9.3 The Acidic Environment

Contextual Outline

Acidic and basic environments exist everywhere. The human body has a slightly acidic skin surface to assist in disease control and digestion occurs in both acidic and basic environments to assist the breakdown of the biopolymers constituting food. Indeed, microorganisms found in the digestive system are well adapted to acidic or basic environments.

Many industries use acidic and basic compounds for a wide range of purposes and these compounds are found in daily use within the home. Because of this, an awareness of the properties of acids and bases is important for safe handling of materials. Currently, concerns exist about the increased release of acidic and basic substances into the environment and the impact of these substances on the environment and the organisms within those environments.

This module increases students' understanding of the history, nature and practice of chemistry, the applications and uses of chemistry and implications of chemistry for society and the environment.

	Students learn to:	*Students:*
1. Indicators were identified with the observation that the colour of some flowers depends on soil composition	• classify common substances as acidic, basic or neutral • identify that indicators such as litmus, phenolphthalein, methyl orange and bromothymol blue can be used to determine the acidic or basic nature of a material over a range, and that the range is identified by change in indicator colour • identify and describe some everyday uses of indicators including the testing of soil acidity/basicity	• perform a first-hand investigation to prepare and test a natural indicator • identify data and choose resources to gather information about the colour changes of a range of indicators • solve problems by applying information about the colour changes of indicators to classify some household substances as acidic, neutral or basic

1. Indicators were identified with the observation that the colour of some flowers depends on soil composition	• classify common substances as acidic, basic or neutral

- perform a first-hand investigation to prepare and test a natural indicator

Question 20 (4 marks)

You have carried out a first-hand investigation to prepare and test a natural indicator.

(a) Outline the procedure used to prepare and test the natural indicator. **2**

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(b) Draw a table to show the results obtained in testing this indicator. **2**

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20. (a) The leaves were chopped into small pieces, and placed in hot water to extract the purple dye. The solution was decanted and allowed to cool. A range of solutions was tested by adding a few drops of the cabbage dye to each. 2

(b)

Subtance	water	ammonia soln.	vinegar	drain cleaner
Dye Colour	blue	green	red	yellow

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Question 19 (4 marks)

You have performed a firsthand investigation to prepare and test a natural acid/base indicator.

(a) Recall the procedure you used to prepare this indicator. **2**

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(b) Identify an everyday situation in which an indicator is used and explain why it is necessary to use the indicator. **2**

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Question 19		9.3.1 H4, H13
(a)	(i) Chop red cabbage into thin pieces. (ii) Grind the cabbage in a mortar and pestle. (iii) Add some methylated spirits to the cabbage. (iv) Drain the coloured liquid.	• Clearly presents procedure used to prepare a natural indicator.................. 1–2
(b)	Indicators can be used to determine the pH of an aquarium. The pH needs to be monitored because the marine life can only survive if the pH is within a specific range.	• Identifies an everyday situation in which an indicator is used and explains why it is necessary to use the indicator 2
		• Identifies an everyday situation in which an indicator is used OR • Explains why it is necessary to use the indicator.......................... 1

- identify that indicators such as litmus, phenolphthalein, methyl orange and bromothymol blue can be used to determine the acidic or basic nature of a material over a range, and that the range is identified by change in indicator colour

- identify data and choose resources to gather information about the colour changes of a range of indicators

Questions 6 and 7 refer to the table below which shows the colour ranges of three acid-base indicators.

Indicator	Very acidic							Neutral					Very basic		
pH	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Bromothymol blue	yellow						→6.0	7.6←						blue	
Methyl orange	red			→3.1	4.5←				yellow						
Phenolphthalein	colourless								→8.3		10.0←			red	

6. A solution is yellow in bromothymol and methyl orange, and colourless in phenolphthalein. What is the pH range of the solution?

(A) 7.5 to 8.5
(B) 6.0 to 7.5
(C) 4.5 to 6.0
(D) 8.5 to 10.0

7. 0.1 mol L^{-1} citric acid ($C_6H_8O_7$) solution is neutralised with a solution of 0.1 mol L^{-1} sodium hydroxide (NaOH). The best indicator for this titration would be:

(A) methyl orange
(B) phenolphthalein
(C) a mixture of methyl orange and bromothymol blue.
(D) bromothymol blue

6	C	7	B

8. The table shows the colours of three indicators at different hydrogen ion concentrations.

[HCl] mol L^{-1}	10^{-2}	10^{-4}	10^{-6}
Methyl Orange	red	orange	yellow
Bromothymol Blue	yellow	yellow	green
Phenol Red	yellow	red	red

What is the pH of a solution that showed the following indicator colours?

Methyl Orange	Yellow
Bromothymol Blue	Green
Phenol Red	Red

(A) 2
(B) 4
(C) 6
(D) 8

$\boxed{C.}$

- identify and describe some everyday uses of indicators including the testing of soil acidity/basicity
- solve problems by applying information about the colour changes of indicators to classify some household substances as acidic, neutral or basic

6. Some household cleaners contain strong bases such as sodium hydroxide. A student tested household cleaning solutions with litmus and recorded the results in the following table:

Cleaning solution	Colour of blue litmus	Colour of red litmus
X	blue	red
Y	blue	blue
Z	red	red

Sodium hydroxide could be present in:

(A) X and Y
(B) X and Z
(C) Y only
(D) Z only

6
C

	Students learn to:	*Students:*
2. While we usually think of the air around us as neutral, the atmosphere naturally contains acidic oxides of carbon, nitrogen and sulfur. The concentrations of these acidic oxides have been increasing since the Industrial Revolution	• identify oxides of non-metals which act as acids and describe the conditions under which they act as acids • analyse the position of these non-metals in the Periodic Table and outline the relationship between position of elements in the Periodic Table and acidity/basicity of oxides • define Le Chatelier's principle • identify factors which can affect the equilibrium in a reversible reaction • describe the solubility of carbon dioxide in water under various conditions as an equilibrium process and explain in terms of Le Chatelier's principle • identify natural and industrial sources of sulfur dioxide and oxides of nitrogen • describe, using equations, examples of chemical reactions which release sulfur dioxide and chemical reactions which release oxides of nitrogen • assess the evidence which indicates increases in atmospheric concentration of oxides of sulfur and nitrogen • calculate volumes of gases given masses of some substances in reactions, and calculate masses of substances given gaseous volumes, in reactions involving gases at 0°C and 100kPa or 25°C and 100kPa • explain the formation and effects of acid rain	• identify data, plan and perform a first-hand investigation to decarbonate soft drink and gather data to measure the mass changes involved and calculate the volume of gas released at 25°C and 100kPa • analyse information from secondary sources to summarise the industrial origins of sulfur dioxide and oxides of nitrogen and evaluate reasons for concern about their release into the environment

2. While we usually think of the air around us as neutral, the atmosphere naturally contains acidic oxides of carbon, nitrogen and sulfur. The concentrations of these acidic oxides have been increasing since the Industrial Revolution	• identify oxides of non-metals which act as acids and describe the conditions under which they act as acids

- analyse the position of these non-metals in the Periodic Table and
- outline the relationship between position of elements in the Periodic Table and acidity/basicity of oxides

- define Le Chatelier's principle
- identify factors which can affect the equilibrium in a reversible reaction
- describe the solubility of carbon dioxide in water under various conditions as an equilibrium process and explain in terms of Le Chatelier's principle

2. The volume of a gas formed during an equilibrium process was monitored under various conditions. The following table summarises the results of these experiments.

Temperature (°C)	*Pressure* (kPa)		
	100	*200*	*300*
200	80 L	85 L	90 L
400	45 L	50 L	60 L
600	15 L	20 L	25 L

Based on these results, what can be concluded about the reaction used to produce this gas?

(A) It is exothermic and favours high pressures.
(B) It is exothermic and favours low pressures.
(C) It is endothermic and favours high pressures.
(D) It is endothermic and favours low pressures.

Question 2 A
The greater amount of gas was produced at lower temperature (indicating that it is an exothermic process) and higher pressure.

4. The following reaction is allowed to establish an equilibrium.

$$HF_{(aq)} + H_2O_{(l)} \rightleftharpoons F^-_{(aq)} + H_3O^+_{(aq)}$$

When added to this equilibrium, which of the following soluble chemicals will **least** affect its position?

