CAMBRIDGE CHECKPOINTS NSW 2019–2020

Chemistry Year 12

- Past examination questions up to 2017
- Suggested responses included

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Contents

Chapter 4
Module 8: Applying Chemical Ideas

Introduction

This book is a collection of over 500 practice questions for the end-of-year written examination in HSC Chemistry. The questions cover the four HSC modules to be examined for the first NESA set examination in 2019. Questions have been included for each dot point in the Syllabus and manipulated to show the various ways the content may be examined.

The book includes all the relevant questions from previous HSC examinations papers where they correlate to the 2018 NESA Syllabus, as well as many new questions for the new content.

Questions with stimulus material and more challenging higher order questions are included as per the sample examination paper issued by NESA. Included are content questions, as well as skills, first-hand investigations and processing of data-style questions.

Questions should be attempted once the relevant theory has been completed. Answers have been included at the end of each chapter.

Cambridge *QuizMeMore*, compatible with all internet-enabled devices, is available via Cambridge GO https://www.cambridge.edu.au/go/.

It features quizzes that are an extra revision tool for use throughout the year and are a fun add-on to your study experience.

FORMULAE SHEET

$$n = \frac{m}{MM} \qquad c = \frac{n}{V} \qquad PV = nRT$$

$$q = mc\Delta T \qquad \Delta G° = \Delta H° - T\Delta S° \qquad \text{pH} = -\log_{10}[H^+]$$

$$pK_a = -\log_{10}[K_a] \qquad A = \varepsilon lc = \log_{10}\frac{I_o}{I}$$

Avogadro constant, N_A ..... 6.022×10^{23} mol^{-1}

Volume of 1 mole ideal gas: at 100 kPa and

at 0°C (273.15 K) ..... 22.71 L

at 25°C (298.15 K) ..... 24.79 L

Gas constant ..... 8.314 J mol^{-1} K^{-1}

Ionisation constant for water at 25°C (298.15 K), K_w ..... 1.0×10^{-14}

Specific heat capacity of water ..... 4.18×10^3 J kg^{-1} K^{-1}

DATA SHEET

Solubility constants at 25°C

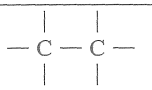
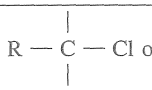
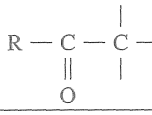
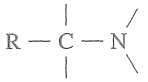
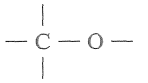
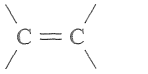
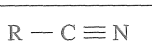
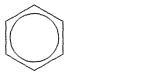
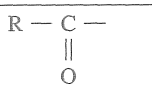
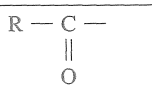
Compound	K_{sp}	*Compound*	K_{sp}
Barium carbonate	2.58×10^{-9}	Lead(II) bromide	6.60×10^{-6}
Barium hydroxide	2.55×10^{-4}	Lead(II) chloride	1.70×10^{-5}
Barium phosphate	1.3×10^{-29}	Lead(II) iodide	9.8×10^{-9}
Barium sulfate	1.08×10^{-10}	Lead(II) carbonate	7.40×10^{-14}
Calcium carbonate	3.36×10^{-9}	Lead(II) hydroxide	1.43×10^{-15}
Calcium hydroxide	5.02×10^{-6}	Lead(II) phosphate	8.0×10^{-43}
Calcium phosphate	2.07×10^{-29}	Lead(II) sulfate	2.53×10^{-8}
Calcium sulfate	4.93×10^{-5}	Magnesium carbonate	6.82×10^{-6}
Copper(II) carbonate	1.4×10^{-10}	Magnesium hydroxide	5.61×10^{-12}
Copper(II) hydroxide	2.2×10^{-20}	Magnesium phosphate	1.04×10^{-24}
Copper(II) phosphate	1.40×10^{-37}	Silver bromide	5.35×10^{-13}
Iron(II) carbonate	3.13×10^{-11}	Silver chloride	1.77×10^{-10}
Iron(II) hydroxide	4.87×10^{-17}	Silver carbonate	8.46×10^{-12}
Iron(III) hydroxide	2.79×10^{-39}	Silver hydroxide	2.0×10^{-8}
Iron(III) phosphate	9.91×10^{-16}	Silver iodide	8.52×10^{-17}
		Silver phosphate	8.89×10^{-17}
		Silver sulfate	1.20×10^{-5}

Aylward and Findlay, *SI Chemical Data* (5th Edition) is the principal source of data for this examination paper. Some data may have been modified for examination purposes.

Infrared absorption data

Bond	Wavenumber/cm^{-1}
N—H (amines)	3300–3500
O—H (alcohols)	3230–3550 (broad)
C—H	2850–3300
O—H (acids)	2500–3000 (very broad)
C≡N	2220–2260
C=O	1680–1750
C=C	1620–1680
C—O	1000–1300
C—C	750–1100

^{13}C NMR chemical shift data

Type of carbon	δ/ppm
	5–40
	10–70
	20–50
	25–60
 alcohols, ethers or esters	50–90
	90–150
	110–125
	110–160
 esters or acids	160–185
 aldehydes or ketones	190–220

UV absorption

(This is not a definitive list and is approximate.)

Chromophore	λ_{max} (nm)
C—H	122
C—C	135
C=C	162

Chromophore	λ_{max} (nm)
C≡C	173 178 196 222
C—Cl	173
C—Br	208

Some standard potentials

$K^+ + e^-$	$\rightleftharpoons$	$K(s)$	–2.94 V
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	$Ba(s)$	–2.91 V
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	$Ca(s)$	–2.87 V
$Na^+ + e^-$	$\rightleftharpoons$	$Na(s)$	–2.71 V
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	$Mg(s)$	–2.36 V
$Al^{3+} + 3e^-$	$\rightleftharpoons$	$Al(s)$	–1.68 V
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	$Mn(s)$	–1.18 V
$H_2O + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g) + OH^-$	–0.83 V
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	$Zn(s)$	–0.76 V
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	$Fe(s)$	–0.44 V
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	$Ni(s)$	–0.24 V
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	$Sn(s)$	–0.14 V
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	$Pb(s)$	–0.13 V
$H^+ + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g)$	0.00 V
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2(aq) + 2H_2O$	0.16 V
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	$Cu(s)$	0.34 V
$\frac{1}{2}O_2(g) + H_2O + 2e^-$	$\rightleftharpoons$	$2OH^-$	0.40 V
$Cu^+ + e^-$	$\rightleftharpoons$	$Cu(s)$	0.52 V
$\frac{1}{2}I_2(s) + e^-$	$\rightleftharpoons$	I^-	0.54 V
$\frac{1}{2}I_2(aq) + e^-$	$\rightleftharpoons$	I^-	0.62 V
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	0.77 V
$Ag^+ + e^-$	$\rightleftharpoons$	$Ag(s)$	0.80 V
$\frac{1}{2}Br_2(l) + e^-$	$\rightleftharpoons$	Br^-	1.08 V
$\frac{1}{2}Br_2(aq) + e^-$	$\rightleftharpoons$	Br^-	1.10 V
$\frac{1}{2}O_2(g) + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O	1.23 V
$\frac{1}{2}Cl_2(g) + e^-$	$\rightleftharpoons$	Cl^-	1.36 V
$\frac{1}{2}Cr_2O_7^{2-} + 7H^+ + 3e^-$	$\rightleftharpoons$	$Cr^{3+} + \frac{7}{2}H_2O$	1.36 V
$\frac{1}{2}Cl_2(aq) + e^-$	$\rightleftharpoons$	Cl^-	1.40 V
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	1.51 V
$\frac{1}{2}F_2(g) + e^-$	$\rightleftharpoons$	F^-	2.89 V

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number
Symbol
Standard Atomic Weight
Name

79
Au
197.0
Gold

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.941 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.64 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.61 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.96 Molybdenum	43 Tc Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57–71 Lanthanoids	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.9 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89–103 Actinoids	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

Lanthanoids

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.1 Ytterbium	71 Lu 175.0 Lutetium

Actinoids

89 Ac Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Standard atomic weights are abridged to four significant figures.
Elements with no reported values in the table have no stable nuclides.
Information on elements with atomic numbers 113 and above is sourced from the International Union of Pure and Applied Chemistry Periodic Table of the Elements (November 2016 version).
The International Union of Pure and Applied Chemistry Periodic Table of the Elements (February 2010 version) is the principal source of all other data. Some data may have been modified.

