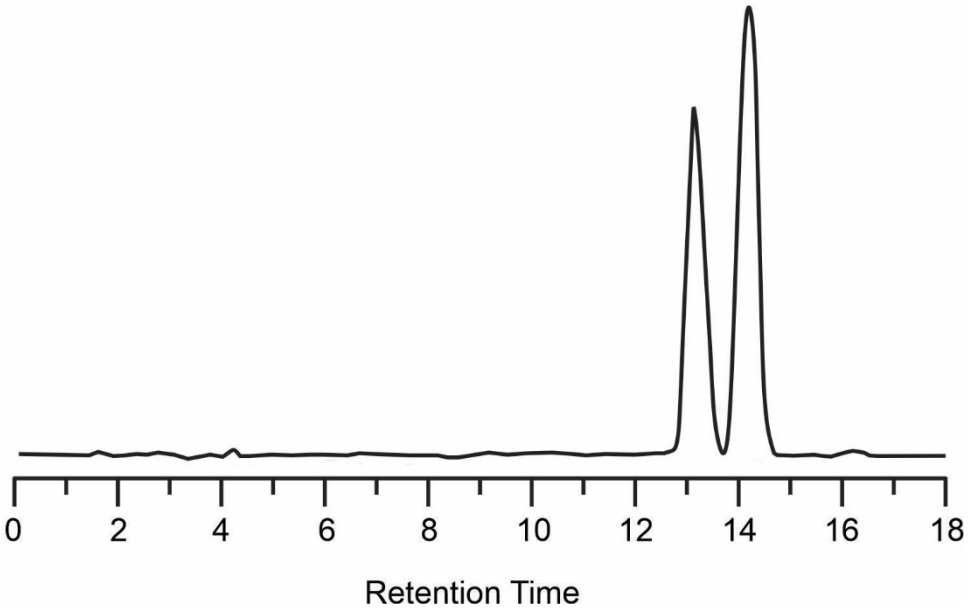

Figure 2

The relative peak areas on the chromatogram were 275 and 325. The percentage, by mass, of vitamin D_2 in the mixture was closest to

A. 45
B. 55
C. 15
D. 85

Question 7

The specific heat capacity of aluminium is 0.921 J g^{-1} K^{-1}.

A sample of aluminium was heated to 95.4 °C and then immediately immersed in 200 g of water, initially at 24.5 °C, in an insulated container.

The temperature of the water increased to 28.4 °C.

Which of the following amounts is closest to the mass of the aluminium sample?

A. 10 g
B. 50 g
C. 100 g
D. 200 g

Question 8

The digestion of starch is an important part of the human condition. Which of the following is **not** directly related to starch digestion?

A. glycaemic index
B. lactose intolerance
C. the amount of amylose present
D. respiration

Question 9

A first order reaction is one in which the rate of reaction is dependent on the concentration of only one reactant.

In a particular first order reaction, 90 % of the reactant present at the start of each hour is remains at the end of the hour. During which hour of the reaction will a total of 50 % of the reactant have been consumed?

A. fourth
B. fifth
C. sixth
D. seventh

Question 10

Which of the following would have the greatest impact on the ability of an enzyme to catalyse a chemical reaction?

A. a decrease in reactant concentration
B. the presence of a chiral substrate
C. the removal of the product as it is formed
D. a change in pH

Question 11

The use of willow bark as a pain reliever dates back to ancient civilizations in Mesopotamia more than 2,000 years ago. In 1829, Johann Büchner, isolated pure salicin from willow bark. Salicin was recognised as the 'active ingredient' in willow bark, i.e., the pain reliever. In the body salicin was converted into salicylic acid.

The laboratory conversion of salicin to salicylic acid involves the intermediate compound salicyl alcohol. The structures of salicin, salicyl alcohol and salicylic acid are represented in **Figure 3**.

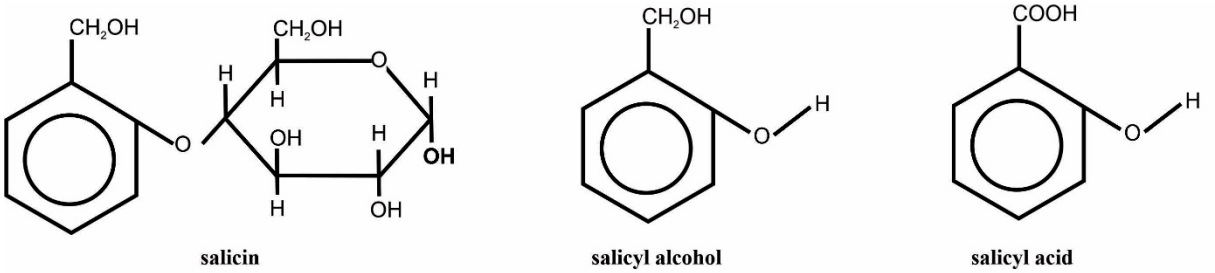

Figure 3

Which of these reaction types is **not** involved in the conversion of salicin to salicyl alcohol and subsequently to salicylic acid?

A. condensation
B. hydrolysis
C. oxidation
D. reduction

Question 12

The decomposition of hydrogen iodide occurs according to the equilibrium

$2HI(g) \rightleftharpoons H_2(g) + I_2(g), \quad \Delta H = 52.1 \text{ kJ mol}^{-1}$

During an investigation of this equilibrium, the following data were recorded.

Experiment	Initial amount - mol			Equilibrium amount - mol		
	HI	I_2	H_2	HI	I_2	H_2
1	0.070	0.00	0.00	0.020		
2	0.00	0.025	0.040		0.005	

Table 1

According to these data,

A. Equilibrium 1 was at the higher temperature.
B. Equilibrium 2 was at the higher temperature.
C. Equilibria 1 and 2 were both at the same temperature.
D. there is not enough information to determine which equilibrium was at the higher temperature.

Question 13

Three solutions of NaCl(aq) of different concentrations were electrolysed for the same amount of time at the same voltage using platinum anodes. The time of each electrolysis was less than that required for complete electrolysis of 1 M NaCl(aq). The changes in pH with time at the anode were plotted as shown in **Figure 4**.

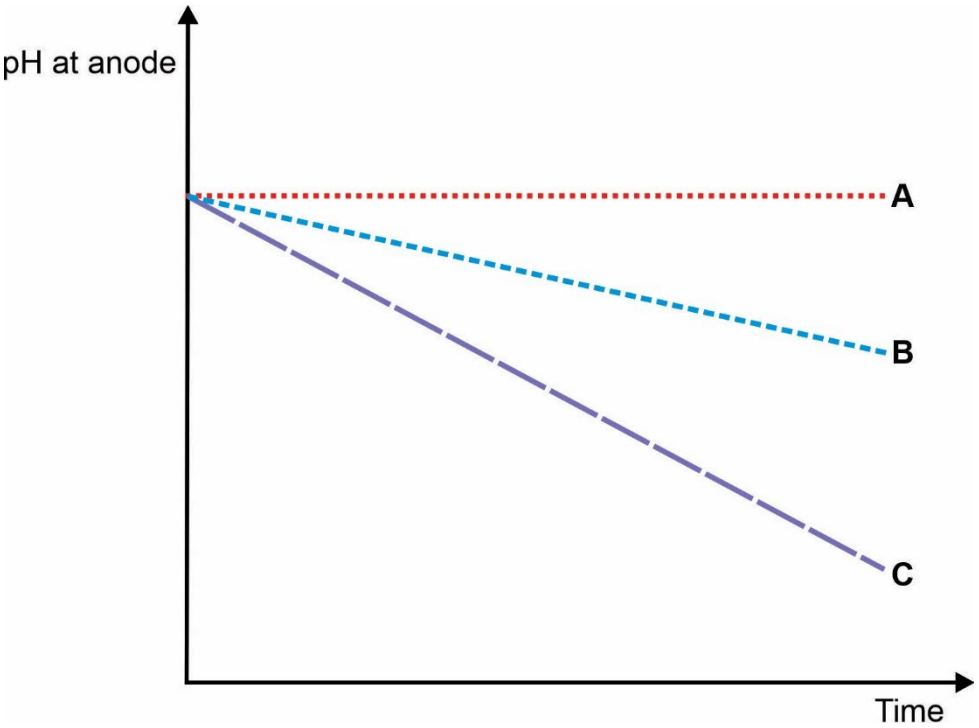

Figure 4

Which of the following alternatives links the data and the concentrations of NaCl(aq) used?