(A) Copper (II) fluoride
(B) Hydrogen chloride
(C) Sodium hydroxide
(D) Copper (II) nitrate

Question 4 D
A. Copper (II) fluoride provides F^- ions and so equilibrium shifts to the left.
B. Hydrogen chloride will dissolve in the water increasing the H_3O^+ concentration and so shift equilibrium to the left.
C. Sodium hydroxide would provide OH^- ions; these would react with the H_3O^+; the equilibrium would shift to the right in an attempt to replace the H_3O^+.
D. Cu^{2+} and NO_3^- ions do not affect any of the species present in this equilibrium.

Question 24 (4 marks)

An equilibrium exists between gaseous and dissolved carbon dioxide in water as shown by the following equation:

$$CO_{2(g)} \Leftrightarrow CO_{2(aq)}$$

With reference to Le Chatelier's principle explain the following:

(a) fizzing occurs when a bottle of a carbonated drink is opened. **2**

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(b) It is observed that the fizzing is less if the bottle is kept under refrigeration rather than at room temperature. Deduce whether the dissolving process is exothermic or endothermic; explaining your reasoning. **2**

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24. (a) Opening the bottle causes a decrease in pressure causing the equilibrium to shift to the side of greatest number of gaseous molecules, therefore formation of more gaseous CO_2 (2 mk)

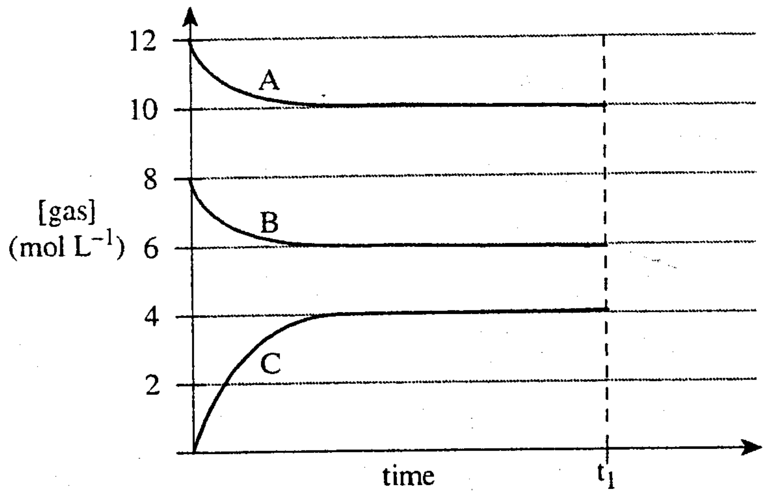
(b) As lowering the temperature favours the formation of aqueous CO_2, this reaction is the reaction that produces heat, therefore the forward reaction as written is exothermic. (2 mk)

7. What effect would the addition of dilute hydrochloric acid have on the following equilibrium?

$$CO_{2(aq)} + H_2O_{(l)} \leftrightarrow H^+_{(aq)} + HCO_3^-{}_{(aq)}$$

(A) The equilibrium would shift to the left, decreasing the concentration of HCO_3^-
(B) The equilibrium would shift to the right, increasing the concentration of HCO_3^-
(C) The equilibrium would not change
(D) The rate at which equilibrium is attained would be increased

8. It is known that gases A and B reach equilibrium as they react together to form gas C. The variation in concentration of these gases was monitored and graphed as illustrated below.



By applying Le Chatelier's principle, it can be predicted that at time t_1 the yield of the forward reaction will

(A) increase if pressure is increased.
(B) decrease if pressure is increased.
(C) decrease if pressure is decreased.
(D) not be affected by a change in pressure.

Question 8	**D**	9.3.2, 9.4.2	H10, H14
The equation for the reaction is $A + B \Leftrightarrow 2C$. Since one mole of each A and B are consumed to form 2 moles of C, there are 2 moles of gas on each side of the equation. Therefore the ratio of moles is unaffected by the change in pressure.			

13. Sulfuric acid reacts with pyrosulfuric acid according to the equation-:

$$H_2SO_{4\,(l)} + H_2S_2O_{7\,(l)} \rightleftharpoons H_3SO_4^+{}_{(l)} + HS_2O_7^-{}_{(l)}$$

Identify a method of increasing the concentration of $H_3SO_4^+$ in the mixture at equilibrium.

(A) increase the pressure on the system
(B) add H_2SO_4
(C) add a catalyst
(D) add $HS_2O_7^-$

$\boxed{B}$

11. Nitrogen dioxide, NO_2, a brown gas and dinitrogen tetroxide, N_2O_4, a colourless gas are in equilibrium according to the equation-:

$$2NO_{2\,(g)} \rightleftharpoons N_2O_{4\,(g)}$$

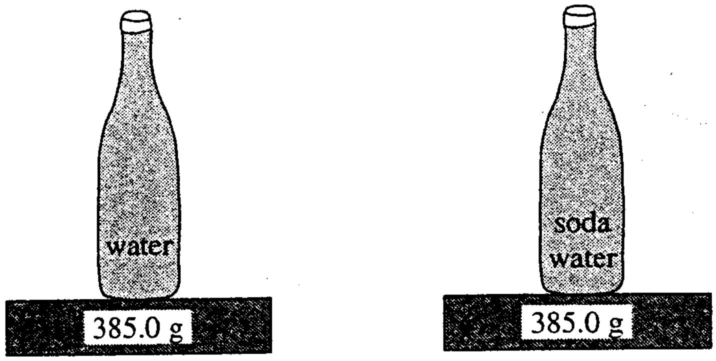
If a sealed tube of the gases is placed in an ice-water bath the colour fades from brown to almost colourless. Which conclusion is correct?

(A) The forward reaction is exothermic
(B) The reverse reaction is exothermic
(C) The pressure has increased.
(D) The pressure has not changed

$\boxed{A}$

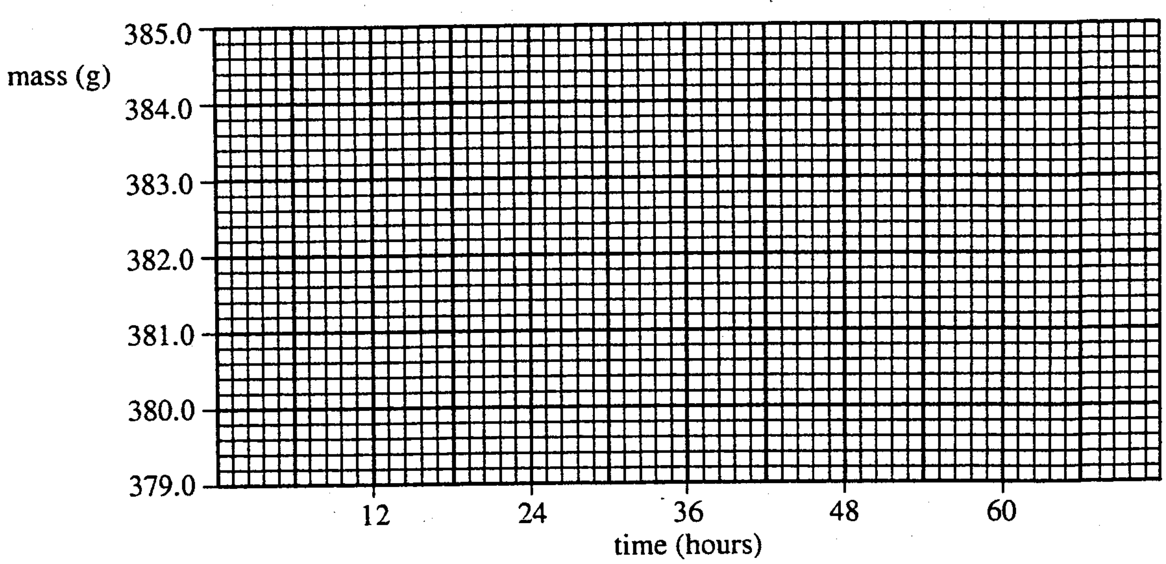
Question 25 (7 marks)

As part of your practical work you decarbonated a beverage. A student decarbonated a sample of soda water by opening the bottle it was in and leaving it for a period of time, weighing it at regular intervals. She also used a non-carbonated sample of water as a control, recording its mass at the same intervals.