Chapter 1
Module 5: Equilibrium and Acid Reactions
Multiple-choice questions

5.1 Static and dynamic equilibrium

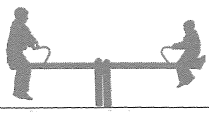
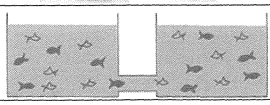
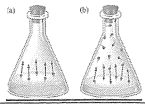
Question 1
Which of these reactions are correct?

	Reversible reaction	*Irreversible reaction*
(A)	$CoCl_2.6H_2O(s) \rightarrow CoCl_2(s) + H_2O(g)$	$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
(B)	$C_8H_{18}(l) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$	$H_2O(g) \rightarrow H_2O(l)$
(C)	$H_2O(g) \rightarrow H_2O(l)$	$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
(D)	$Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$	$CoCl_2.6H_2O(s) \rightarrow CoCl_2(s) + H_2O(g)$

Question 2
What is chemical equilibrium?

(A) A state of balance in a chemical reaction where the speed of the forward reaction is unequal to the reverse reaction.
(B) A chemical reaction in which the forward and reverse reactions are occurring at the same time and at the same rate.
(C) A neutralisation reaction with equal number of moles of an acid and a base.
(D) A steady state in which matter is entering and leaving the system at a constant rate.

Question 3
Which of the following is an incorrect model?

	Dynamic equilibrium
(A)	
(B)	
(C)	
(D)	

Question 4

A drug used to treat hypertension undergoes a decomposition reaction to give an insoluble product. Calculate the temperature at which this reaction becomes spontaneous if the enthalpy of the reaction at 298 K is 51 kJ mol^{-1} and the entropy of the reaction at this temperature is 118.74 J K^{-1} mol^{-1}.

(A) 430 K **(B)** 2300 K **(C)** 0.5 K **(D)** 430°C

Question 5

When the system A + B ⇌ C + D is at equilibrium:

(A) the sum of [A] and [B] are equal the sum of [C] and [D].
(B) the forward reaction has stopped.
(C) the reverse reaction has stopped.
(D) neither the forward nor the reverse reaction has stopped.

Question 6

In the production of nitric acid, an important step is the conversion of nitric oxide (NO) into nitrogen dioxide (NO_2).

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g); \quad \Delta H = -114 \text{ kJ mol}^{-1}$$

Which of the sets of conditions below would be expected to give the best equilibrium yield of nitrogen dioxide?

(A) 500°C and 4 atm pressure. **(B)** 30°C and 4 atm pressure.
(C) 500°C and 1 atm pressure. **(D)** 30°C and 1 atm pressure.

Question 7

An important industrial process is the conversion of carbon monoxide into carbon dioxide using steam.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g); \quad \Delta H = -40 \text{ kJ mol}^{-1}$$

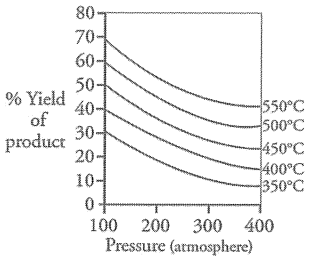
Which of the following would increase the percentage conversion of CO into CO_2?

(A) Increasing the pressure **(B)** Raising the temperature
(C) Increasing the concentration of water **(D)** Using a catalyst

Question 8

The graph on the right shows how the percentage of products in a reaction changes with variations in temperature and pressure.

Which chemical equation is consistent with this graph?

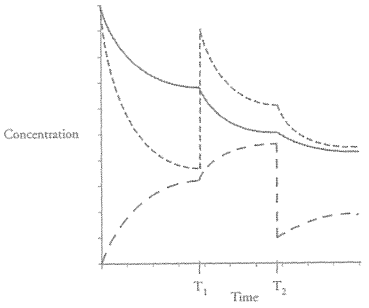


(A) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$; $\Delta H = -92$ kJ mol^{-1}
(B) $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$; $\Delta H = +250$ kJ mol^{-1}
(C) $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$; $\Delta H = +10$ kJ mol^{-1}
(D) $C_3H_8(g) + 5O_2(g) \rightleftharpoons 3CO_2(g) + 4H_2O(g)$; $\Delta H = -2045$ kJ mol^{-1}

Question 9

The graph on the right shows the concentrations over time for the system:

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$



What has happened at times T_1 and T_2?

	T_1	T_2
(A)	H_2 added	CH_3OH removed
(B)	CO added	CH_3OH removed
(C)	H_2 added	CO removed
(D)	CO added	CO and H_2 removed

[BOS 2012 Q16]

Question 10

What effect does a catalyst have on a reaction?

(A) It increases the rate.
(B) It increases the yield.
(C) It increases the heat of reaction.
(D) It increases the activation energy.

[BOS 2012 Q3]

Question 11

The following equilibrium is set up in a sealed reaction vessel.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g); \quad \Delta H = +54.8 \text{ kJ mol}^{-1}$$

Which of the following would INCREASE the yield of nitrogen dioxide?

(A) Adding a catalyst to the reaction vessel.
(B) Decreasing the volume of the reaction vessel.
(C) Raising the temperature of the reaction vessel.
(D) Increasing the pressure by adding argon to the reaction vessel.

[BOS 2013 Q10]

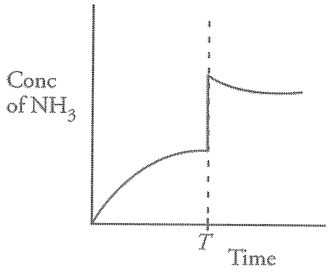
Question 12

This equation shows an equilibrium established in the synthesis of ammonia from its component gases:

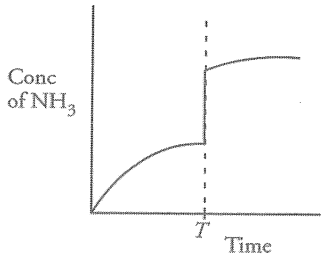
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

If the volume of the reaction chamber is suddenly halved at time *T*, which of the following best depicts changes in the concentration of ammonia over time?

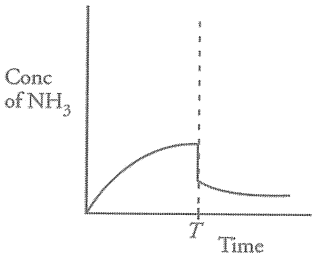
(A)



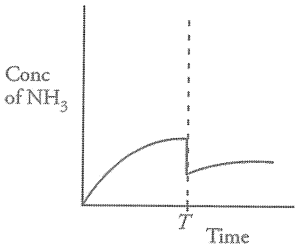
(B)



(C)



(D)



[BOSTES 2014 Q13]

Question 13

The equation describes an equilibrium reaction occurring in a closed system.

$$X(g) + Y(g) \rightleftharpoons 4Z(g); \qquad \Delta H = +58 \text{ kJ}$$

Under which set of conditions would the highest yield of Z(*g*) be obtained?

	Temperature (°C)	*Presssure* (kPa)
(A)	50	100
(B)	50	200
(C)	300	100
(D)	300	200

[BOSTES 2015 Q16]

Question 14

Consider the following endothermic reaction taking place in a closed vessel.

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

Which of the following actions would cause more N_2O_4 to be produced?

(A) Adding a catalyst.
(B) Decreasing the volume.
(C) Decreasing the pressure.
(D) Increasing the temperature.

[BOSTES 2016 Q14]

Question 15
The following equilibrium is established in a closed system.

$$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq) \qquad \Delta H = -19.4 \text{ kJ mol}^{-1}$$

How can the gas pressure in the system be decreased?

(A) Add more $CO_2(g)$.
(B) Add hydroxide ions to the solution.
(C) Decrease the volume of the container.
(D) Increase the temperature of the system.

[NESA 2017 Q16]

5.2 Factors that affect equilibrium

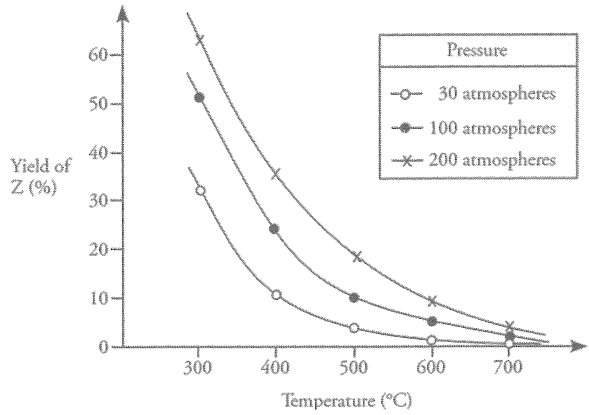
Question 16
The statements below are possible explanations for changes that occur to a reaction when the temperature is increased.