	1.0 M NaCl(aq)	4 M NaCl(aq)	10.0 M NaCl(aq)
A.	Graph A	Graph B	Graph C
B.	Graph C	Graph B	Graph A
C.	Graph A	Graph C	Graph B
D.	Graph C	Graph A	Graph B

Question 14

Figure 5 represents the progress of a reaction between calcium carbonate pieces and excess hydrochloric acid. Plot A reflects the progress under the initial conditions and plot B the progress after the initial conditions were modified.

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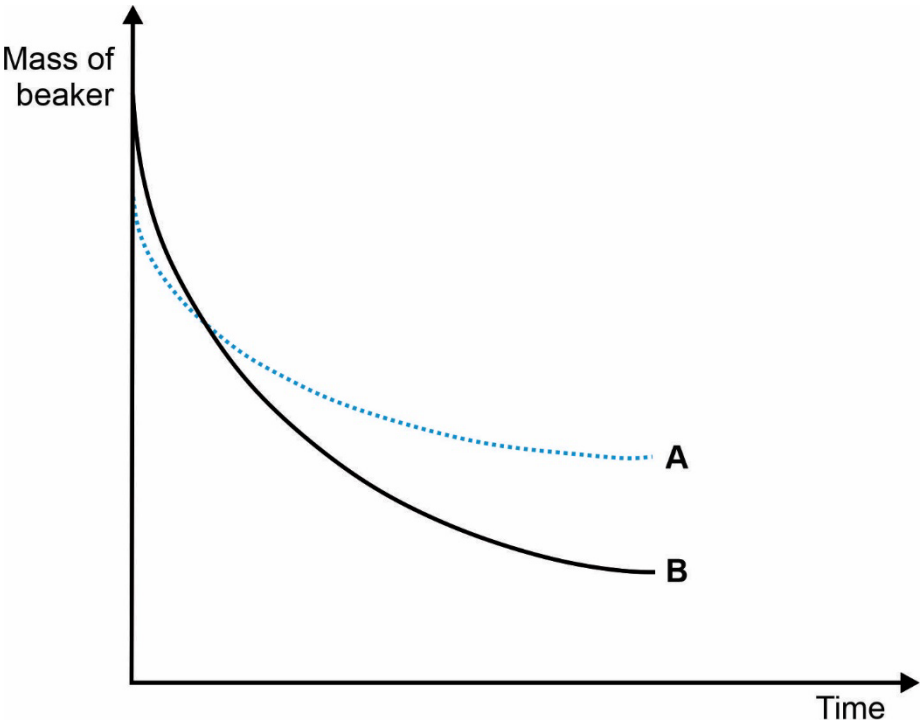


Figure 5

The most likely modification to the initial conditions was that

A. a larger volume of acid was used.

B. a larger mass of powdered calcium carbonate was used.

C. a higher temperature was used, and the acid volume was doubled.

D. the acid concentration was doubled and powdered calcium carbonate was used.

Question 15

Maleic acid and fumaric acid are both forms of but-2-enedioic acid. Their molecular structures are shown in **Figure 6**.

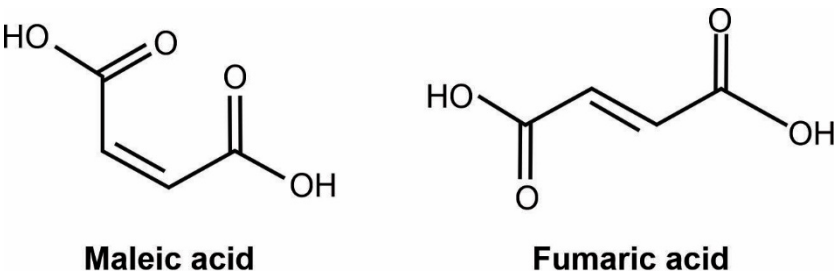


Figure 6

The melting temperatures of maleic acid and fumaric acid are 130 °C and 286 °C respectively. The solubilities, in water at 25 °C, of maleic acid and fumaric acid are 788 g L^{-1} and 7 g L^{-1} respectively.

These data are best explained by the

A. polarity of the trans isomer.

B. stronger intermolecular bonding of the trans isomer.

C. presence of optical isomers.

D. presence of two carboxyl groups on the molecules.

Question 16

Canola, linseed and soybean oils all contain the four 18 C fatty acids included in ***(Table 9 of the Chemistry Data Book)***.

If the temperature of a mixture of these four fatty acids is gradually lowered enough so that all four of these fatty acids can solidify, which one will solidify last?

A. linoleic acid

B. linolenic acid

C. oleic acid

D. stearic acid

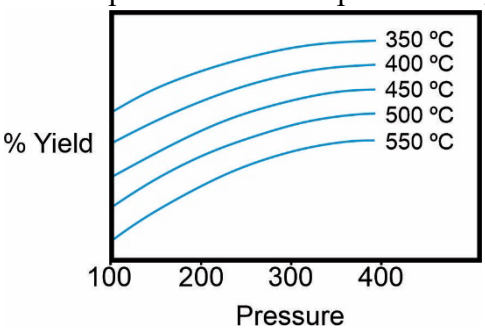
Question 17

The production of sulfuric acid depends on the equilibrium.

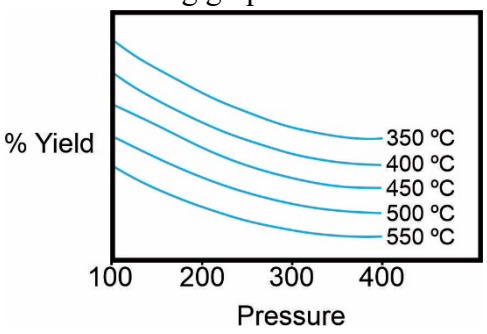
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -192 \text{ kJ mol}^{-1}$

The yield of SO_3 at different temperatures and pressures was investigated and presented as a plot of yield against pressure at different temperatures. The relationship between yield, temperature and pressure is best represented by which of the following graphs?

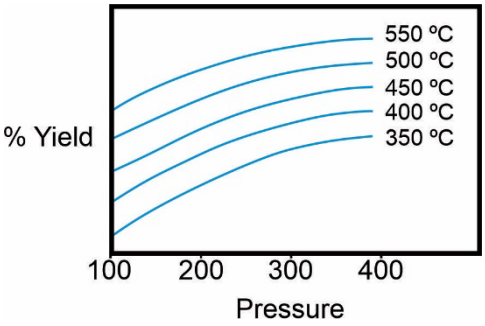
A.



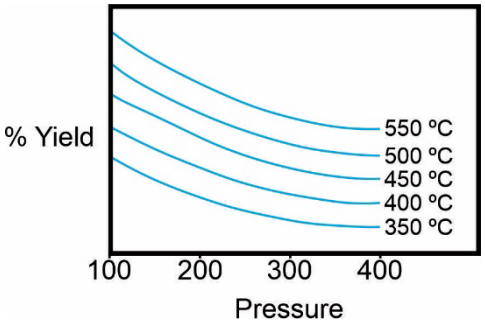
B.



C.



D.



Question 18

An equilibrium mixture of $SO_2(g)$, $O_2(g)$ and $SO_3(g)$ contains 1 mol of each species.

Four other mixtures of $SO_2(g)$, $O_2(g)$ and $SO_3(g)$ each contain 1 mol SO_3 in the same size of container but are not at equilibrium.

The initial amounts of $SO_2(g)$ and $O_2(g)$ in these mixtures are:

Mixture 1 – 1.2 mol SO_2, 0.8 mol O_2

Mixture 2 – 1.1 mol SO_2, 0.9 mol O_2

Mixture 3 – 0.9 mol SO_2, 1.1 mol O_2

Mixture 4 – 0.8 mol SO_2, 1.2 mol O_2

Which of these mixtures will have the largest amount of SO_3 present when it reaches equilibrium at constant temperature?

A. Mixture 1

B. Mixture 2

C. Mixture 3

D. Mixture 4

Question 19

The structures of four complex carbohydrates associated with human nutrition are represented in **Figure 7**.