	mass (g)					
	Initial	*After 12 hours*	*24 hours*	*36 hours*	*48 hours*	*60 hours*
soda water	385.0	382.6	381.1	380.7	380.3	380.0
plain water	385.0	384.7	384.2	383.7	383.4	383.0

(a) Graph the information shown for each water sample on the same graph. **2**



(b) Interpret the trends shown in the graph. **2**

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(c) Use the graph to determine the volume of CO_2 gas produced at 25°C and 100 kPa. Show your working. **2**

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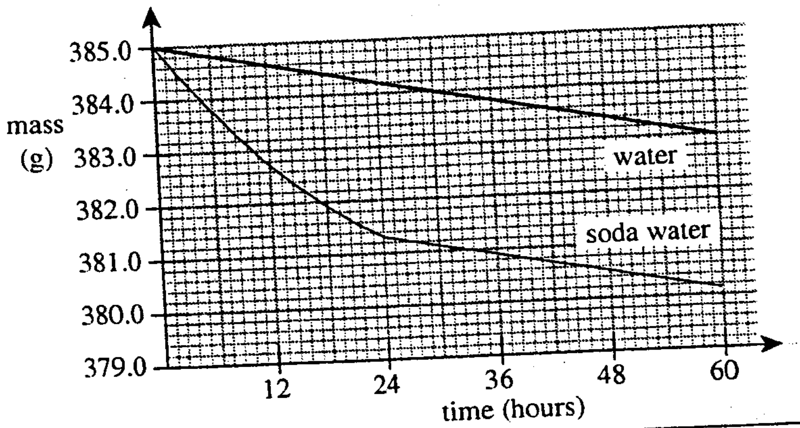
Sample answer	Syllabus content, course outcomes and marking guide
	9.3.2 H10, H13
Question 25	
(a) 	• Correctly plots points and draws lines for two data sets. . . . . 2 • Correctly plots points but draws incorrect lines. OR • Plots points. 1
(b) The water graph shows the loss of mass due to evaporation. The soda water graph shows the loss of mass due to water evaporation AND carbon dioxide gas. When no more CO_2 remains the line parallels the water graph.	• Interprets each graph and forms relationship between them 2
(c) From the graph, the mass of carbon dioxide gas lost is 3.0 g. Volume of gas is mol × molar volume: $V_{CO_2} = \frac{3.0 \times 24.79}{44} = 1.69$ L	• Correct calculation using mass of carbon dioxide from graph. 2

- identify natural and industrial sources of sulfur dioxide and oxides of nitrogen
- describe, using equations, examples of chemical reactions which release sulfur dioxide and chemical reactions which release oxides of nitrogen
- assess the evidence which indicates increases in atmospheric concentration of oxides of sulfur and nitrogen
- analyse information from secondary sources to summarise the industrial origins of sulfur dioxide and oxides of nitrogen and evaluate reasons for concern about their release into the environment

Question 21 (6 marks) **Marks**

A sample of lignite, a high sulfur content coal, was analysed and found to contain 4.32% sulphur.

(a) Calculate the volume of sulfur dioxide, at 25°C and 100 kPa, that would be produced by burning 1.0 kg of lignite coal. **3**

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(b) Assess the impact, on the environment, of using lignite as a fuel, writing equations where appropriate. **3**

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21. (a) Moles of sulfur = 43.5/32 = 1.35 mol
Moles of SO_2 formed = 1.35 mol
Volume of SO_2 formed = 1.35 x 24.79 = 33.47 L 3

(b) Combustion of the lignite releases SO_2 into the atmosphere. This gas causes breathing difficulties for some people. It also undergoes oxidation to SO_3 which dissolves in rainwater to form sulfuric acid. Acid rain causes many problems including corrosion of metals and building materials, damage to plants and aquatic systems such as freshwater lakes and release of heavy metals by accelerated weathering of rocks. 3

Marks

Question 22 (6 marks)

Assess the evidence which indicates that the atmospheric concentration of oxides of sulfur and nitrogen have been increasing. 6

Sample answer	Syllabus content, course outcomes and marking guide
Question 22	
Oxides of sulfur and nitrogen are found in the atmosphere as a result of a number of natural processes, notably volcanic action and decomposition of organic wastes in the case of SO_2, and lightning in the case of oxides of nitrogen. Since the beginning of the industrial revolution, processes associated with industrialisation and increased human population have added greatly to these natural sources of these oxides. These manmade sources include the processing of sulfide ores to extract metals and production of sulfuric acid, which increase concentration of SO_2, and combustion of fossil fuels in power plants, car engines and jet engines, which have increased concentrations of the oxides of sulfur and nitrogen. The increased concentrations of these oxides has been evident by the formation of acid rain, which has resulted in damage to waterways, forests, crops and buildings over many years. Other evidence for the increased concentration of these oxides has come from atmospheric pollution, with nitrogen oxides contributing to photochemical smog. Higher levels of these oxides have also contributed to high rates of breathing difficulties often seen in large cities. Over the last few decades, anti-pollution measures have been introduced to reduce industrial SO_2 output and catalytic converters have been a compulsory part of the pollution control equipment of new cars to reduce oxides of nitrogen. Together with standards requiring lower levels of sulfur in fuels, these measures have resulted in many industrial countries experiencing a decrease in the level of these oxides.	9.3.2 H3, H4, H8, H13, H14 • Assesses evidence relating to increases in concentrations of the oxides of nitrogen and sulfur .... 5–6 • Describes evidence that the concentrations of oxides of nitrogen and sulfur have increased due to human causes ...... 5–6 • Describes effects of the oxides of nitrogen and sulfur 1–2

- calculate volumes of gases given masses of some substances in reactions, and calculate masses of substances given gaseous volumes, in reactions involving gases at 0°C and 100kPa or 25°C and 100kPa

- identify data, plan and perform a first-hand investigation to decarbonate soft drink and gather data to measure the mass changes involved and calculate the volume of gas released at 25°C and 100kPa

Question 17 (4 marks)

A small amount of pure sodium metal is dropped into 1.2 L of water. The reaction is summarised in the following equation.

$$2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$$

The gas collected occupied a volume of 4.68 L at 25°C and 1 atm pressure.

(a) Calculate the amount in moles of gaseous product. **1**

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(b) Calculate the final pH of the water. **3**

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Question 17	
(a) $n(H_2) = \frac{4.68}{24.47} = 0.19$ mol	H10 • Correct calculation (with or without unit)....................... 1
(b) by molar ratio, NaOH : H_2 = 2 : 1 $\therefore n(NaOH) = 2 \times 0.19 = 0.38$ mol $\therefore n(OH^-) = 0.38$ mol $[OH^-] = \frac{0.38}{1.2} = 0.32$ mol L^{-1} pOH $= -\log_{10}[0.32] = 0.50$ $\therefore$ pH of water = 13.50	H10 • Correct calculation showing appropriate working .... 3 • Correct answer with incomplete working .... 2 • Correct answer (no working) OR • Appropriate working with calculation error 1

Question 21 (2 marks)

When 1.5 L of HCl gas and 1.8 L of NH_3 gas are mixed, a white solid of NH_4Cl is formed. Calculate the mass of NH_4Cl formed if the gas volumes were measured at 25°C and 101.3 kPa. **2**

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21 Moles HCl (limiting reactant) = 1.5/24.47 = 0.0613 mol (1 mk)
Mass NH_4Cl formed = 0.0613 x mol. mass = 0.0613 x 53.5 = 3.28 g (1 mk)

Question 27 (3 marks)

The data below gives the percentage composition of air by volume at sea level for a town on the far north coast of NSW.

Constituent	**Symbol**	**Volume % in air**	**Molar mass**
Nitrogen	N_2	78.084	28.01
Oxygen	O_2	20.9476	32.00
Argon	Ar	0.934	39.95
Carbon dioxide	CO_2	0.037	44.01
Neon	Ne	0.001818	20.18
Helium	He	0.000524	4.00
Methane	CH_4	0.00017	16.04

(a) Calculate the moles of oxygen present in 20 litres of this air at 25°C and 101.3 kPa. **1**

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(b) Calculate the mass of argon which could be extracted from 200 litres of this air. **2**

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27. (a) moles of oxygen = 20 x 0.2095/24.47 = 0.171 mol (1 mk)
(b) moles of argon = 200 x 0.00934/24.47 = 0.0763 mol (1 mk)
mass of argon = moles x mol. mass = 0.0763 x 39.95 =3.05 g (1 mk)

Question 21 (5 marks) **Marks**

Low sulfur diesel fuels used in coal mining must have a sulfur content of less than 0.05% sulfur by mass.