I. Particles move faster at higher temperatures and cause the reactant particles to collide more often.
II. At higher temperatures, reactant particles have energy greater than the activation energy.

Which answer best explains the reason the reaction rate is greater at higher temperatures?

(A) I only **(B)** II only **(C)** I and II
(D) I and II, but II to has a greater influence on the reaction

Question 17
This graph represents the yield of an equilibrium reaction at different temperature and pressure conditions inside a reaction vessel.



Which of the following reactions could produce the trends shown in the graph?

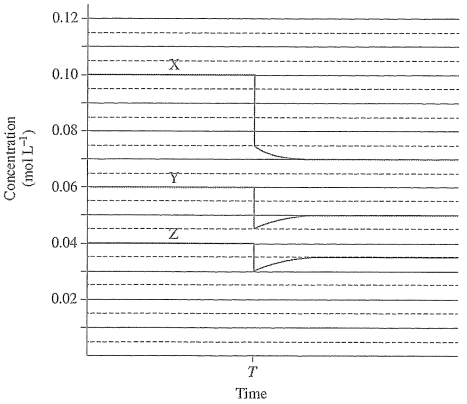
(A) $X(g) + Y(g) \rightleftharpoons 3Z(g)$; $\Delta H = +100$ kJ
(B) $X(g) + Y(g) \rightleftharpoons 2Z(g)$; $\Delta H = -100$ kJ
(C) $2X(g) + 2Y(g) \rightleftharpoons Z(g)$; $\Delta H = +100$ kJ
(D) $4X(g) + 2Y(g) \rightleftharpoons 3Z(g)$; $\Delta H = -100$ kJ

[BOSTES 2014 Q20]

Question 18

Three gases X, Y and Z were mixed in a closed container and allowed to reach equilibrium. A change was imposed at time *T* and the equilibrium was re-established. The concentration of each gas is plotted against time.

Which reaction is represented by the graph?

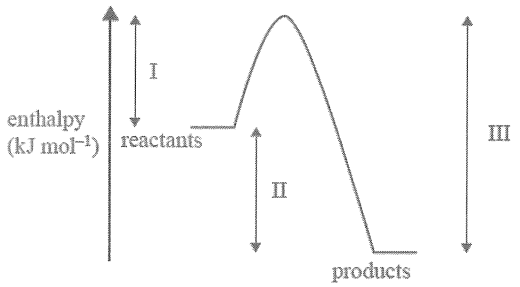


(A) $X(g) + Y(g) \rightleftharpoons 2Z(g)$
(B) $2X(g) \rightleftharpoons Y(g) + Z(g)$
(C) $2X(g) \rightleftharpoons Y(g) + 3Z(g)$
(D) $X(g) \rightleftharpoons Y(g) + Z(g)$

[NESA 2017 Q18]

Question 19

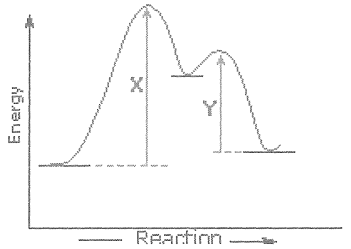
Consider the following energy profile for a chemical reaction, where I, II and III represent enthalpy changes during the reaction.



Which one of the following statements is correct?

(A) The activation energy for the reverse reaction is (III – II).
(B) The net energy released for the forward reaction is represented by II.
(C) The energy required to break the reactant bonds is represented by II.
(D) The energy released by the formation of new bonds is represented by I.

Question 20
Which one of the answers correctly describes the following energy diagram?



(A) A two-step exothermic reaction having an activation energy = **X**.
(B) A two-step endothermic reaction having an activation energy = **Y**.
(C) A two-step exothermic reaction having an activation energy = **Y**.
(D) A two-step endothermic reaction having an activation energy = **X**.

Question 21
Which one of the following statements is NOT generally correct?

(A) The enthalpy of the products is greater than the enthalpy of the reactants.
(B) The rate of a reaction is proportional to its activation energy.
(C) The rate of a reaction generally increases as the temperature is raised.
(D) All reactions in which bonds are broken and formed have a significant activation energy.

Question 22
The effect of a catalyst on reaction rate is to:

(A) offer a route with a lower activation energy.
(B) enable more molecules to overcome the lower activation energy.
(C) increase the number of successful collisions.
(D) All the of the above.

Question 23
The following reaction shows how a reversible reaction can be manipulated by changing the concentration of the reactants then products:

$$\underset{\text{pink}}{Co(H_2O)_6^{2+}} + 4Cl^-(aq) \qquad \underset{\text{blue}}{CoCl_4^{2-}}(aq) + 6H_2O(aq)$$

- Adding HCl to the reaction mixture increases the concentration of Cl^-.
- The equilibrium shifts towards the products to reduce the concentration of the Cl^-.
- The resulting colour change is from pink to blue.

At equilibrium, what would occur if water was added to the reaction mixture?

(A) The Cl^- concentration decreases.
(B) The reaction moves towards the product to increase the Cl^- concentration.
(C) The resulting colour changes from pink to blue.
(D) The temperature increases.

Question 24
A syringe contains two gases in equilibria, as follows:

$$N_2O_4 \rightleftharpoons 2NO_2 \qquad N_2O_4 \text{ is colourless and } NO_2 \text{ is brown.}$$

When the syringe is depressed, which of the following statements is correct?

(A) An increase in pressure will shift the equilibrium to produce more brown-coloured NO_2, as more N_2O_4 will collide.
(B) With an increase in pressure, the equilibrium will shift to the left, to colourless N_2O_4, to reduce the number of moles in the syringe.
(C) An increase in pressure will produce more brown-coloured NO_2, as the equilibrium will shift to the side with the most number of moles of gas.
(D) An increase in pressure will cause an increase in temperature, hence the equilibrium will shift to the forward reaction.

5.3 Calculating the equilibrium constant K_{eq}

Question 25
Arrange the following reactions in order of their increasing tendency to reach completion.

I. $4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6H_2O(g)$; $K_{eq} = 1.0 \times 10^{22}$
II. $2HF(g) \rightleftharpoons H_2(g) + F_2(g)$; $K_{eq} = 1.0 \times 10^{-13}$
III. $2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$; $K_{eq} = 4.7 \times 10^{-4}$
IV. $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$; $K_{eq} = 5.0 \times 10^{-31}$

(Note: For each reaction, the equilibrium constant was determined under different conditions.)

(A) I, III, II, IV
(B) III, II, IV, I
(C) IV, II, III, I
(D) I, IV, II, III

Question 26
The concentrations of reactants and products were studied for the following reaction:

$$H_2(g) + F_2(g) \rightleftharpoons 2HF(g); \qquad K_{eq} = 313 \text{ at } 25°C$$

In an experiment, the initial concentrations of the gases were
$[H_2] = 0.0120$ M, $[F_2] = 0.0200$ M and $[HF] = 0.500$ M.

When the reaction reaches equilibrium at 25°C, the concentration of HF will be:
(A) 0.550 M.
(B) 0.25 M.
(C) less than 0.500M.
(D) between 0.500 M and 0.550 M.

Use the following information for Questions 27 and 28.

Consider the equilibrium reaction:

$$2ClF_3(g) \rightleftharpoons 3F_2(g) + Cl_2(g) \qquad \Delta H = \text{negative value}$$

Question 27

An expression for the equilibrium constant for this reaction is:

(A) $\dfrac{[ClF_3]}{[F_2]^3[Cl_2]}$ **(B)** $\dfrac{3[F_2][Cl_2]}{2[ClF_3]}$

(C) $\dfrac{[F_2]^3[Cl_2]}{[ClF_3]^2}$ **(D)** $\dfrac{2[ClF_3]}{3[F_2][Cl_2]}$

Question 28

For the equilibrium reaction, the temperature is lowered and the amount of ClF_3 changed by 0.150 mol. The changes occurring would be:

	ClF_3	*F_2*	*Cl_2*
(A)	Increase by 0.150 mol	Decrease by 0.225 mol	Decrease by 0.075 mol
(B)	Increase by 0.150 mol	Decrease by 0.100 mol	Decrease by 0.075 mol
(C)	Decrease by 0.150 mol	Increase by 0.225 mol	Increase by 0.075 mol
(D)	Decrease by 0.150 mol	Increase by 0.100 mol	Increase by 0.075 mol

5.4 Solution equilibria

Question 29

What is the solubility product constant expression for $MgCl_2$?