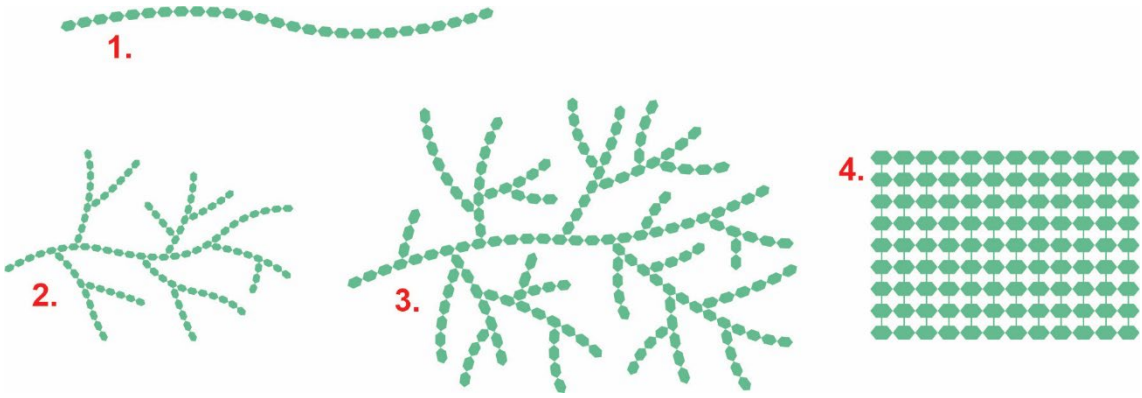


Figure 7

Which of these carbohydrates is not ingested but produced in the body?

A. 1
B. 2
C. 3
D. 4

Question 20

A nanoporous gold leaf that shows electrocatalytic properties toward both hydrazine (N_2H_4) oxidation and hydrogen peroxide (H_2O_2) reduction, has allowed for the implementation of a direct hydrazine-hydrogen peroxide fuel cell (DHHPFC) as a unique power source for air-independent applications under extreme conditions, such as outer space and underwater environments.

The inputs of the DHHPFC are shown in **Figure 8**.

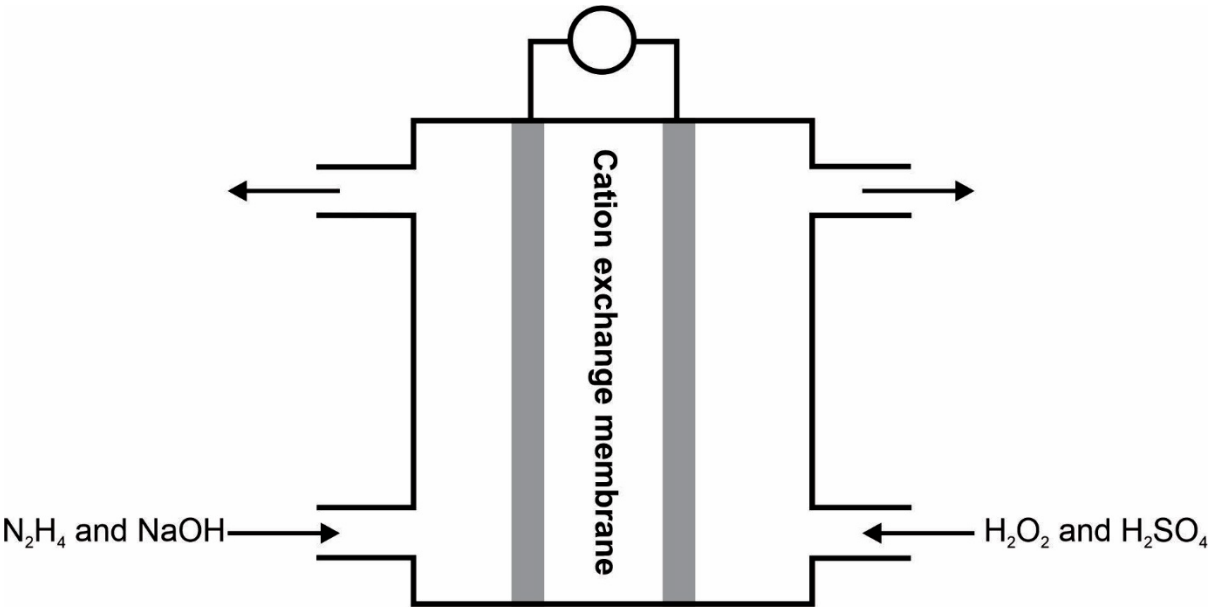


Figure 8

Which of the following is unlikely to be present in the outlet streams of the DHHPFC?

A. $NH_3(g)$
B. $Na_2SO_4(aq)$
C. $NaOH(aq)$
D. $H^+(aq)$

Question 21

Lactic acid, also known as 2-hydroxypropanoic acid, is formed from the anaerobic respiration of glucose.

The heat of combustion of lactic acid is 15 kJ g^{-1}.

The mass of products formed when 100 kJ of energy is obtained from complete combustion of lactic acid is closest to

A. 10 g
B. 15 g
C. 20 g
D. 30 g

Question 22

The thermal efficiency per mol of fuel for a fuel cell can be calculated from the following relationship.

Efficiency = Electrical energy / ΔH

What is the thermal efficiency of an ethanol/O_2 fuel cell, with an acidic electrolyte, operating at 0.576 V?

A. 10 %
B. 25 %
C. 50 %
D. 75 %

Question 23

The reaction bomb of a bomb calorimeter has a heat capacity of 0.500 kJ $°C^{-1}$. A 10.0 g sample of crushed potato chips is added to the reaction bomb in a bomb calorimeter with a heat capacity of 0.500 kJ $°C^{-1}$. The bomb is then immersed in the 1.5 L of water in the calorimeter**.** Calculate the energy contained in the food per gram if, after combustion of the chips, the temperature of the water in the calorimeter increases to 52.7 °C from an initial temperature of 22.1 °C.

What was the energy content of the chips in kJ g^{-1}?

A. 4
B. 14
C. 18
D. 21

Question 24

The relative strengths of acids are reflected in an equilibrium constant called an acidity constant, represented by the symbol K_a.

The K_a values, at 25 °C, of methanoic and ethanoic acids are 1.8×10^{-4} M and 1.7×10^{-5} M respectively. For comparison purposes it may be assumed that the change in acid concentration as it ionises to equilibrium is minimal compared to its original concentration.

Based on the information supplied, it may be deduced that compared to the pH of 0.10 M HCOOH(aq), the pH of 0.10 M CH_3COOH(aq) will be

A. lower, because ethanoic acid is the stronger acid.
B. higher, because ethanoic acid is the stronger acid.
C. lower, because ethanoic acid is the weaker acid.
D. higher, because ethanoic acid is the weaker acid.

Question 25

Consider the compound represented in **Figure 9**.

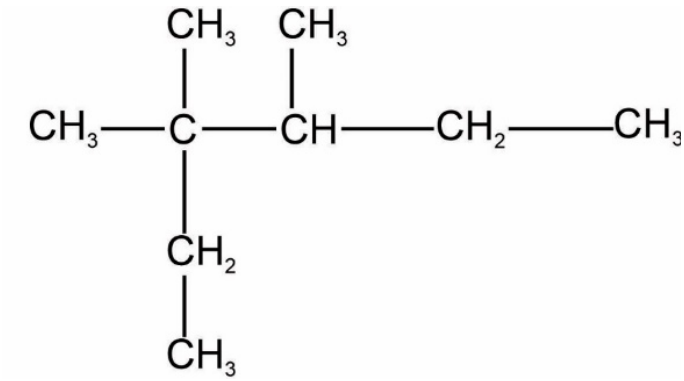


Figure 9

What is the systematic name of this compound?

A. 2-ethyl-2,3-dimethylpentane
B. 3,4-dimethyl-4-ethylpentane
C. 3,4,4-trimethylhexane
D. 3,3,4-trimethylhexane

Question 26

A student was provided with three spirit burners, unlabelled and identical except for the alcohol in the burner. The three burners contained methanol, ethanol and 1-propanol respectively.

Each spirit burner was sitting on a balance pan under a container holding 200 g water and the water was heated until the temperature had increased by 20 °C. At that point the flame was extinguished and the change in mass of the burner recorded.