(a) Calculate the volume of sulfur dioxide at 25°C and 100 kPa produced by burning 1.0 kg of low (0.05%) sulfur diesel. 2

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(b) Discuss the impact on the environment of using high sulfur fuels. 3

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21. (a) $S(s) + O_2(g) \rightarrow SO_2(g)$

Mass of sulfur in lignite = 1000 x 0.05/100 = 0.5g

Moles of sulfur = mass/molar mass = 0.5/32.07 = 1.56×10^{-2}

Moles of sulfur dioxide = moles of sulfur = 1.56×10^{-2} 1

Volume of SO_2 = Moles x Molar volume

= $1.56 \times 10^{-2} \times 24.79$ 1

= 0.386 L

(b) The impact of burning large quantities of high sulfur fuels is detrimental to the environment where that fuel is being burned.

- high sulfur fuels release large amounts of sulfur dioxide into the atmosphere. 1
- Sulfur dioxide is poisonous to living things 1
- Sulfur dioxide dissolves in water in the atmosphere to produce sulphurous/ic acid
- sulphurous/ic acids fall as acid rain lowering the pH of many natural systems with the potential to change the environment and the organisms in it 1

- explain the formation and effects of acid rain

3. Acids occur in many foods, drinks and even within our stomachs

Students learn to:

- define acids as proton donors and describe the ionisation of acids in water
- identify acids including acetic (ethanoic), citric (2-hydroxypropane-1,2,3-tricarboxylic), hydrochloric and sulfuric acid
- describe the use of the pH scale in comparing acids and bases
- describe acids and their solutions with the appropriate use of the terms strong, weak, concentrated and dilute
- identify pH as $-\log_{10} [H^+]$ and explain that a change in pH of 1 means a ten-fold change in $[H^+]$
- compare the relative strengths of equal concentrations of citric, acetic and hydrochloric acids and explain in terms of the degree of ionisation of their molecules
- describe the difference between a strong and a weak acid in terms of an equilibrium between the intact molecule and its ions

Students:

- solve problems and perform a first-hand investigation to use pH meters/probes and indicators to distinguish between acidic, basic and neutral chemicals
- plan and perform a first-hand investigation to measure the pH of identical concentrations of strong and weak acids
- gather and process information from secondary sources to write ionic equations to represent the ionisation of acids
- use available evidence to model the molecular nature of acids and simulate the ionisation of strong and weak acids
- gather and process information from secondary sources to explain the use of acids as food additives
- identify data, gather and process information from secondary sources to identify examples of naturally occurring acids and bases and their chemical composition
- process information from secondary sources to calculate pH of strong acids given appropriate hydrogen ion concentrations

3. **Acids occur in many foods, drinks and even within our stomachs**	• define acids as proton donors and describe the ionisation of acids in water	• gather and process information from secondary sources to write ionic equations to represent the ionisation of acids

6. Consider each of the following equations:

(i) $HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$

(ii) $HCl_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$

(iii) $NH_{3(aq)} + H_2O_{(l)} \rightarrow NH_4{}^+_{(aq)} + OH^-_{(aq)}$

(iv) $NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$

An acid can be defined as a proton donor. This can be seen in

(A) equation (i) only.

(B) equation (ii) only.

(C) equations (ii) and (iii).

(D) all of the equations.

Question 6 **C**	9.3.3	H6
Equation (i) shows the HCl ionising. Equation (iv) shows the NaOH dissociating. In equation (ii), HCl is acting as a proton donor. In equation (iii), H_2O is acting as a proton donor.		

- identify acids including acetic (ethanoic), citric (2-hydroxypropane-1,2,3-tricarboxylic), hydrochloric and sulfuric acid

- describe the use of the pH scale in comparing acids and bases
- describe acids and their solutions with the appropriate use of the terms strong, weak, concentrated and dilute
- solve problems and perform a first-hand investigation to use pH meters/probes and indicators to distinguish between acidic, basic and neutral chemicals

9. The pH of four acids and their concentrations are shown in the table below.

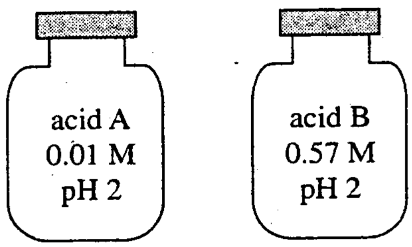
Acid	Conc. (mol L^{-1})	pH
A	0.1	1.0
B	0.05	1.0
C	0.01	2.0
D	0.1	2.0

Which acid in the table is the weakest?

(A) A
(B) B
(C) C
(D) D

9 | D

3. Consider the following reagent bottles of acids:



In comparing these two solutions we can say that

(A) the $[H^+]$ is greater in the solution of acid A.
(B) the $[H^+]$ is greater in the solution of acid B.
(C) the acids are of equal strength.
(D) A is the stronger acid.

Question 3 **D**	9.3.3	H8, H10
Since both acids have the same pH, their respective $[H^+]$ must be the same. However, acid A is of a lower concentration and so must be a stronger acid.		

- compare the relative strengths of equal concentrations of citric, acetic and hydrochloric acids and explain in terms of the degree of ionisation of their molecules
- describe the difference between a strong and a weak acid in terms of an equilibrium between the intact molecule and its ions
- plan and perform a first-hand investigation to measure the pH of identical concentrations of strong and weak acids
- use available evidence to model the molecular nature of acids and simulate the ionisation of strong and weak acids

1. In an aqueous solution of the weak acid nitrous acid, HNO_2, which of the following species is present in the highest concentration?

(A) HNO_2
(B) H_3O^+
(C) OH^-
(D) NO_2^-

Answer and explanation

Question 1 A

Since this is a weak acid, only a small proportion of molecules have ionised. Therefore, the majority of molecules have remained intact.

6. Citric acid (2-hydroxypropane-1,2,3-tricarboxylic acid) is a weaker acid than sulfuric acid, even though citric acid is triprotic.
Which of the following best explains the above statement?

(A) Citric acid ionises more completely than sulfuric acid.
(B) Sulfuric acid will react completely with a base, but citric acid will only react partially with a base.
(C) Sulfuric acid is diprotic and therefore ionises more easily.
(D) Citric acid ionises less completely than sulfuric acid.

Question 6 D Acid strength is measured by the extent of ionisation of the acid. Weak acids ionise less than stronger acids.	9.3.3	H8, H14

8. A number of solutions were tested with a conductivity probe attached to a data logger. Which of the following solutions would record the highest conductivity reading?

(A) 0.01 mol L^{-1} HCl
(B) 0.1 mol L^{-1} HCl
(C) 0.01 mol L^{-1} CH_3COOH
(D) 0.1 mol L^{-1} CH_3COOH

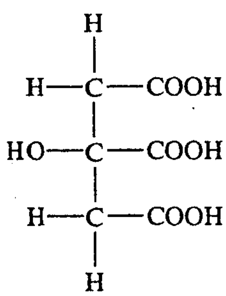
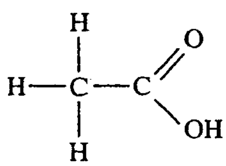
8
B

Question 22 (3 marks)

Citric acid and acetic acid are both weak acids.

(a) Write the structural formula of each acid. **2**

(b) State why citric acid is stronger than acetic acid. **1**

Question 22	9.3.3 H6, H13
(a) citric acid:  acetic acid: 	• Draws two correct structural formulae . . 2 • Draws one correct structural formulae. . . 1
(b) Citric acid ionises more than acetic acid, hence it is a stronger acid. *Note: not acceptable to state that citric acid is triprotic.*	• States a correct reason 1

- identify pH as $-\log_{10} [H^+]$ and explain that a change in pH of 1 means a ten-fold change in $[H^+]$

- process information from secondary sources to calculate pH of strong acids given appropriate hydrogen ion concentrations

3. A solution of pH 9 has enough water added to it so that it now has a pH of 8. What effect does this have on the solution?
   (A) It becomes 10 times more concentrated and less alkaline.
   (B) It becomes 10 times more dilute and more alkaline.
   (C) It becomes 10 times more concentrated and more alkaline.
   (D) It becomes 10 times more dilute and less alkaline.