(A) $[Mg^{2+}][Cl^-]$ **(B)** $[Mg^{2+}][Cl^-]^2$ **(C)** $[Mg^{2+}]^2[Cl^-]$ **(D)** $[Mg^{2+}]/[Cl^-]^2$

Question 30

The solubility product expression for tin(II) hydroxide is:

(A) $[Sn^{2+}][OH^-]$ **(B)** $[Sn^{2+}]^2[OH^-]$

(C) $[Sn^{2+}][OH^-]^2$ **(D)** $[Sn^{2+}]^3[OH^-]$

Question 31

Consider the following solubility data for various chromates at 25°C.

Chromate	*K_{sp}*
Ag_2CrO_4	9.0×10^{-12}
$BaCrO_4$	2.0×10^{-10}
$PbCrO_4$	1.8×10^{-14}
Tl_2CrO_4	9.8×10^{-15}

The chromate that is the most soluble in water at 25°C on a molar basis is:

(A) Ag_2CrO_4 **(B)** $BaCrO_4$ **(C)** $PbCrO_4$ **(D)** Tl_2CrO_4

Question 32
There are two unlabelled solutions. One is barium nitrate and the other lead nitrate. Which of the following could be added to the two unlabelled solutions to distinguish between them?

(A) Sodium sulfate
(B) Sodium nitrate
(C) Sodium chloride
(D) Sodium carbonate

[NESA 2017 Q8]

Free-response questions

5.1 Static and dynamic equilibrium

Question 1
(i) Models are often used to help explain complex concepts. Outline a first-hand investigation that can model an equilibrium reaction. [2 marks]

(ii) Assess the validity of the information that could be collected in this investigation. [3 marks]

[BOS 2011 Q33d; Total = 5 marks]

Question 2
Calculate $\Delta S°$, the entropy change, for the complete combustion of liquid octane with $O_2(g)$ at 298 K.

[2 marks]

Question 3
1-bromopropane reacts with sodium hydroxide solution to give propan-1-ol. The hydroxide ions replace the bromine in the organic molecule.

This reaction involves a collision between the 1-bromopropane and the hydroxide ions.

Explain the effect of DOUBLING the concentrations of both reactants.

[2 marks]

Question 4
For the complete combustion of methane, there is a decrease in entropy.
Explain the reason for the decrease in entropy. Include an equation in your response.

[2 marks]

Question 5
Photosynthesis reactions do not occur spontaneously. Use the standard entropy data in the table below to justify the need for sunlight, as the energy source, to drive the reaction.

Substance	*Standard entropy* (J/K per mole)
Water	70
Carbon dioxide	214
Oxygen	205
Glucose	212

[4 marks]

5.2 Factors that affect equilibrium

Question 6

(a) Draw a simple energy profile for:

(i) an exothermic reaction in which 100 kJ mol^{-1} is evolved, and which has an activation energy of 50 kJ mol^{-1}. [1 mark]

(ii) an endothermic reaction in which 50 kJ mol^{-1} is absorbed and which has an activation energy of 100 kJ mol^{-1}. [1 mark]

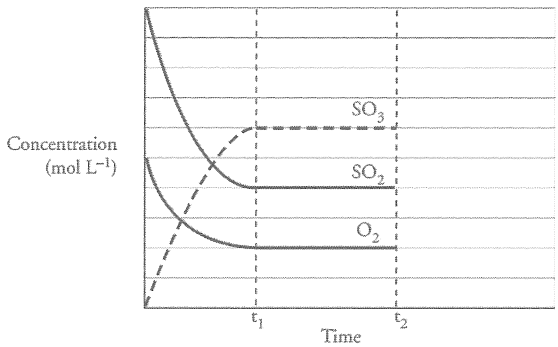
(b) Why do reactions have an activation energy? Explain your response with reference to one of the energy profile graphs drawn. [2 marks]

(c) Draw simple energy profiles to explain how the catalyst affects the activation energy of a reaction. [1 mark]

[Total = 5 marks]

Question 7

The graph below shows how the concentration of reactants and product varies with time for production of sulfur trioxide.



(a) What is the significance of time t_1? [1 mark]

(b) At time t_2, the concentration of oxygen was increased.

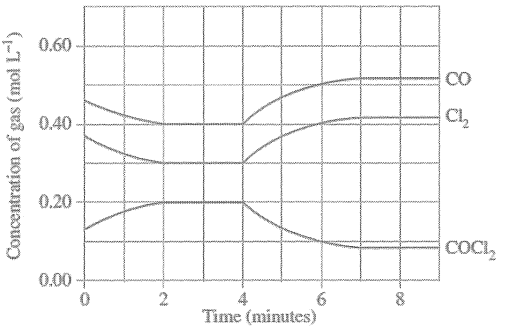
(i) On the graph above, sketch how the concentrations of reactants and product would change after the concentration of oxygen was increased at constant temperature. [2 marks]

(ii) Explain the changes that you have made on the graph. [2 marks]

[Total = 5 marks]

Question 8

A mixture of carbon monoxide, chlorine and phosgene ($COCl_2$) gases was placed in a closed container. The concentrations of the gases were monitored over time.



(a) At what time does the system first reach equilibrium? Justify your answer. [2 marks]

(b) At four minutes, the temperature of the container was increased.

Explain, with reference to the graph, whether the decomposition of $COCl_2$ into CO and Cl_2 is exothermic or endothermic. [3 marks]

[BOSTES 2016 Q28; Total = 5 marks]

Question 9

Explain the impact of an increase in pressure and an increase in temperature on the solubility of carbon dioxide in water. Include a relevant equation in your answer.

[BOS 2012 Q23; 3 marks]

Question 10

State Le Chatelier's principle.

[1 mark]

Question 11

Ethanoic acid and ethanol react reversibly to form ethyl ethanoate and water.
In a closed system, a dynamic equilibrium is set up.

(a) What effect would adding ethanol have on the percentage of ethanoic acid converted into ethyl ethanoate? Explain your answer using Le Chatelier's principle. [2 marks]

(b) This reaction is fairly slow and is usually done in the presence of a small amount of concentrated sulfuric acid as a catalyst to speed it up.

What effect would that have on the percentage of ethanoic acid converted into ethyl ethanoate? Explain your answer. [2 marks]

[Total = 4 marks]

Question 12

The Haber process for the manufacture of ammonia from nitrogen and hydrogen involves this reversible reaction:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g); \qquad \Delta H = -90 \text{ kJ mol}^{-1}$$

(a) Using Le Chatelier's principle, explain the effect on the position of equilibrium if the pressure is increased. [2 marks]

(b) In order to get the maximum possible percentage of NH_3 in the equilibrium mixture, is high or low temperature ideal? Explain your answer using Le Chatelier's principle. [2 marks]

(c) With reference to your response in part **(b)**, explain whether there are any disadvantages for a manufacturer of ammonia in using this temperature. [2 marks]

[Total = 6 marks]

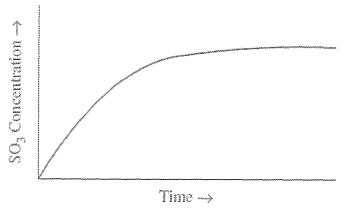
Question 13

The Contact process for the production of sulfuric acid includes a step whereby sulfur dioxide is converted to sulfur trioxide in an equilibrium reaction:

$$SO_2(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons SO_3(g) \qquad \Delta H = -99 \text{ kJ mol}^{-1}$$

SO_2 and O_2 were added to a closed container. The production of SO_3 over time is shown on the graph below.

(i) Copy the graph below and sketch a second curve on the same axes to demonstrate the production of SO_3 over time when the reaction is repeated at a higher temperature. Clearly label the two curves. [2 marks]



(ii) At a certain temperature, the equilibrium constant, K, is 12.1 for this reaction as written in the equation above.

At the same temperature, 1.0 mol SO_2 and 1.0 mol O_2 were added to a 1.0 litre closed container. At a point in time, the concentration of SO_3 in the container was measured as 0.70 mol L^{-1}.

Had equilibrium been reached in the container at this point? Use calculations to justify your answer. [4 marks]

[NESA 2017 Q31b; Total = 6 marks]

Question 14

At temperatures above 100°C, hydrogen and carbon monoxide react to form methanol gas in this reversible reaction.

$$2H_2(g) + CO(g) \rightleftharpoons CH_3OH(g)$$

A mixture of hydrogen, carbon monoxide and methanol is placed in a container with a volume that can be changed. The mixture is allowed to reach equilibrium.

(i) The initial volume of the container is 1.00 L. Account for any changes in the concentration of hydrogen gas when the volume of the container is rapidly increased to 2.00 L. [2 marks]

(ii) The initial mixture placed in the container had 0.50 mol of hydrogen, 1.00 mol of carbon monoxide and 2.50 mol of methanol. Once the volume of the container had been increased to 2.00 L and equilibrium had been re-established, the number of moles of hydrogen in the mixture had changed by 0.36 mol. Calculate the equilibrium constant for this reaction. [3 marks]

[BOSTES 2015 Q31a; Total = 5 marks]

Question 15

Briefly summarise the Haber process and evaluate the necessity to monitor and optimise the conditions used.