The recorded mass changes were 0.866 g, 0.664 g, 0.585 g.

Based on the information provided, the heat of combustion of 1-propanol in kJ g^{-1} would be

A. 19
B. 25
C. 29
D. 39

Question 27

The relationship between rate of reaction and temperature for a particular reaction is represented in **Figure 10**.

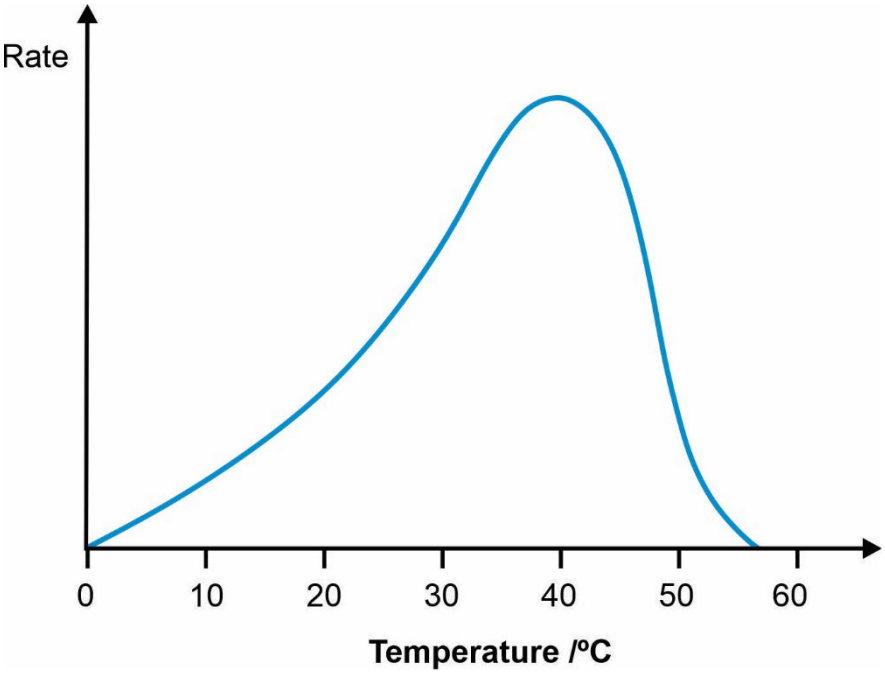


Figure 10

To which of the following processes is this relationship most relevant?

A. ester production
B. ethanol production
C. ethene production
D. ethane production

Question 28

The galvanic cell represented in **Figure 11** produced a voltage when the electrodes were connected to a voltmeter. Both half-cells contain the same electrode area and volume of solution.

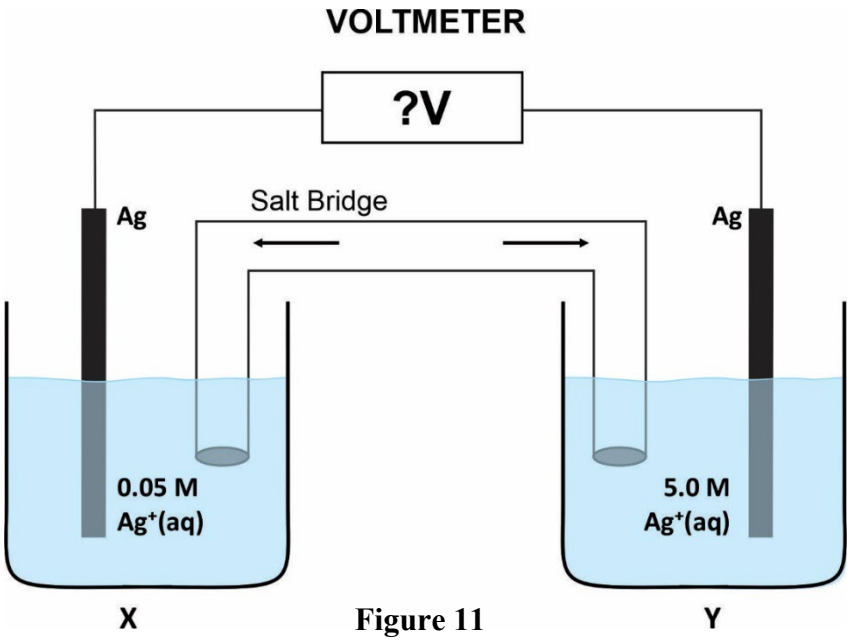


Figure 11

When the cell is operating,

A. the total concentration of $Ag^+(aq)$ decreases.
B. cations move into half-cell X.
C. the mass of Ag increases.
D. oxidation occurs in half-cell X.

Question 29

Excess acidified potassium dichromate is added to the same chemical amount of four different compounds. Which of these compounds is least likely to react with acidified potassium dichromate?

A. propan-1-ol
B. propan-2-ol
C. methylpropan-1-ol
D. methylpropan-2-ol

Question 30

Compared to petrodiesel, which one of the following statements is correct with respect to biodiesel?

A. Petrodiesel and biodiesel, in which molecules have the same number of carbon atoms, will require the same amount of oxygen for complete combustion.
B. Biodiesel is not suitable for very low temperature regions.
C. Using biodiesel as a fuel is a fully carbon neutral activity.
D. Biodiesel has a higher energy content than petrodiesel.

END OF SECTION A

SECTION B

Instructions for Section B

Answer **all** questions in the spaces provided.
Give simplified answers to all numerical questions, with an appropriate number of significant figures; unsimplified answers will not be given full marks.
Show all working in your answers to numerical questions; no marks will be given for an incorrect answer unless it is accompanied by details of the working.
Ensure chemical equations are balanced and that the formulas for individual substances include an indication of state, for example, $H_2(g)$, NaCl(s).
Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1 (14 marks)

In an experimental exercise to measure the energy content of two different brands of peanut butter, a bomb calorimeter was first calibrated via the complete combustion of 1.253 g ethanol in the reaction bomb, and the change in temperature of the water in the calorimeter measured.
The reaction bomb was then cleaned, and a 1.53 g sample of peanut butter X was added to undergo reaction with oxygen. The change in temperature of water in the calorimeter was measured.
The reaction bomb was cleaned again, and a 1.25 g sample of peanut butter Y was added and reacted with oxygen. The change in temperature was again recorded.
Six temperatures were recorded during the analysis. In order from start to finish they were

- 22.30 °C
- 24.87 °C
- 23.15 °C
- 25.47 °C
- 24.83 °C
- 27.09 °C

a. Determine the calibration factor for the bomb calorimeter used. 2 marks

b. Determine the energy content, in kJ, per 100 g of peanut butter X. 2 marks

c. Determine the energy content, in kJ, per 100 g of peanut butter Y. 1 mark

d. **i.** Given that different sample sizes of different peanut butters are investigated, what is the independent variable in this exercise? 1 mark

ii. The change in temperature in the calorimeter during reaction of the peanut butter is dependent on two variables. Is this a valid statement? 1 mark

e. Information from the nutrition labels for 100 g of peanut butters X and Y is shown below in **Table 2**.

Peanut Butter X	Nutrient	Peanut butter Y
27.1 g	protein	23.8 g
42.5 g	fat	51.4 g
5.3 g	carbohydrate	13.3 g

Table 2

i. Are these data consistent with the relative values of the energy contents of X and Y determined via the investigation? Explain. 1 mark

ii. In terms of the relative amounts of the nutrients shown in **Table 2**, suggest **two** reasons why peanut butter X might be considered the healthier option for consumers. 1 mark

f. The structure of a fat present in peanut butter is shown in **Figure 12**.