Question 3 D
By adding more water, the solution must now be more dilute. Since the pH has decreased, the solution is also less alkaline.

10. The pH of a solution of magnesium hydroxide of concentration 4.5×10^{-3} mol L^{-1} is closest to:

   (A) 11.9
   (B) 11.6
   (C) 2.1
   (D) 2.4

10	A

5. A solution of pH 3 has the necessary changes made to it so that it is now a pH of 5.
   What change has been made to the concentration of H^+?
   (A) It has become more concentrated by a factor of 2.
   (B) It has become more concentrated by a factor of 100.
   (C) It has become less concentrated by a factor of 2.
   (D) It has become less concentrated by a factor of 100.

Question 5 D — 9.3.3 — H8, H10
At a pH of 3, the concentration of H^+ is equal to 10^{-3} mol L^{-1}.
At a pH of 5, the concentration of H^+ is equal to 10^{-5} mol L^{-1}.
Therefore, the solution is now more dilute, because the concentration of H^+ has decreased by a factor of $10^{-3}/10^{-5} = 100$.

9. The pH of a 10 mL HCl solution was determined to be a value of 1. Water was added to this solution until its pH changed to a value of 2. The amount of water added was
   (A) 10 mL.
   (B) 20 mL.
   (C) 90 mL.
   (D) 100 mL.

Question 9 C — 9.3.3 — H10
An increase in a value of pH of 1 means that the dilution factor was 10.
Therefore, the total new volume of the acid solution became 100 mL.
This would have been achieved by adding 90 mL to the original

Question 23 (5 marks) **Marks**

A student used indicator paper to estimate the pH of three different acids, to the nearest integer value. Each acid was at a concentration of 0.10 mol L^{-1} in aqueous solution.
The table below records these measurements:

Acid	pH
acetic	3
citric	2
hydrochloric	1

(a) Compare the hydrogen ion concentrations in these three solutions. **2**

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(b) Account for the differences in these values. **3**

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23. (a) The hydrogen ion concentration in the HCl is 0.1 mol L^{-1}. This is 10 times the concentration in citric acid and 100 times the concentration in the acetic acid. 2

(b) Hydrochloric acid is 100% ionised in dilute solution, so that the hydrogen ion concentration is equal to the acid concentration.(1mk) Citric acid is only partly ionised (~5%) and acetic acid is a still weaker acid and has lower degree of ionisation.(1 mk) In both weak acids the hydrogen ion concentration is much less than the concentration of the dissolved acid.(1 mk) 3

- gather and process information from secondary sources to explain the use of acids as food additives
- identify data, gather and process information from secondary sources to identify examples of naturally occurring acids and bases and their chemical composition

Question 21 (4 marks)

Vinegar is an aqueous solution of acetic (ethanoic) acid, a weak acid.

(a) Apart from its taste, explain why acids such as vinegar are often used as food additives. **2**

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(b) Explain why such a solution would have a higher pH than a hydrochloric acid solution of the same concentration. **2**

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Question 21		
(a)	The addition of the acid to food is as a preservative. The acidic condition inhibits the growth of microorganisms.	9.3.3 H3, H4, H8 • Identifies and explains use as preservatives. . . . . 2 • Identifies use as preservatives 1
(b)	Acetic acid is a weak acid. Therefore the acid molecules do not fully ionise, leaving the $[H^+]$ lower than expected, resulting in a higher pH. Hydrochloric acid is a strong acid. Therefore it completely ionises, making the $[H^+]$ high and so the pH is lower.	9.3.3 H8, H13, H14 • Correctly relates strengths of the acids to $[H^+]$ and correctly relates $[H^+]$ to pH. . . . 2 • Correctly relates strengths of the acids to $[H^+]$ OR • Correctly relates $[H^+]$ to pH. 1

4. Because of the prevalence and importance of acids, they have been used and studied for hundreds of years. Over time, the definitions of acid and base have been refined

Students learn to:

- outline the historical development of ideas about acids including those of:
  - Lavoisier
  - Davy
  - Arrhenius
- outline the Brönsted-Lowry theory of acids and bases
- describe the relationship between an acid and its conjugate base and a base and its conjugate acid
- identify a range of salts which form acidic, basic or neutral solutions and explain their acidic, neutral or basic nature
- identify conjugate acid/base pairs
- identify amphiprotic substances and construct equations to describe their behaviour in acidic and basic solutions
- identify neutralisation as a proton transfer reaction which is exothermic
- describe the correct technique for conducting titrations and preparation of standard solutions
- qualitatively describe the effect of buffers with reference to a specific example in a natural system

Students:

- gather and process information from secondary sources to trace developments in understanding and describing acid/base reactions
- choose equipment and perform a first-hand investigation to identify the pH of a range of salt solutions
- perform a first-hand investigation and solve problems using titrations and including the preparation of standard solutions, and use available evidence to quantitatively and qualitatively describe the reaction between selected acids and bases
- perform a first-hand investigation to determine the concentration of a domestic acidic substance using computer-based technologies
- analyse information from secondary sources to assess the use of neutralisation reactions as a safety measure or to minimise damage in accidents or chemical spills

4. Because of the prevalence and importance of acids, they have been used and studied for hundreds of years. Over time, the definitions of acid and base have been refined	• outline the historical development of ideas about acids including those of: - Lavoisier - Davy - Arrhenius	• gather and process information from secondary sources to trace developments in understanding and describing acid/base reactions

9. According to Lavoisier's ideas about acids, which of the following compounds would be acidic in water?

(A) NO_2

(B) NH_3

(C) HCl

(D) HBr

Question 9 A	9.3.4	H1, H8
According to Lavoisier, oxygen in compounds formed with nonmetals causes acidity.		

- outline the Brönsted-Lowry theory of acids and bases
- describe the relationship between an acid and its conjugate base and a base and its conjugate acid

7. Consider the reactions shown below.

I $H_2SO_3 + H_2O \rightarrow H_3O^+ + HSO_3^-$

II $Fe^{3+} + SCN^- \rightarrow FeSCN^{2+}$

Which of the following statements is correct?

(A) I and II are both acid-base reactions.

(B) H_2SO_3 / HSO_3^- and Fe^{3+} / $FeSCN^{2+}$ are conjugate pairs.

(C) Reaction I involves the formation of a co-ordinate covalent bond.

(D) Reaction I shows HSO_3^- acting as an acid.

Question 7 C Reaction II is not an Arrhenius or Lowry–Brönsted acid base reaction; Fe^{3+}|$FeSCN^{2+}$ are not a conjugate pair; HSO_3^- acting as a base.	9.3.4	H8

- identify a range of salts which form acidic, basic or neutral solutions and explain their acidic, neutral or basic nature

- choose equipment and perform a first-hand investigation to identify the pH of a range of salt solutions

Question 20 (5 marks)

An acid, HX, is prepared by dissolving 0.1 moles of it in enough water to make 1 litre of solution. A pH meter shows that the solution pH is 3.5.

(a) Calculate the $[H_3O^+]$ for the solution. **1**

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(b) Explain whether HX is a weak or strong acid. **2**

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(c) The salt, NaX, is dissolved in water. Predict whether the solution is acidic, neutral or basic, using an appropriate equation to justify your prediction. **2**

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Question 20		
(a)	$[H_3O^+] = 10^{-3.5}$ mol L^{-1} (or 3.2×10^{-4} mol L^{-1})	H10 • Correct calculation 1
(b)	HX is a weak acid, as the concentration of H_3O^+ is much lower than that of the acid, indicating that it has only partially ionised.	H2 • States HX is a weak acid AND has partially ionised since its pH is greater than 1 2
		• Poor explanation 1
(c)	X^- is a strong conjugate base compared to the weak acid HX. X^- will then ionise water to produce OH^- ions, so the solution will be basic. $X^- + H_2O \rightarrow HX + OH^-$	H8 • States solution is basic AND shows production of OH^- ions 2
		• States solution is basic OR • Shows production of OH^- ions 1

10. Identify the pH at the neutralisation point when sodium hydroxide is neutralised by hydrochloric acid.

(A) pH = 0
(B) pH = 7
(C) pH > 7
(D) pH < 7

$\boxed{B}$

Question 18 (3 marks)

Certain salts dissolve in water to lower its pH.