[6 marks]

Question 16

Fizzy drinks are made by forcing carbon dioxide gas into the drink under high pressure. This process is called carbonation and causes $CO_2(g)$ to dissolve in the drink to form $CO_2(aq)$. Fizzy drinks 'taste' fizzy because of this dissolved carbon dioxide.

In an unopened bottle of soft drink, the majority of the CO_2 molecules will be dissolved in the solution, i.e. in the aqueous form.

When carbon dioxide dissolves, the following four equilibria are established.

1. $CO_2(g) \rightleftharpoons CO_2(aq)$
2. $CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$ carbonic acid
3. $H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ hydrogen carbonate ions
4. $HCO_3^-(aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$ carbonate ions

(a) Predict and explain what will happen to the pH of the coke when the bottle is opened. [2 marks]

(b) Use the equations above, suggest why adding a slice of lemon to soft drink may cause it to taste slightly flat. [2 marks]

(c) Carbon dioxide is more soluble in cold solutions than warm solutions. Use this information to label each arrow below as either exothermic or endothermic.

$$CO_2(aq) \rightleftharpoons CO_2(g)$$ [2 marks]

(d) Given enough time, a bottle of soft drink may go flat even if it was not opened. This is because the CO_2 molecules are small enough to pass through the microscopic holes in the plastic. Describe and explain what would happen to the pH of the bottle if this happened. [2 marks]

[Total = 8 marks]

5.3 Calculating the equilibrium constant K_{eq}

Question 17
The reaction between ethene and steam to produce ethanol is an example of a homogeneous equilibrium:

$$CH_2{=}CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g); \qquad \Delta H = -45 \text{ kJ mol}^{-1}$$

(a) Explain the term *homogeneous* when it refers to an equilibrium reaction. [1 mark]

(b) Write the expression for the equilibrium constant K_{eq} for the reaction above. [2 marks]

[Total = 3 marks]

Question 18
Write an expression for the equilibrium constant for the following reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

[2 marks]

Question 19
Haemoglobin, a protein containing iron, is the material in red blood cells responsible for transporting oxygen to the cells. Each haemoglobin molecule attaches to four oxygen atoms, and the equilibrium conditions of the haemoglobin–oxygen interaction can be expressed thus:

$$Hb(aq) + 4O_2(g) \rightleftharpoons Hb(O_2)_4(aq)$$ where Hb stands for haemoglobin.

(a) Write the equilibrium expression for this reaction. [1 mark]

(b) When someone is exposed to CO gas, a frightening variation on the normal haemoglobin–oxygen interaction occurs. Carbon monoxide 'fools' haemoglobin into mistaking it for oxygen because it also bonds to haemoglobin in groups of four and O_2 is expelled.

Write this equilibrium reaction. [2 marks]

(c) To reverse the effects of the carbon monoxide, pure oxygen must be introduced to the body. It will react with the carboxyhaemoglobin to produce properly oxygenated haemoglobin, along with carbon monoxide.

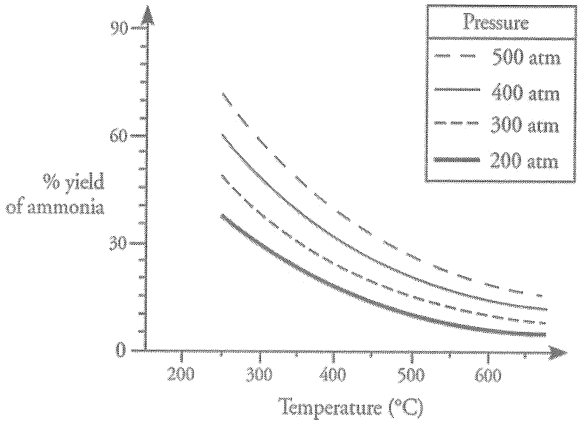
Write the equilibrium expression for this reaction. [2 marks]

[Total = 5 marks]

Question 20

The graph shows the percentage yield of ammonia produced from nitrogen and hydrogen at different temperatures and pressures.

The Haber process is the main industrial procedure for the production of ammonia. Explain the conditions used in the Haber process with reference to the graph.



[BOSTES 2015 Q30; 6 marks]

Question 21

Consider this chemical system which is at equilibrium.

$$X(g) + Y(g) \leftrightharpoons Z(g) + \text{heat}$$

(a) Explain the effect of decreasing the volume of the reaction vessel. [2 marks]

(b) Explain the effect of adding a catalyst to this equilibrium mixture. [2 marks]

[BOS 2013 Q24; Total = 4 marks]

Question 22

Solid ammonium hydrogen sulfide (NH_4HS) decomposes to form ammonia gas and hydrogen sulfide gas (H_2S). 2.00 moles of ammonium hydrogen sulfide were placed in a sealed 3.00 L container and the system was allowed to reach equilibrium. At equilibrium, there were 0.0328 moles of ammonia gas.

Calculate the equilibrium constant for this reaction.

[BOSTES 2016 Q31c(ii); 4 marks]

Question 23

Hydrochloric acid is produced in an exothermic and reversible reaction from hydrogen and chlorine gases.

(a) Write the equation and the equilibrium expression for this reaction. [2 marks]

(b) What would happen to the value of K_{eq} if heat is added to the system? [2 marks]

[Total = 4 marks]

Question 24
1.00 M of phosgene gas ($COCl_2$) in a 1.00 L container decomposes to produce carbon monoxide and chlorine gases.

At equilibrium, the concentration of chlorine gas is 0.028 M.

(i) Calculate the concentration of carbon monoxide. [2 marks]

(ii) Write the equilibrium constant expression for this composition reaction [1 mark]

(iii) Calculate the equilibrium constant for this reaction [2 marks]
[Total = 5 marks]

Question 25
Consider the following equilibrium:
$3Zn(s) + 6H^+(aq) + 2HNO_3(aq) \rightleftharpoons 3Zn^{2+}(aq) + 2NO(g) + 4H_2O + Heat$

Indicate what will happen to the concentration of nitric acid in each of the scenarios given below.

(i) temperature decreases [1 mark]

(ii) Zinc ion concentration increases [1 mark]

(iii) nitrogen oxide concentration decreases [1 mark]

(iv) pH increases [1 mark]
[Total = 4 marks]

Question 26
The equilibrium constant expression for a gaseous reaction is as follows.

$$K = \frac{[N_2][O_2]}{[NO]^2}$$

(i) Write the equation for this reaction. [1 mark]

(ii) 0.400 moles of NO was placed in a 1.00 L vessel at 2000°C. The equilibrium concentration of N_2 was found to be 0.198 mol L^{-1}.

Calculate the equilibrium constant for this reaction and use this value to describe the position of equilibrium. [3 marks]

(iii) What could be changed that would result in a different value of K for this equilibrium? [1 mark]
[BOS 2012 Q34b; Total = 5 marks]

Question 27
Nitrosyl chloride is introduced into an empty container. It then dissociates into nitric oxide and chlorine according to the equation:

$2NOCl(g) \leftrightharpoons 2NO(g) + Cl_2(g)$; the reaction is endothermic.

(i) Explain the effect on the yield of $NO(g)$ if the temperature is increased. [2 marks]

(ii) The equilibrium constant, K_{sp}, for the reaction is 0.028. Calculate the equilibrium concentration of $NOCl(g)$ if the equilibrium concentration of $Cl_2(g)$ is 0.17 mol L^{-1}. [3 marks]
[BOSTES 2014 Q32b; Total = 5 marks]

Question 28

(i) Methane and water vapour react to form carbon monoxide and hydrogen in a closed container as shown.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \quad \Delta H = +206 \text{ kJ}$$

Compare the impact on the equilibrium system of a decrease in volume of the container to the impact of a decrease in temperature. Refer to the equilibrium constant in your answer.

[3 marks]

(ii) Solid ammonium hydrogen sulfide (NH_4HS) decomposes to form ammonia gas and hydrogen sulfide gas (H_2S). 2.00 moles of ammonium hydrogen sulfide were placed in a sealed 3.00 L container and the system was allowed to reach equilibrium. At equilibrium, there were 0.0328 moles of ammonia gas. Calculate the equilibrium constant for this reaction.

[4 marks]

[BOSTES 2016 Q31c, Total = 7 marks]

5.4 Solution equilibria

Question 29

25.0 mL of 0.0020 M potassium chromate is mixed with 75.0 mL of 0.000125 M lead(II) nitrate. Will a precipitate of lead(II) chromate form?