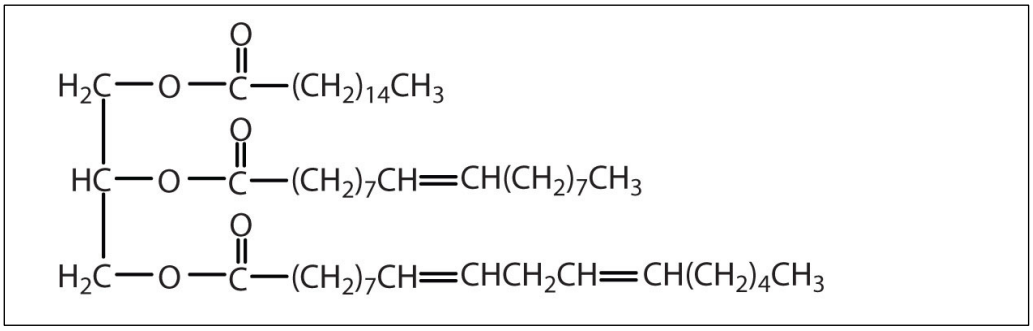


Figure 12

i. Identify and classify each of the fatty acids that would be released from this fat during digestion. 3 marks

ii. **Figure 13** shows the structure of resveratrol, a compound present in peanut acid. Does this structure suggest a reason why resveratrol helps maintain the structural integrity of the fats and fatty acids present? Explain. 2 marks

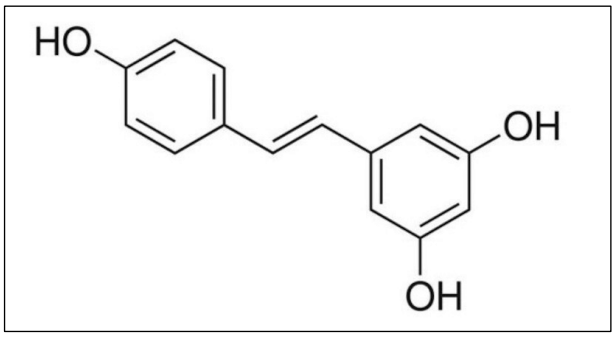


Figure 13

Question 2 (10 marks)
An unknown metal M forms a soluble compound, $M(NO_3)_2$.
An aqueous solution of $M(NO_3)_2$ is electrolysed.
When a constant current of 2.50 amperes is applied for 35.0 minutes, 3.06 grams of metal M are deposited.

a. Calculate the molar mass of M and identify the metal. 3 marks

b. A galvanic cell is constructed in which this element is present in a solution of its conjugate oxidant in one half-cell. The other cell contains the element with relative atomic mass 63.5 in a solution of its conjugate oxidant.

i. Determine the theoretical voltage of this cell and explain why the voltage generated could be significantly lower. 2 marks

ii. Give the chemical formula of a compound which could be used in the salt-bridge solution and explain how and why this compound interacts with the half-cell containing the metal M. 2 marks

c. How will the products of electrolysis of 1 M $MCl_2(aq)$ differ from the products of electrolysis of 1 M $MBr_2(aq)$? Explain, using half-equations, any differences. 3 marks

Question 3 (12 marks)

An organic chemical starting from compound W proceeds to the product compound Z via compounds X and Y according to W → X→ Y → Z.

A spectrum of the end product, Z, is shown in **Figure 14** and a spectrum of the starting compound, W, is shown in **Figure 15**. The molar mass of W is 78.5 g mol^{-1}.

Spectrum produced with data obtained from SDBSWeb: https://sdbs.db.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 5 August 2023)

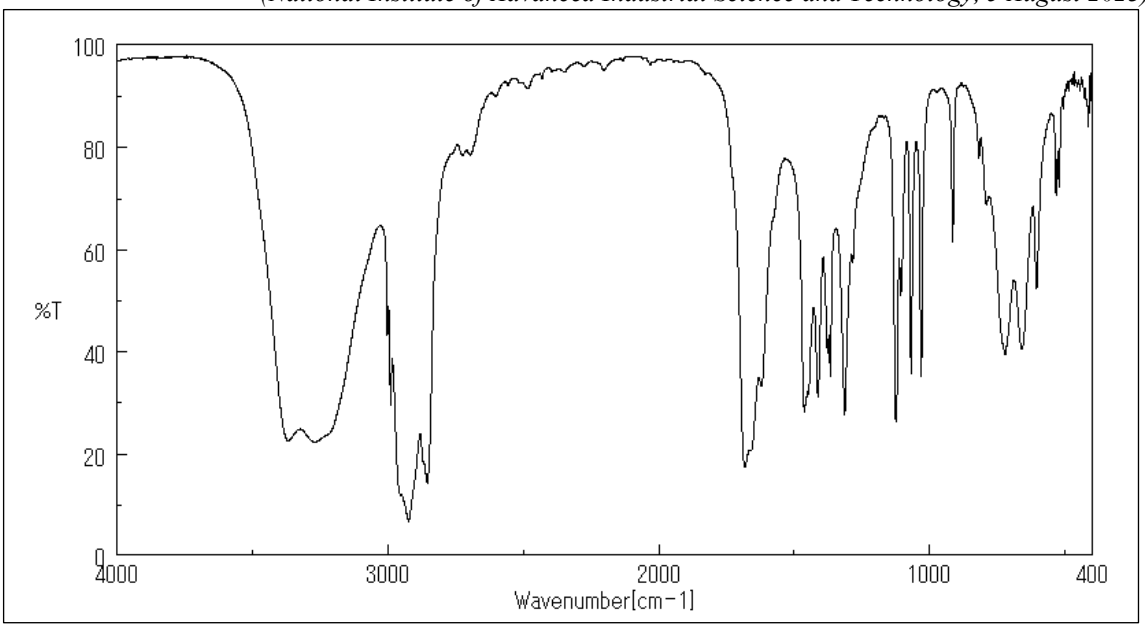


Figure 14: Spectrum of compound Z

Spectrum produced with data obtained from SDBSWeb: https://sdbs.db.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 5 August 2023)

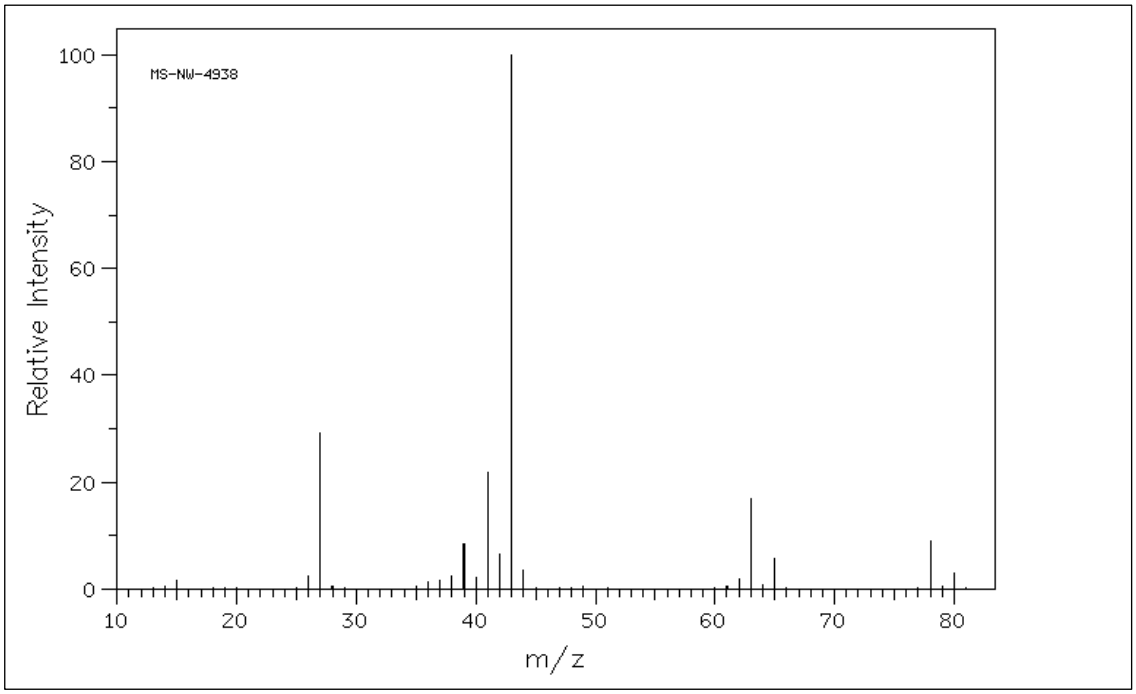


Figure 15: Spectrum of compound W

a. What can be deduced about the final product from the spectrum in **Figure 14**. 2 marks

b. Use the molar mass of the starting compound, W, and information present on the spectrum in **Figure 15** to determine the molecular formula of W. 3 marks

c. The spectra shown in **Figures 16 and 17** are both linked to a compound, X, produced directly from the starting compound, W. This compound, X, is oxidised in the reaction pathway.