(a) Identify such a salt. **1**

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(b) With the help of an equation, explain how the pH is lowered. **2**

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Sample answer	Syllabus content, course outcomes and marking guide
Question 18	9.3.4 H6, H8
(a) ammonium chloride	• Identifies ammonium chloride as the salt 1
(b) $NH_4Cl + H_2O \rightarrow H_3O^+ + Cl^- + NH_3$ The H_3O^+ produced in this reaction lowers the pH.	• Identifies that the formation of H_3O^+ lowers the pH and provides a suitable equation 2
	• Identifies that the formation of H_3O^+ lowers the pH or provides a suitable equation 1

- identify conjugate acid/base pairs
- identify amphiprotic substances and construct equations to describe their behaviour in acidic and basic solutions

Question 22 (3 marks) **Marks**

Choose an example of an amphiprotic substance and write equations to help explain its behaviour in acidic and basic solutions. **3**

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22. eg: sodium hydrogen carbonate (or the hydrogen carbonate ion) (1 mk)
This species acts as a proton donor and acceptor, shown by:-

$HCO_3^- + H_3O^+ \rightarrow H_2CO_3 + H_2O$ (or $CO_2 + 2H_2O$) (1 mk)

$HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$ (1 mk)

10. The conjugate base of the NH_4^+ ion has the formula:

(A) NH_4OH
(B) OH^-
(C) NH_3
(D) NH_4^{2+}

10
C

7. Which of the following statements identifies the conjugate base of the acid HNO_3?

(A) NaOH is the conjugate base of the acid HNO_3
(B) OH^- is the conjugate base of the acid HNO_3
(C) NO_3 is the conjugate base of the acid HNO_3
(D) NO_3^- is the conjugate base of the acid HNO_3

$\boxed{D}$

Marks

Question 20 (3 marks)

A student dissolved some $NaHCO_3$ in a small amount of water. She knew that $HCO_3^-{}_{(aq)}$ could react in each of the following ways.

I $HCO_3^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3(aq)} + OH^-{}_{(aq)}$

OR

II $HCO_3^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons CO_3^{2-}{}_{(aq)} + H_3O^+{}_{(aq)}$

(a) Name the type of behaviour being shown by $HCO_3^{-1}{}_{(aq)}$. **1**

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(b) Describe a simple test you could perform to determine whether reaction I or II is more likely to occur. Give the expected result for your test. **2**

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Question 20		
(a)	It is amphiprotic, acting as a base in I by accepting a proton and as an acid in II by donating a proton to water.	9.3.4 H8 • Names amphiprotic, no description necessary 1
(b)	Dissolve a small quantity of $NaHCO_3$ in water and add some universal indicator or litmus. If I is more likely then the indicator will be blue or violet or red litmus will turn blue. If II is more likely then the indicator will be yellow or red, and blue litmus will turn red.	9.3.1 H8, H11 • Describes a suitable test and gives the appropriate result .... 2 • Describes a test OR • Gives a result 1

- identify neutralisation as a proton transfer reaction which is exothermic

10. 40 mL of 5 mol L^{-1} HCl is added to 20 mL of 5 mol L^{-1} NaOH. Which of the following correctly summarises the results?

	Temperature Change	*Final pH of mixture*
(A)	increase	= 7
(B)	increase	< 7
(C)	decrease	> 7
(D)	decrease	< 7

Question 10 **B** The reaction of an acid with a base is exothermic, and so the temperature would have increased. However, in this case, the acid is in excess and so the final pH is still acidic.	9.3.3	H8, H10

- describe the correct technique for conducting titrations and preparation of standard solutions

- perform a first-hand investigation and solve problems using titrations and including the preparation of standard solutions, and use available evidence to quantitatively and qualitatively describe the reaction between selected acids and bases
- perform a first-hand investigation to determine the concentration of a domestic acidic substance using computer-based technologies

Questions 13 and 14 are based on the following information.

For a practical test, a student carried out a series of titrations using hydrochloric acid to determine the concentration of household ammonia. The student used the 0.1 mol L^{-1} HCl provided for the titration and the household ammonia solution which had been diluted by a factor of 10. Three titrations were performed and the results were 12.3 mL, 12.5 mL and 12.3 mL. The expected concentration of the ammonia solution was 3% but the student's value was calculated to be 4.5%.

13. What should the student do to assess the validity of her results?

(A) Check the concentration of the 0.1 mol L^{-1} HCl against a primary standard.

(B) Perform more titrations and average the results.

(C) Use the full strength ammonia solution to obtain a more accurate result.

(D) Dilute the ammonia by a factor of 20 to obtain a more accurate result.

14. Which of the following reasons, given by other students, best justifies the difference between the calculated results and the expected value?

(A) Titration is not an accurate method.

(B) The difference between 3% and 4.5% is not significant.

(C) Titration is an accurate method and the solutions provided should be checked.

(D) Spectrophotometry would have been a more suitable method to determine concentration.

Question 13 A

Of the alternatives provided, this would be the most useful because the titration values were so close.

Question 14 C

There must have been an error in preparation of the solutions as titration is a suitable method.

Question 19 (8 marks)

The accuracy of acid-base titrations depends on several factors. These include the primary standard used, how the glassware is prepared and how the equivalence point is determined.

(a) Explain why sodium hydroxide is not used as a primary standard. **1**

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(b) Anhydrous sodium carbonate can be used as a primary standard. How can we ensure that the sodium carbonate remains anhydrous? **1**

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(c) During a titration, a conical flask is prepared by rinsing it with distilled water. While this flask is still wet, a clean, dry pipette is used to transfer 20 mL of a standard solution into it. Will the accuracy of the titration be affected? Explain your answer. **2**

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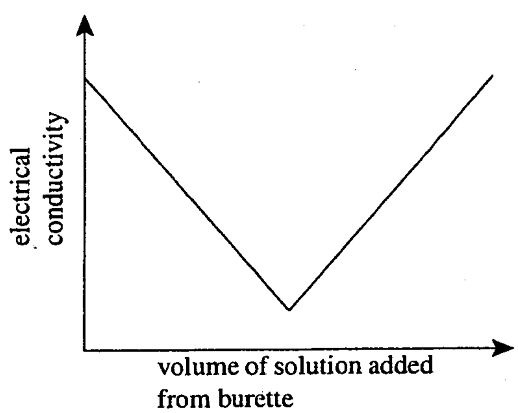
(d) Although an indicator can be used to determine the equivalence point of an acid-base titration, an alternative method is to monitor the electrical conductivity of the reaction mixture during the titration. The following graph shows the variation in electrical conductivity during such a titration.



Explain why the electrical conductivity:

(i) starts at a maximum but then decreases to a minimum value. **2**

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(ii) does not reach a zero value. **1**

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(iii) starts to increase again after the minimum value. **1**

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	Sample answer	Syllabus outcomes and marking guide
Question 19		
(a)	Sodium hydroxide deliquesces when exposed to moisture. Therefore as it is being weighed its mass increases as it absorbs moisture. Since it is not possible to know how much moisture it has absorbed, the mass measurement is inaccurate.	H11, H12 • Sodium hydroxide reacts with the atmosphere 1
(b)	The sodium carbonate can be stored in a desiccator.	H12 • Keep sodium carbonate in a dry environment.................... 1
(c)	The accuracy of the titration will not be affected. This is because the moles of the reactant transferred from the pipette into the conical flask is unaffected by the volume of water already in that flask.	H10 • States moles of reactant is unaffected with explanation......................... 2 • States moles of reactant is unaffected with no explanation 1
(d) (i)	The concentration of ions at the beginning of the titration is at a maximum, hence there is maximum electrical conductivity. As the solution from the burette is added, neutralisation begins to occur. This effectively decreases the concentration of the ions and therefore the electrical conductivity of the solution will also decrease.	H10 • Relates maximum conductivity to maximum concentration of ions AND relates decrease to decreasing concentration of ions..... 2 • Relates maximum conductivity to maximum concentration of ion OR • Relates decrease to decreasing concentration of ions 1
(ii)	At minimum electrical conductivity, the equivalence point has been achieved. However there are still ions present from the salt produced by the reaction, therefore there is still some conductivity possible.	H10 • Relates minimum conductivity to equivalence point and minimum concentration of ions 1
(iii)	As solution from the burette is still being added to the reaction mixture, but there are no further ions available for reaction, the concentration of the ions in the solution increases and hence so does its electrical conductivity.	H10 • Relates increasing conductivity to increasing concentration of ions 1

8. Three pieces of apparatus used in titrations are a conical flask, a burette and a pipette. Which of these pieces of apparatus should be rinsed with distilled water immediately prior to use in a titration?