K_{sp} of lead(II) chromate is 1.8×10^{-14}.

[2 marks]

Question 30

Determine the solubility of silver chromate at 298 K and determine the concentration of the two ions.

K_{sp} (Ag_2CrO_4) = 1.1×10^{-12}.

[3 marks]

Question 31

Estimate the solubility of barium sulfate in a 0.020 M sodium sulfate solution.

K_{sp} (barium sulfate) = 1.1×10^{-10}.

[2 marks]

Question 32
The following four substances all dissolve to some extent in water.

potassium chloride	glucose
propan-2-ol	magnesium hydroxide

These substances can be classified as an electrolyte or a nonelectrolyte.
Choose an electrolyte and a nonelectrolyte from the list and explain the reasons for their classification.

[3 marks]

Question 33
Name one ionic and one molecular compound and describe what happens when each dissolves in a polar solvent.

[2 marks]

Question 34
Cadmium is a highly toxic environmental pollutant that enters wastewaters associated with zinc smelting and in some electroplating processes. One way of controlling cadmium in effluent streams is to add sodium hydroxide, which precipitates insoluble $Cd(OH)_2$ ($K_s = 2.5 \times 10^{-14}$).

If 1000 L of a certain wastewater contains Cd^{2+} at a concentration of 1.6×10^{-5} M, what concentration of Cd^{2+} would remain after addition of 10 L of 4 M NaOH solution?

[3 marks]

Chapter 2
Module 6: Acid/Base Reactions
Multiple-choice questions

6.1 Properties of acids and bases

Question 1
Which of the following combinations are the correct properties for an acid?

(A) Has a soapy feel, bitter taste, turn blue litmus red and is an electrolyte.
(B) Corrosive, has a soapy feel, conducts electricity and is a good preservative for some food.
(C) Has a sour taste and a soapy feel, conducts electricity and is corrosive.
(D) Has a sour taste, can be used as a food preservative, conducts electricity and turns blue litmus red.

Question 2
Inorganic acids are named according to IUPAC nomenclature. Some earlier non-systematic names are also accepted. Which one of the following alternatives is correct?

	IUPAC name	*Common name*	*Symbol*
(A)	Trihydrogen phosphate	Phosphoric acid	H_3PO_4
(B)	Phosphorous trihydride	Phosphine	H_3PO_4
(C)	Trihydrogen phosphate	Phosphoric acid	H_2PO_4
(D)	Trihydrogen phosphorous	Phosphoric acid	H_3PO_4

Question 3
The correct IUPAC name for HNO_2 is:

(A) nitric acid.
(B) hydrogen nitrate.
(C) nitrous acid.
(D) nitrite acid.

Question 4
Which one of the following is **not** an acid–base indicator?

(A) Methyl violet
(B) Methyl orange
(C) Methyl propanoate
(D) Methyl red

Use the following information to answer Questions 5 and 6.

2.00 g of sodium hydrogen carbonate was added to 100.00 mL of 0.45 M hydrochloric acid.

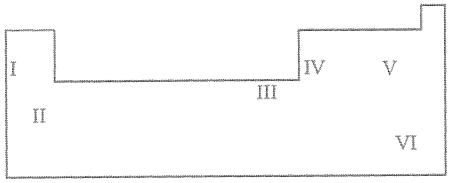
Question 5
What volume of gas was produced at 25°C and 100 kPa?

(A) 57.01 mL of CO_2
(B) 570.17 mL of CO_2
(C) 57.017 mL of H_2
(D) 570.17 mL of H_2

Question 6
Which of the reactants were in excess?

(A) 0.023 g of sodium hydrogen carbonate was in excess.
(B) 0.022 mol of hydrochloric acid was in excess.
(C) The reactants completely reacted.
(D) There is insufficient data to determine an answer.

Question 7
A diagram of the periodic table is shown below. The positions of six elements are shown using the labels I, II, III, IV, V and VI.



The oxides of these elements will react with acids or bases or with both acids and bases. Which one of the following alternatives is correct?

	Oxide only reacts with acids	*Oxide only reacts with bases*	*Oxide reacts with both acids and with bases*
(A)	V	II	III
(B)	VI	I	III
(C)	II	V	IV
(D)	II	VI	IV

Question 8
Since the 1770s, several definitions have been suggested for an acid. Which scientist was the first to suggest that acids contain hydrogen?

(A) Lavoisier **(B)** Davy **(C)** Arrhenius **(D)** Brønsted

Question 9
50.0 mL of 0.025 mol L^{-1} barium hydroxide solution is added to 50.0 mL of 0.350 mol L^{-1} hydrochloric acid.

How many moles of hydrochloric acid was in excess?

(A) 0.0025 mol **(B)** 0.00125 mol **(C)** 0.015 mol **(D)** 0.0012 mol

Question 10
The ideal pH of soil is 6–7. If the soil is too acidic; metal ions, such as aluminium, that are toxic to plants, are released as their compounds become soluble. Gardeners neutralise the soil's acidity by adding a strong base, such as:

(A) ammonia.
(B) calcium hydroxide.
(C) ammonium nitrate.
(D) phenolphthalein.

Question 11

The neutralisation reaction of an acid and a base produce a salt and water.
Which of the following pairs of substances are involved in the neutralisation reaction?

I	Nitric acid and copper(II) oxide
II	Nitric acid and calcium hydroxide
III	Hydrochloric acid and sodium carbonate
IV	Phosphoric acid and magnesium oxide

(A) I and II only
(B) I, II and IV only
(C) I, III and IV only
(D) I, II, III and IV

Question 12

A man suffering from gastritis. He takes an antacid tablet to lower the acidity in his stomach. Which of the following chemicals are found in antacid tablets?

(A) Sodium hydroxide
(B) Lemon juice
(C) Salt water
(D) Magnesium hydroxide

Question 13

Which of the following substances is most suitable to be applied on acidic ant bites?

(A) Vinegar
(B) Baking powder
(C) Lemon juice
(D) Ethanol

Question 14

Consider the reaction between hydrochloric acid and sodium chloride. Is the enthalpy of the products more than that of the reactant?

(A) There is no enthalpy change.
(B) The products are more as it is an exothermic reaction
(C) The products are less as it is an endothermic reaction
(D) The products are less as heat is lost to the surrounding.

Question 15

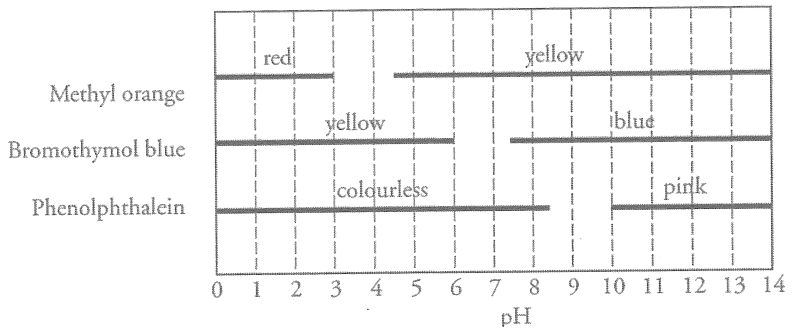
In which row of the table below are the listed oxides correctly classified?

	Acidic	*Basic*	*Neutral*	*Amphoteric*
(A)	CO_2	Na_2O	SO_3	Al_2O_3
(B)	Na_2O	CO_2	H_2O	Al_2O_3
(C)	CO_2	MgO	H_2O	ZnO
(D)	SO_2	K_2O	CO	CO_2

[BOS 2012 Q15]

Question 16

Methyl orange, bromothymol blue and phenolphthalein indicators were mixed together to form a solution. Over what pH range would the solution be yellow?

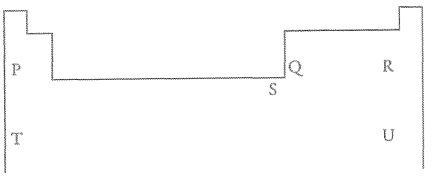


(A) 0–14 **(B)** 3–4.5 **(C)** 3–7.5 **(D)** 4.5–6

[BOS 2012 Q7]

Question 17

A representation of the Periodic Table is shown below. The position of six different elements, P, Q, R, S, T and U are given.



Which row of the following table shows the correct acid and base reactivities of the oxides of these elements?

	Oxide reacts with acid only	*Oxide reacts with base only*	*Oxide reacts with both acid and base*
(A)	P, T	R, U	Q, S
(B)	P, R	T, U	Q, S
(C)	Q, R	P, S	T, U
(D)	Q, S	R, U	P, T

[BOS 2013 Q6]

Question 18

Which row of the table correctly matches the scientist(s) with their theory of acids?