Spectrum produced with data obtained from SDBSWeb: https://sdbs.db.aist.go.jp
(National Institute of Advanced Industrial Science and Technology, 5 August 2023)

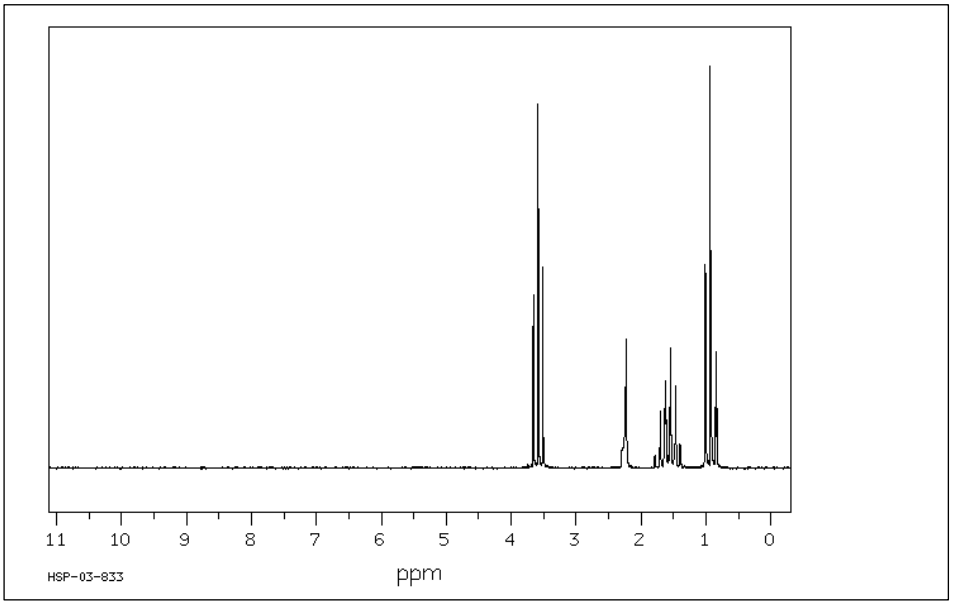


Figure 16: Spectrum of compound X

Spectrum produced with data obtained from SDBSWeb: https://sdbs.db.aist.go.jp
(National Institute of Advanced Industrial Science and Technology, 5 August 2023)

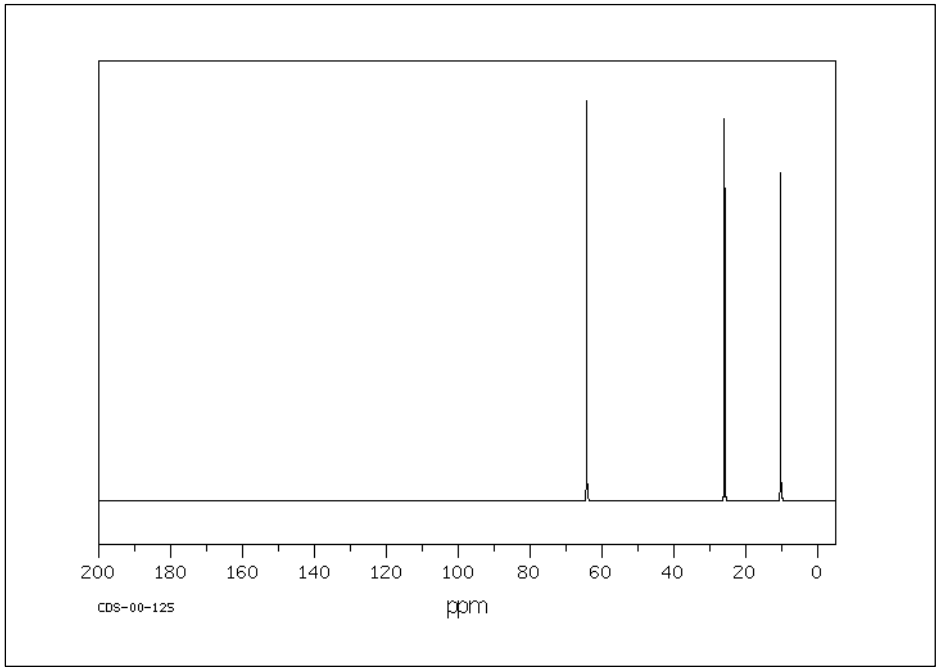


Figure 17: Spectrum of compound X

i. Describe what can be deduced about the compound, X, from each spectrum. **Figure 16** is a ^{1}H NMR spectrum. 2 marks

ii. Draw the structural formula of compound, X. 1 mark

d. The spectrum shown in **Figure 18** is associated with the compound, Y, which is produced from compound X and then reacted with an inorganic reagent to produce the final product.

Spectrum produced with data obtained from SDBSWeb: https://sdbs.db.aist.go.jp
(National Institute of Advanced Industrial Science and Technology, 5 August 2023)

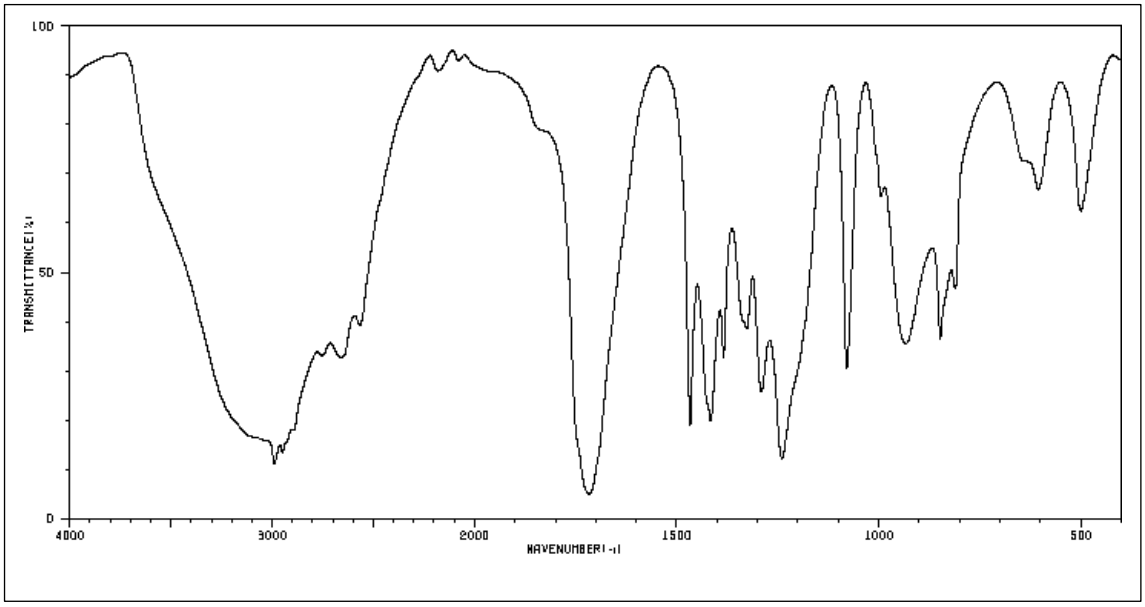


Figure 18: Spectrum of compound Y

i. Give the semi-structural formula of compound Y. 1 mark

ii. Write a balanced oxidation half-equation for the production of compound Y from compound X. 1 mark

iii. Write a balanced equation for the production of the final product, Z, from compound Y. 1 mark

iv. Name the final product, Z. 1 mark

Question 4 (13 marks)

Steel production is currently responsible for about 7% of global CO_2 emissions. To cut these emissions, scientists in the industry are intensively investigating hydrogen-based ironmaking approaches as sustainable pathways to replace carbon reductants.

In steel making, iron(III) oxide in iron ore is reduced to iron by reaction with carbon monoxide. Hydrogen-based steel making is designed to replace the carbon monoxide with green hydrogen.

However, supplies of green hydrogen are limited and current means of storing and transporting hydrogen require high pressures and low temperatures, both of which are costly to maintain.

The possibility of using ammonia in steel production would overcome some of the limitations of hydrogen storage and transport.

The Haber process, the current common method of producing ammonia, currently combines nitrogen from the air with hydrogen derived mainly from fossil fuels via steam reforming. The Haber process is represented in **Figure 19**.