(A) all three
(B) conical flask only
(C) burette only
(D) pipette only

8	B

9
B

Question 25 (4 marks) **Marks**

In a titration it is found that 20.0 mL of 0.200 mol L^{-1} sulfuric acid is required to neutralise 25.0 mL of a potassium hydroxide solution.

(a) Write a balanced equation for the neutralisation. **1**

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(b) Calculate the concentration of the potassium hydroxide in mol L^{-1}. **2**

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(c) Calculate the mass of the potassium hydroxide in 5 litres of the above solution. **1**

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25. (a) $H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O$ (1 mk)

(b) no. of moles of KOH = 2 x no. of moles of H_2SO_4

25.0 x [KOH] = 2 x 0.200 x 0.0200 (1 mk)

[KOH] = 0.320 mol L^{-1}

(c) Mass KOH = molarity x volume x mol. mass

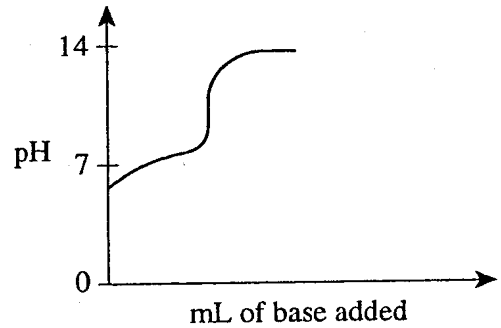
= 0.32 x 5 x 56.1 (1 mk)

= 89.8g

9. A student used a pipette to transfer 25.0 mL of a solution to a flask. After draining the solution into the flask a small amount of solution remained in the tip of the pipette. To deliver the correct volume of solution to the flask the student should:

(A) blow the remaining solution into the flask
(B) touch the inside of the flask with the tip of the pipette
(C) shake the pipette to dislodge the remaining solution
(D) rinse the pipette with a small quantity of distilled water into the flask

8. A student performed a titration and presented her results in the following graph.



What does the pH of the equivalence point suggest?

(A) The solution was neutral at that point.
(B) There are more OH^- ions than H^+ ions.
(C) There are free OH^- present in the original solution.
(D) The acid/base mixture was never neutral.

Question 8 B	9.3.4	H13
Since the equivalence point is at a pH > 7 the mixture is alkaline. This means there must be more OH^- than H^+ present.		

Question 22 (7 marks) **Marks**

To prepare a standard solution of sodium hydroxide a student first dissolved 1.0 g of solid sodium hydroxide in 250 mL of distilled water. By titration, 25.0 mL of this solution required 23.2 mL of standard 0.100 mol L^{-1} hydrochloric acid for neutralisation.

(a) Why is titration necessary to standardise the sodium hydroxide solution? **1**

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(b) Calculate the concentration of the standardised sodium hydroxide solution. **2**

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(c) Describe the titration procedure for this standardisation. **4**

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22. (a) sodium hydroxide absorbs both water and carbon dioxide from the air, so that it cannot be used as a primary standard. Titration is needed to determine its concentration. 1

(b) [NaOH] = 23.2 x 0.100/25.0 = 0.0928 mol L^{-1} (mole ratio HCl:NaOH = 1:1) 2

Q22 (c) Titration procedure to include use of pipette for NaOH solution, burette for HCl, conical flask and suitable indicator such as phenolphthalein. All glassware to be rinsed with distilled water, followed by the solutions for the pipette and burette. 2

Titration carried out with swirling of flask contents, with the end point recorded as the volume of HCl to decolorise the indicator. Rinse flask with distilled water after each titration.

Minimum of three titration measurements, with two agreeing within 0.1 mL. 2

Marks

Question 23 (5 marks)

A titration was carried out using 0.246 mol L^{-1} HCl to standardise 25.0 mL aliquots of a solution of the weak base, sodium carbonate. An appropriate indicator was chosen to show the end point of the neutralisation. The results gained are shown in the table below.

Run	*1*	2	*3*	*4*	*5*
Initial burette volume (mL)	0.5	23.6	0.7	23.5	0.2
Final burette volume (mL)	23.5	45.8	23.0	46.2	22.4

(a) Calculate the concentration of the sodium carbonate solution. Justify the steps in your calculation. **3**

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(b) The student had a choice of indicators: **2**

- methyl orange; changes from red to orange from pH 3.0 to 4.5.
- phenolphthalein; changes from colourless to pink from pH 8.3 to 10.0.

Select the indicator that should be used for this titration, giving a reason for your choice.

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Sample answer	Syllabus content, course outcomes and marking guide
Question 23	9.3.3 H10, H12

(a)

Run	*1 (rough)*	2	*3*	*4*	*5*
Initial burette volume (mL)	0.5	23.6	0.7	23.5	0.2
Final burette volume (mL)	23.5	45.8	23.0	46.2	22.4
Volume used	23.0	22.2	22.3	22.7	22.2

Ignore the first (rough) titration and the fourth as they are too far away from the other readings. Therefore, the average volume of the concordant readings is 22.23 mL.

$$Na_2CO_3 + 2HCl \rightarrow 2\ NaCl + CO_{2(g)} + H_2O_{(l)}$$

$$\text{Mol } Na_2CO_3 = \frac{1}{2}\text{mol}(HCl)$$

$$cV\ (Na_2CO_3) = \frac{1}{2}cV\ (HCl)$$

$$0.25 \times C = \frac{1}{2} \times 0.0246 \times 0.02223$$

$$Na_2CO_3 = 0.109 \text{ mol L}^{-1}$$

Marking guide (a):

- Correct calculation justifying average titre used 3
- Correct calculation using average of all values 2
- Correct equation.

OR

- Some correct working 1

(b) Reaction between a strong acid and a weak base will produce an acidic solution, so methyl orange will be suitable.

Marking guide (b):

- Chooses correct indicator and provides appropriate reason 2

Marks

Question 24 (6 marks)

A bottle of vinegar is labelled *4.0% w/v* (4.0 g per 100 mL of solution) acetic acid (ethanoic acid).

(a) Describe the laboratory procedure you would use to verify this concentration. **3**

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(b) Calculate the volume of 0.118 mol L^{-1} NaOH required to neutralise the acid in 5.0 mL of this vinegar. **3**

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24. (a) The vinegar was diluted accurately using a pipette and volumetric flask. 1
The diluted vinegar was titrated against a standard NaOH solution 1
The end point was found using phenolphthalein indicator, and the concentration of the undiluted vinegar calculated from the titration result. 1

24(b) $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$
mass of acid in 5 mL = 5 x 4/100 = 0.20 g ; mole mass of acetic acid = 60 g 1
moles of acid = mass/molar mass = 0.20/60 = 0.0033 mole
moles of NaOH required = 0.0033 1
Volume of NaOH = moles/molarity = 0.0033/0.118 = 0.0280 L = 28.0 mL 1

- qualitatively describe the effect of buffers with reference to a specific example in a natural system

Question 18 (4 marks)

The pH of human blood is maintained at about 7.4 by various buffers. One of the most important of these is the dihydrogen phosphate/hydrogen phosphate ($H_2PO_4^-/HPO_4^{2-}$) equilibrium.