	Scientist(s)	*Theory*
(A)	Arrhenius	Acids contain oxygen
(B)	Brønsted and Lowry	Acids are proton donors
(C)	Davy	Acids are able to produce hydrogen ions in water
(D)	Lavoisier	Acids contain hydrogen

[BOSTES 2014 Q3]

Question 19

This table below contains information on three indicators.

Indicator	*pH range*	*Colour (lower pH – higher pH)*
Methyl orange	3.1–4.4	Red – yellow
Methyl red	4.4–6.2	Pink – yellow
Phenolphthalein	8.3–10.0	Colourless – pink

A substance is tested with each of the indicators and the results are recorded below.

Indicator	*Colour*
Methyl orange	Yellow
Methyl red	Yellow
Phenolphthalein	Colourless

(A) Lemonade pH 2.9
(B) White wine pH 4.2
(C) Tap water pH 7.2
(D) Ammonia pH 11.2

[BOSTES 2014 Q7]

Question 20

The oxides CaO, CO_2, Na_2O and N_2O_4 are placed in water to form four separate solutions. Which row of the table correctly indicates the solutions with pH less than 7 and the solutions with pH greater than 7?

	Solutions			
	pH less than 7		*pH greater than 7*	
(A)	CO_2	N_2O_4	CaO	Na_2O
(B)	CaO	N_2O_4	CO_2	Na_2O
(C)	CaO	Na_2O	CO_2	N_2O_4
(D)	CO_2	Na_2O	CaO	N_2O_4

[BOSTES 2015 Q5]

Question 21

Which indicator in the table would be best for distinguishing between lemon juice (pH = 2.3) and potato juice (pH = 5.8)?

	Indicator	*Colour at different pH*	
(A)	Crystal violet	0.2 – yellow	1.8 – blue
(B)	Methyl orange	3.2 – red	4.4 – yellow
(C)	Bromothymol blue	6.0 – yellow	7.6 – blue
(D)	Phenolphthalein	8.2 – colourless	10.0 – pink

[BOSTES 2016 Q7]

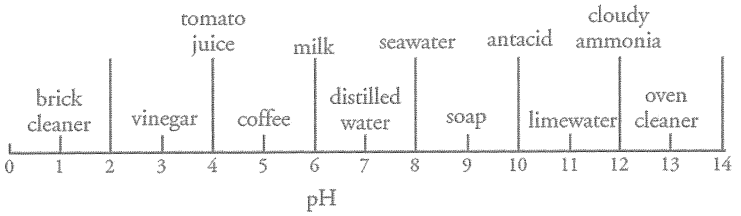
Question 22
Which combination of equimolar solutions would produce the most basic mixture?

(A) Acetic acid and barium hydroxide
(B) Acetic acid and sodium carbonate
(C) Sulfuric acid and barium hydroxide
(D) Sulfuric acid and sodium carbonate

[BOSTES 2016 Q6]

6.2 Using Brønsted–Lowry theory

Question 23
The pH of some common substances is given in the diagram below.



Four students were asked to compare the hydrogen ion concentration, $[H^+]$, of pairs of solutions. Their statements were:

Student 1: In vinegar, $[H^+]$ is four times greater than in cloudy ammonia
Student 2: The $[H^+]$ is twice as large in antacid as it is in coffee.
Student 3: In soap, $[H^+]$ is 10 000 times greater than in oven cleaner.
Student 4: The $[H^+]$ is 1000 times larger in tomato juice than in brick cleaner.
Which student's statement is correct?

(A) Student 1 **(B)** Student 2 **(C)** Student 3 **(D)** Student 4

Question 24
A student is asked to compare solutions of two acids. Acid I is 0.50 mol L^{-1} citric acid and acid II is 0.050 mol L^{-1} nitric acid. Which one of the following statements is correct?

(A) Acid I is stronger than acid II and acid I is more concentrated.
(B) Acid I is weaker than acid II and acid I and more concentrated.
(C) Acid I is stronger than acid II and acid I is more dilute.
(D) Acid I is weaker than acid II and acid I and more dilute.

Question 25
The pH values and concentrations of four acids are given in the table below.

Acid	*pH*	*Concentration*
I	2.73	0.20
II	2.06	0.10
III	3.77	1.00
IV	4.78	0.50

Which acid is the strongest?

(A) Acid I **(B)** Acid II **(C)** Acid III **(D)** Acid IV

Question 26
The concentration of a barium hydroxide solution is 5.00×10^{-3} mol L^{-1}. Assume that the substance is completely dissociated. What is the pH of this solution?

(A) 2.0 **(B)** 2.3 **(C)** 11.7 **(D)** 12.0

Question 27
Which one of the following aqueous solutions will have a pH of less than 7?

(A) Sodium acetate **(B)** Potassium chloride
(C) Ammonium chloride **(D)** Sodium nitrate

Question 28
The pH of a 5.0×10^{-5} mol L^{-1} solution of barium hydroxide is:

(A) 4.0 **(B)** 4.3 **(C)** 9.7 **(D)** 10.0

Question 29
A solution has a pH of 3.0. The concentration of hydroxide ions in this solution is:

(A) 3.0 mol L^{-1} **(B)** 1.0×10^{-3}mol L^{-1}
(C) 1.0×10^{-11} mol L^{-1} **(D)** 3.0×10^{-14}mol L^{-1}

Question 30
During the reaction of magnesium with dilute sulfuric acid to produce hydrogen gas, the pH of the reaction mixture would:

(A) rise from a low level. **(B)** fall from a high level.
(C) stay constant at a low level. **(D)** stay constant at a high level.

Question 31
The pH of 0.1 mol L^{-1} solutions of acetic, citric and hydrochloric acids was measured. Which solution has the highest pH?

(A) Citric acid **(B)** Acetic acid **(C)** Hydrochloric acid
(D) The pH of the three solutions is the same.

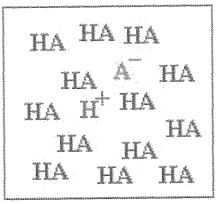
[BOS 2012 Q11]

Question 32
Which of the following changes take place when 50 mL of water is added to 50 mL of 0.1 mol L^{-1} acetic acid?

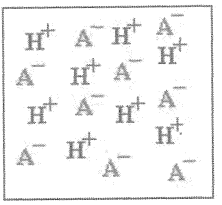
	pH	*Degree of ionisation*
(A)	Increase	Decrease
(B)	Decrease	Increase
(C)	Increase	Increase
(D)	Decrease	Decrease

[BOS 2012 Q18]

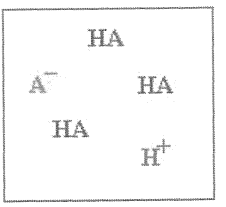
Refer to the diagrams below to answer Questions 33 and 34.



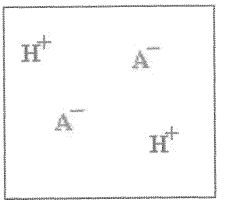
Acid I



Acid II



Acid III



Acid IV

Question 33

Which of these models depict the behaviour of a strong acid?

(A) Acid I
(B) Acid I and II
(C) Acid II
(D) Acid II and IV

Question 34

Choose the correct answer to match the properties of the four acids.

	Acid I	*Acid II*	*Acid III*	*Acid IV*
(A)	Strong and concentrated	Weak and fully dissociated	Weak and dilute	Strong and dilute
(B)	Weak and concentrated	Strong and concentrated	Weak and dilute	Strong and dilute
(C)	Strong and concentrated	Weak and concentrated	Weak and dilute	Strong and dilute
(D)	Strong and concentrated	Strong and concentrated	Weak and dilute	Weak and dilute

Question 35

What is the pH of a 0.018 mol L^{-1} solution of hydrochloric acid?

(A) 0.74 **(B)** 0.96 **(C)** 1.04 **(D)** 1.74

[BOSTES 2014 Q14]

Question 36

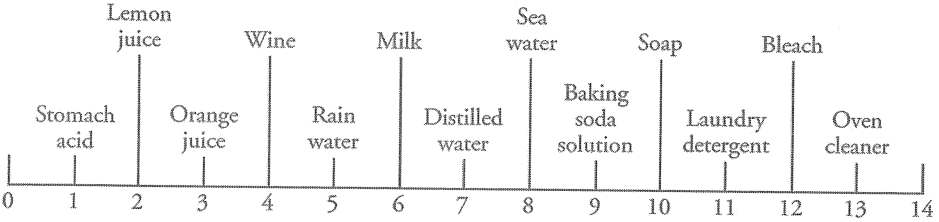
If exactly one gram of each of the following compounds is treated with excess hydrochloric acid, which would release the greatest volume of $CO_2(g)$ at 25°C and 100 kPa?