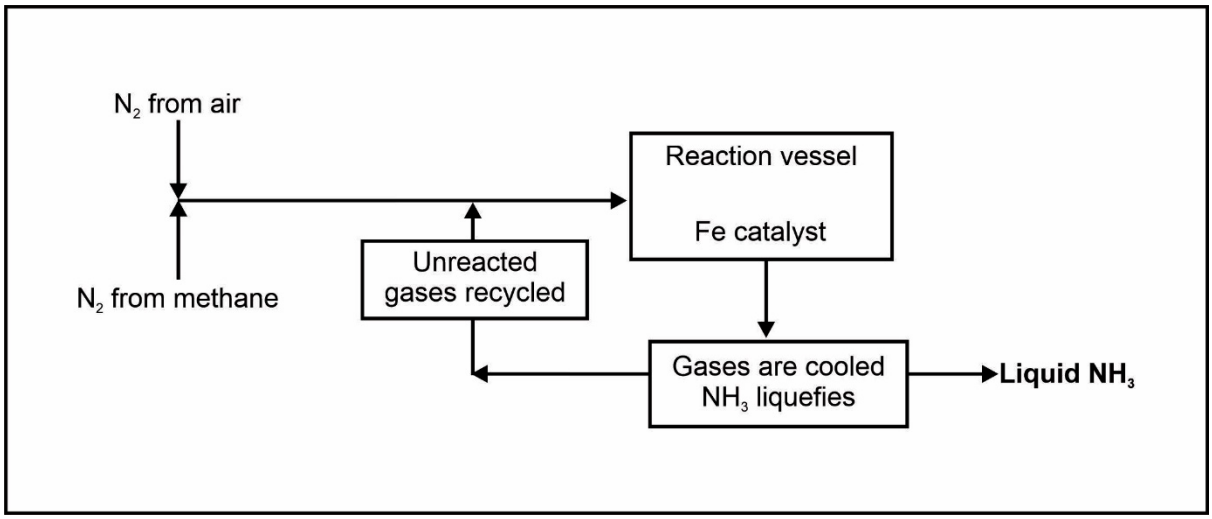


Figure 19

a. Write a balanced equation for the reaction between iron(III) oxide and carbon monoxide. 1 mark

The production of hydrogen from methane occurs via a process known as steam reforming and the water gas reaction via the equilibria

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g); \ \Delta H = +206 \text{ kJ mol}^{-1}$$
$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) ; \ \Delta H = -41 \text{ kJ mol}^{-1}$$

b. Write the thermochemical equation for the overall reaction between methane and steam and use that as a basis for describing the favoured conditions for this reaction. 3 marks

c. In situations where the CO_2 produced during the production of hydrogen is captured and stored, the ammonia ultimately produced is classified as blue ammonia. How would the process need to be altered for the ammonia to be classified as green ammonia? 1 mark

d. Fractional distillation involves the liquefaction of air followed by gentle heating. How does this separate nitrogen from oxygen in the sample? 1 mark

Analysis of reaction conditions for the reaction vessel produced the information provided in **Figure 20**.

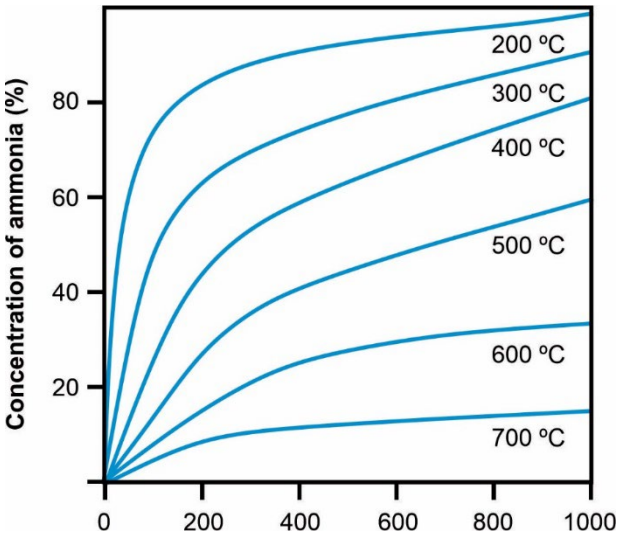


Figure 20

e. These data suggest that the yield of ammonia increases at high pressure and low temperature. Suggest a reason why low temperatures may not be economically viable. 1 mark

f. The energy required to break chemical bonds is known as the bond dissociation energy (BDE). The BDEs, kJ mol^{-1}, for the bonds involved in the reaction are:
N≡N: 945, H-H: 435, N-H: 390
Write a balanced thermochemical equation for the production of NH_3 in the Haber process. 3 marks

g. Explain why NH_3 liquefies at a much higher temperature than the other reactants in the Haber process. 1 mark

h. One area of current fuel research involves the use of green NH_3 as a viable alternative to H_2 in solid oxide fuel cells. Solid oxide fuel cells use oxide, O^{2-}, ions as the electrolyte.

i. Write a balanced half-equation for the oxidation reaction in a green NH_3 solid oxide fuel cell. 1 mark

ii. Identify the economic benefit in supplying ammonia rather than hydrogen for fuel cells. 1 mark

Question 5 (11 marks)

The functional groups represented in **Figure 21** are significant and associated with three major nutrients we ingest in our food.

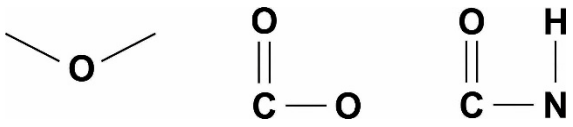
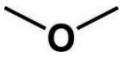
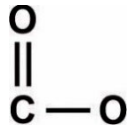


Figure 21

a. Identify the nutrient group associated with each of the functional groups and give a reason why each of the nutrient groups is included in the diet. 3 marks





b. Identify and discuss the reaction types and functional group changes that occur during digestion and post digestion. 4 marks

c. Describe the chemistry of the use of the major digestion product of the nutrient represented in **Figure 22**. 2 marks

Figure 22

d. Some products of the digestion of one of the nutrients may be linked to the digestion of all three nutrients. Explain the chemistry behind this function and why it may also be linked to another component of a balanced diet. 2 marks

Question 6 (11 marks)
An article in the New Scientist of July 11, 2023, was titled,
'Blanket for electric cars helps battery performance'.
'The lithium-ion batteries in electric cars work best within a certain temperature range, so researchers have created a blanket to keep your car cool in the sun and warm in the cold'.

Lithium-ion battery cells have solid electrodes which allow for the intercalation of lithium ions, i.e., lithium ions can become part of the electrodes without significantly affecting the structure. Many lithium-ion batteries have lithium intercalated graphite as one electrode material and a lithium intercalated transition metal oxide as the other electrode material. Lithium ions are present in both electrodes.

One electrode in a lithium-ion battery is represented as LiC_6. The other electrode is a mix of lithium ions and transition metal oxides, e.g., $LiCoO_2$, $LiNiMnCoO_2$.

Lithium-ion batteries contain a lithium-ion electrolyte and depend on the simultaneous transfer of lithium ions and electrons.