(a) Write an equation for this equilibrium. **1**

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(b) With reference to this equation, explain how a solution containing this buffer could resist a change in pH if a small amount of acid were added to it. **3**

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Question 18		
(a)	$H_2PO_4^- \rightleftharpoons HPO_4^{2-} + H^+$	H13 • Correct equation.................... 1
(b)	In a buffer solution, the concentration of the weak acid and its conjugate base is considerably greater than the concentration of the H^+. In this case if a small amount of acid were added, the extra H^+ added would react with the HPO_4^{2-} ion forcing the equilibrium to shift to the left. However, since the $[HPO_4^{2-}]$ is so much greater than the $[H^+]$, then the original amount of H^+ remains virtually unchanged. The volume change is very small and so the new $[H^+]$ is almost identical to what it was before the acid was added. Therefore, the pH remains almost the same.	H8 • Detailed explanation (cause and effect) with reference to the equation in part (a)..... 3 • Brief explanation with reference to equation .... 2 • Brief explanation with no reference to equation 1

1. A small amount of acid is added to a buffer solution. As a result the pH of this solution will
   (A) not change.
   (B) decrease slightly.
   (C) increase slightly.
   (D) approach pH = 7.

Answer and explanation		Syllabus content and course outcomes	
Question 1	**B**	9.3.4	H8
A buffer solution will resist a change in pH, but will not prevent it.			

Question 24 (3 marks)

Define the term *buffer* in relation to acid-base systems and describe ONE example of buffer action in a natural system. **3**

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24. A buffer is a solution which maintains almost constant pH when small quantities of acid or base are added. The buffer consists of a weak acid and its conjugate base, at roughly equal concentrations.
An example is our blood, which is buffered by the presence of the hydrogen carbonate ion, maintaining a stable pH as it circulates though the body. 3

Question 22 (4 marks) **Marks**

The phosphate buffer system operates in the internal fluid of all cells. This buffer system is represented by the chemical equation below:

$$H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$$

(a) Define the term 'buffer' and identify the key components of any buffer system. 2

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(b) Using relevant equations explain what happens if: 2

(i) H^+ ions are added to this system.

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(ii) OH^- ions are added to this system.

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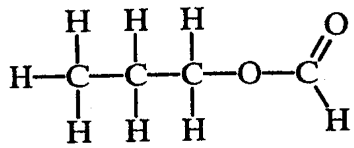
22. (a) A buffer is a system which can maintain approximately the same pH even when significant amounts of strong acid or base are added. 1
Buffered solutions contain comparable amounts of a weak acid and its conjugate base 1
(b) (i) According to le Chateliers principle addition of H^+ ions will move the equilibrium to the left, restoring the original H^+ ion concentration. 1
(ii) addition of OH^- ions will move the equilibrium to the right, restoring the original H^+ ion concentration. 1

- analyse information from secondary sources to assess the use of neutralisation reactions as a safety measure or to minimise damage in accidents or chemical spills

	Students learn to:	Students:
5. Esterification is a naturally occurring process which can be performed in the laboratory	• describe the differences between the alkanol and alkanoic acid functional groups in carbon compounds • identify the IUPAC nomenclature for describing the esters produced by reactions of straight-chained alkanoic acids from C1 to C8 and straight-chained primary alkanols from C1 to C8 • explain the difference in melting point and boiling point caused by straight-chained alkanoic acid and straight-chained primary alkanol structures • identify esterification as the reaction between an acid and an alkanol and describe, using equations, examples of esterification • describe the purpose of using acid in esterification for catalysis • explain the need for refluxing during esterification • outline some examples of the occurrence, production and uses of esters	• identify data, plan, select equipment and perform a first-hand investigation to prepare an ester using reflux • process information from secondary sources to identify and describe the uses of esters as flavours and perfumes in processed foods and cosmetics

5. Esterification is a naturally occurring process which can be performed in the laboratory	• describe the differences between the alkanol and alkanoic acid functional groups in carbon compounds • identify the IUPAC nomenclature for describing the esters produced by reactions of straight-chained alkanoic acids from C1 to C8 and straight-chained primary alkanols from C1 to C8	• explain the difference in melting point and boiling point caused by straight-chained alkanoic acid and straight-chained primary alkanol structures • identify esterification as the reaction between an acid and an alkanol and describe, using equations, examples of esterification

5. The following structure describes an ester.



Which organic reactants were used to form this ester?

(A) Methanol and propanoic acid
(B) 1-propanol and methanoic acid
(C) Ethanol and ethanoic acid
(D) 1-butanol and butanoic acid

Question 5 B

The esters structure has double bonded oxygen on the single carbon; this C must be from the acid therefore the acid was methanoic acid. The other carbon chain in the ester contains 3 consecutive C atoms therefore this section was originally 1-propanol.

9. What is a correct name for the compound with the molecular formula CH_2O_2?

(A) ethanoic acid
(B) ethanol
(C) methanol
(D) methanoic acid

$\boxed{D}$

- describe the purpose of using acid in esterification for catalysis
- explain the need for refluxing during esterification
- identify data, plan, select equipment and perform a first-hand investigation to prepare an ester using reflux

Question 23 (8 marks) **Marks**

(a) To perform an esterification reaction in the laboratory a student was provided with methanol and propanoic acid, which she heated together under reflux with a catalyst.

(i) Name the ester which could be synthesised. **1**

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(ii) Draw a structural formula for this ester. **1**

(iii) Name a suitable catalyst for this reaction. **1**

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(iv) Justify the use of heating under reflux for this experiment. **2**

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(b) The ester formed in the above reaction has a molar mass of 88 g and boils at 78°C. Two other substances with the same molar mass are:

1-pentanol	BP 138°C
butanoic acid	BP 163°C

Explain the difference in boiling points between these three substances. **3**

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23. (a) (i) methyl propanoate (1 mk)
(ii) $CH_3CH_2COOCH_3$ or expanded formula (1 mk)
(iii) any strong acid, phosphorus pentoxide etc (1 mk)
(iv) Heating under reflux increases the reaction rate (higher temperature) (1 mk)
while preventing loss of reactants or products by vaporisation to outside. (1 mk)
(b) The ester has low polarity resulting in much weaker intermolecular forces (1 mk)
than in pentanol and butanoic acid which both have polar OH groups. (1 mk)
With an additional O atom butanoic acid is still more polar OR
Pentanol and butanoic acid also form hydrogen bonds.
The boiling points reflect the strengths of these intermolecular forces. (1 mk)

Marks

Question 23 (5 marks)

In your studies, you have investigated the production of esters, an endothermic process, and the Haber process, an exothermic process. 5

Compare the application of reaction rate and equilibrium principles in the production of esters and the Haber process.

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Question 24 (1 mark)

Internal combustion engines use petrol or diesel as fuels. State why computers in modern cars monitor the levels of carbon monoxide and nitrogen oxides produced. 1

Sorry – wrong spot

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Question 23	
Esterification is an equilibrium reaction with the equilibrium position well to the left. It is also a slow reaction. The reaction to produce ammonia is also slow, although its equilibrium position is well to the right. In each case reaction rate is increased through the use of higher temperatures and a catalyst (concentrated acid for esterification, iron for ammonia). Increasing the temperature also shifts the equilibrium position to the right in the case of esters, increasing yield, but to the left for ammonia, decreasing yield. High pressure (up to 350 atmospheres) is used to increase rate and yield in the Haber process, which is a gas phase reaction, whereas esterification proceeds at atmospheric pressure. Each process removes a product, ammonia is liquefied so that the equilibrium shifts further to the right, and water is removed in esterification so that the equilibrium also shifts to the right.	9.3.5, 9.4.2 H3, H8, H13 • Compares the processes in terms of how rate and position of equilibrium are controlled .... 4–5 • Compares rate factors OR • Equilibrium factors only OR • Superficial treatment of both .... 2–3 • An understanding of rate or equilibrium........................ 1

Question 24	
Carbon monoxide is highly toxic to humans, while both substances contribute to environmental pollution. Monitoring the level of these oxides helps the car's computer to adjust settings to ensure complete combustion of fuel takes place, minimising the level of these oxides.	9.4.1 H4, H8 • States a reason for monitoring 1

Question 23 (4 marks) **Marks**

During your practical work you performed a first hand investigation to prepare an ester.

(a) Identify an ester by name and draw its structural formula. 2

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(b) Explain the need for refluxing in this investigation. 2

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23. (a) eg., ethyl acetate (ethanoate) $CH_3CH_2OCOCH_3$ or expanded structural formula 2

(b) The reaction is slow and requires and is carried at by boiling with a catalyst. As the reactants and product are volatile, and highly flammable, a reflux condenser is needed to continuously condense the escaping vapour and return the condensate to the reaction flask. 2

esters

flavours and perfumes in processed foods and cosmetics