In a discharging lithium-ion battery, Li^+ ions and electrons are released at one electrode.

a. Write a balanced half-equation for this change. 1 mark

b. Lithium atoms are not formed at the cathode in the discharging reaction of lithium-ion cells but Li^+ ions become part of the electrode. The most abundant element in a lithium transition metal oxide electrode is Co found as cobalt(IV) oxide.
The only product in the half-equation for the cathode reaction in a lithium-ion cell is $LiCoO_2$.
Write the balanced half-equation and identify the associated oxidation number change. 2 marks

c. The ideal operating temperature range for lithium-ion batteries is around 15-40 °C. Suggest reasons why operation outside of that temperature range is undesirable. 2 marks

d. Lithium-ion batteries in cars range in capacity from 30 kWh to 100 kWh and have energy consumption of around 20 kWh per 100 km. 1 kWh = 3.6 MJ.

i. What is the energy consumption in kJ per 100 km? 1 mark

ii. Calculate the volume of petrol (density 750 g L^{-1}) needed to provide the energy equivalent to 20 kWh. Assume that petrol is octane. 2 marks

iii. Explain why the volume of petrol which contains the equivalent of 20 kWh of energy is significantly less than the amount needed to travel 100 km in a petrol driven car. 1 mark

e. As the demand for lithium-ion batteries grows, so does the demand for cobalt, nickel and manganese, all of which have to be extracted from low yield ores. Where might this have negative impacts? 1 mark

f. In recent years, the forty-eight nickel-hydrogen ($Ni\text{-}H_2$) batteries used on the International Space Station to store electrical energy generated by the station's solar arrays were replaced by lighter and more efficient lithium-ion batteries.
$Ni\text{-}H_2$ cells use 26 % potassium hydroxide (KOH) as an electrolyte and were able to last up to seven years on the space station before being replaced.
In the $Ni\text{-}H_2$ cells, one electrode was made up of porous nickel plaque, which contains nickel oxide hydroxide, NiO(OH); the other included platinum.
The reaction occurring at the (+) electrode when this battery is delivering energy is $NiOOH(s) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq)$.
Give a half-equation for the reaction at the (-) electrode. 1 mark

Question 7 (10 marks)
A particular brand of analgesic tablets states that each tablet contains 325 mg of aspirin and 50 mg of caffeine. The structures of aspirin and caffeine are shown in **Figure 23**.

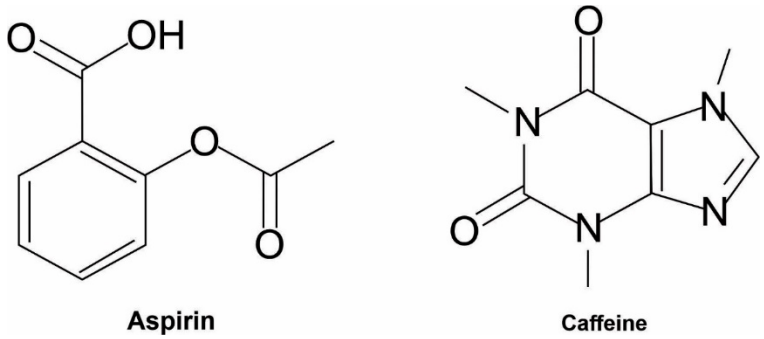


Figure 23

a. Which form of chromatography, HPLC or GC, would be most suitable for an analysis of the relative amounts of aspirin and caffeine present in the solution? Why? 2 marks

b. If a non-polar stationary phase was used in the chromatograph, which substance would have the higher retention time? Explain your reasoning. 2 marks

c. Sketch a possible chromatogram for the separation and elution of the aspirin and caffeine. 2 marks

d. Some analgesics also contain phenacetin, $C_{10}H_{13}NO_2$. Where on your chromatogram would you expect the peak for phenacetin to be, relative to those for aspirin and caffeine? 1 mark

e. An analgesic tablet containing 325 mg of aspirin as its only acidic substance is crushed, dissolved in water, and the resultant solution is titrated with 0.120 M NaOH(aq) to the phenolphthalein end point. Given that aspirin is a monoprotic acid:

i. Write an equation describing the reaction occurring during the titration. 1 mark

ii. Calculate the volume of titre theoretically needed to reach the equivalence point. 2 marks

Question 8 (9 marks)

Figure 24 shows the concentrations, as a function of time, for a mixture of gases, X, Y and Z, added to a one litre container and allowed to reach equilibrium.

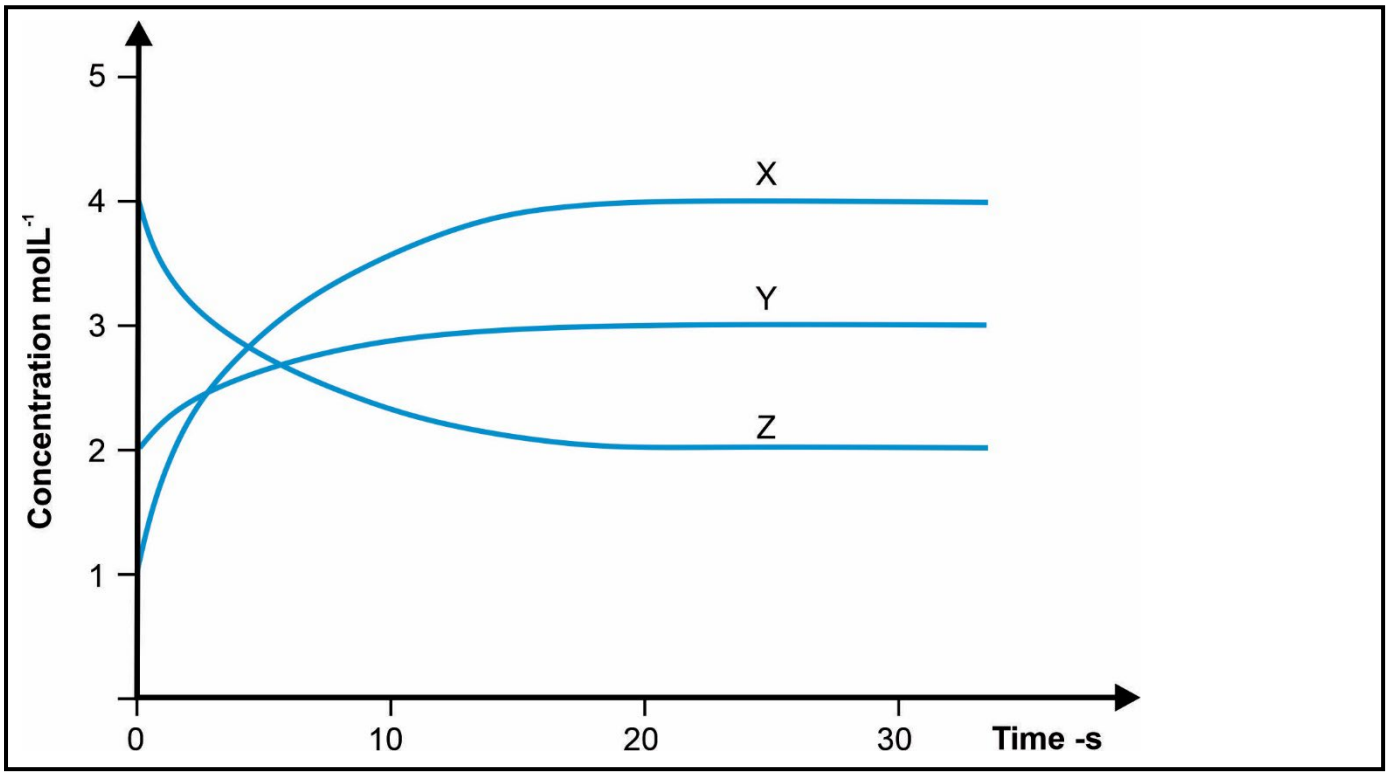


Figure 24

a. How long does the mixture take to reach equilibrium? 1 mark

b. **i.** Use the information provided on the graph to complete **Table 3** below. 3 marks

	Initial concentration	**Equilibrium concentration**	**How the concentration changes as the system moves to equilibrium**
X			
Y			
Z			

Table 3

ii. Use the information you completed in **Table 3** to deduce the equation for the equilibrium reaction and determine the value of the equilibrium constant.

3 marks

c. Use the concentration time in the graphs in **Figure 24** to show how the concentration of X would change if, at 30 seconds, the volume of the container was doubled. 2 marks

END OF QUESTION AND ANSWER BOOK

STUDENT NUMBER									Letter

Datasheet for multiple-choice questions

Question				
1	A	B	C	D
2	A	B	C	D
3	A	B	C	D
4	A	B	C	D
5	A	B	C	D
6	A	B	C	D
7	A	B	C	D
8	A	B	C	D
9	A	B	C	D
10	A	B	C	D
11	A	B	C	D
12	A	B	C	D
13	A	B	C	D
14	A	B	C	D
15	A	B	C	D
16	A	B	C	D
17	A	B	C	D
18	A	B	C	D
19	A	B	C	D
20	A	B	C	D

Datasheet for multiple-choice questions

Question				
21	A	B	C	D
22	A	B	C	D
23	A	B	C	D
24	A	B	C	D
25	A	B	C	D
26	A	B	C	D
27	A	B	C	D
28	A	B	C	D
29	A	B	C	D
30	A	B	C	D

Signed:_____