(A) K_2CO_3 **(B)** $KHCO_3$ **(C)** Na_2CO_3 **(D)** $NaHCO_3$

[BOSTES 2014 Q15]

Question 37

The diagram shows the pH values of some substances.



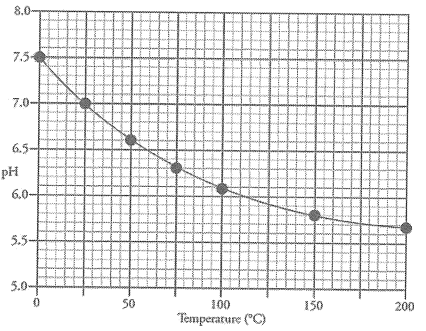
Based on the information provided, which of the following statements about the relative concentration of hydrogen ions is correct?

(A) It is 2 times higher in bleach than in milk.
(B) It is 10 times lower in stomach acid than in soap.
(C) It is 1000 times lower in distilled water than in wine.
(D) It is 100 times higher in laundry detergent than in baking soda solution.

[BOSTES 2014 Q12]

Question 38

The graph shows the pH of a solution of a weak acid, HA, as a function of temperature.



What happens as the temperature decreases?

(A) HA becomes less ionised and the H^+ concentration increases.
(B) HA becomes less ionised and the H^+ concentration decreases.
(C) HA becomes more ionised and the H^+ concentration increases.
(D) HA becomes more ionised and the H^+ concentration decreases.

[BOSTES 2014 Q8]

Question 39

Which of the following solutions has the highest pH?

(A) 1.0 mol L^{-1} acetic acid
(B) 0.10 mol L^{-1} acetic acid
(C) 1.0 mol L^{-1} hydrochloric acid
(D) 0.10 mol L^{-1} hydrochloric acid

[BOSTES 2015 Q13]

Question 40

20.0 mL of 0.020 mol L^{-1} barium hydroxide solution is added to 50.0 mL of 0.040 mol L^{-1} hydrochloric acid solution.

What is the pH of the final solution?

(A) 0.2 **(B)** 1.6 **(C)** 1.8 **(D)** 2.9

[NESA 2017 Q20]

Question 41
Which of the following substances is amphiprotic in nature?

(A) HSO_4^- **(B)** H_2SO_4 **(C)** SO_4^{2-} **(D)** H_2SO_3

[NESA 2017 Q5]

Question 42
A pH 3.0 solution of HCl(*aq*) is diluted by adding water to produce a pH 5.0 solution.

Which row of the following table correctly identifies an appropriate volume of the original solution and the volume of water added for this dilution?

	Volume of original solution (mL)	*Volume of water added* (mL)
(A)	100	900
(B)	100	1000
(C)	10	990
(D)	1	1000

[BOS 2013 Q15]

6.3 Quantitative analysis

Question 43
A solution was obtained by boiling flowers in water. After various substances were added to separate samples of the solution, the colour of each was noted.

Substance added	*Colour observed*
0.1 mol L^{-1} HCl(*aq*)	Bright pink
0.01 mol L^{-1} HCl(*aq*)	Bright pink
0.001 mol L^{-1} HCl(*aq*)	Pale yellow
Distilled water	Bright yellow
0.001 mol L^{-1} NaOH(*aq*)	Bright yellow
0.01 mol L^{-1} NaOH(*aq*)	Bright yellow

For which of the following titrations would it be appropriate to use this solution as an indicator?

(A) HCl(*aq*) + NH_3(*aq*)
(B) HCl(*aq*) + NaOH(*aq*)
(C) CH_3COOH(*aq*) + NH_3(*aq*)
(D) CH_3COOH(*aq*) + NaOH(*aq*)

[BOS 2013 Q19]

Question 44
25.0 mL of a 0.100 mol L^{-1} acid is to be titrated against a sodium hydroxide solution until final equivalence is reached.

Which of the following acids, if used in the titration, would require the greatest volume of sodium hydroxide?

(A) Acetic **(B)** Citric **(C)** Hydrochloric **(D)** Sulfuric

[NESA 2017 Q13]

Question 45

Which of the following could be added to 100 mL of 0.01 mol L^{-1} hydrochloric acid solution to change its pH to 4?

(A) 900 mL of water
(B) 900 mL of 0.01 mol L^{-1} hydrochloric acid
(C) 9900 mL of water
(D) 9900 mL of 0.01 mol L^{-1} hydrochloric acid

[BOSTES 2016 Q12]

Question 46

40 mL of 0.10 mol L^{-1} NaOH is mixed with 60 mL of 0.10 mol L^{-1} HCl.

What is the pH of the resulting solution?

(A) 7.0 **(B)** 1.7 **(C)** 1.4 **(D)** 1.2

[BOSTES 2016 Q18]

Question 47

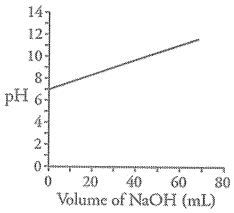
Acetic acid has a pK_a of 4.76. How would an unknown acid with a pK_a of 3.29 be classified?

(A) It is weaker than acetic acid.
(B) It is stronger than acetic acid.
(C) Insufficient information has been supplied to classify it.
(D) Its K_a value is 1.8×10^{-5}.

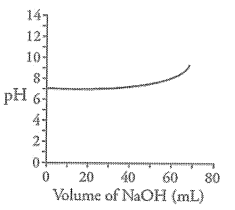
Question 48

A buffer solution has a pH of 7. Dilute sodium hydroxide solution is added to 200 mL of this buffer. Which of the graphs below shows how the pH will vary during this addition?

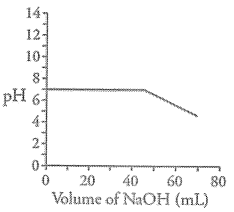
(A)



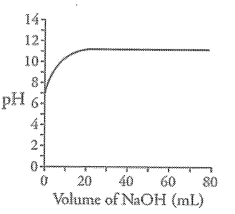
(B)



(C)



(D)



Question 49

Which one of the mixtures below would **not** produce a buffer solution?

(A) $HNO_3(aq)$ and $NaNO_3(aq)$
(B) $NaH_2PO_4(aq)$ and $Na_2HPO_4(aq)$
(C) $NH_4Cl(aq)$ and $NH_3(aq)$
(D) Sodium citrate(aq)/citric acid(aq)

Question 50

A student is asked to titrate a strong base with a strong acid using the procedure outlined below to determine the concentration of the acid.

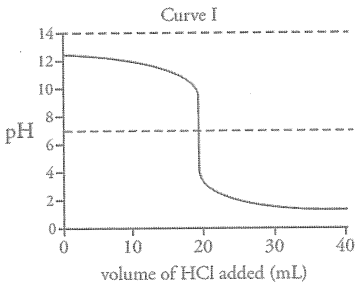
1. A burette was rinsed with the acid, emptied and then filled with the solution of the acid.
2. A conical flask was rinsed with water.
3. A pipette was rinsed with water and then used to transfer a volume of the standard base solution to the conical flask.
4. An indicator was added to the solution of the base and the acid was added from the burette until the indicator changed colour.

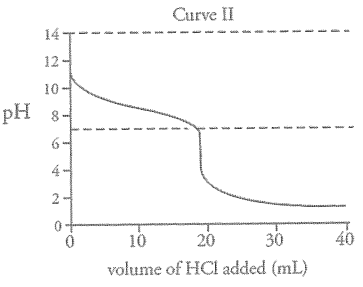
The student then calculates the concentration of the acid. Which one of the following statements about his value is correct?

(A) His acid concentration will be too high.
(B) His acid concentration will be too low.
(C) It is not possible to reach a conclusion about the acid concentration since his technique was faulty.
(D) His acid concentration will be correct.

Question 51

A student carried out a titration by adding 0.100 mol L^{-1} HCl from a burette to 20.00 mL of NaOH solution in a conical flask. During the titration the pH in the flask was measured and plotted against the volume of HCl added. Curve I resulted.





In a second titration 0.100 mol L^{-1} HCl was added to 20.00 mL of a different base. Again, the pH of the liquid in the flask was measured. The result was curve II. To find the equivalence point in acid–base titrations, several indicators are used. The table below gives the relevant information for four of these indicators.

Indicator	*Acidic colour*	*Range of colour change*	*Basic colour*
Thymol blue	Red	1.2–2.8	Yellow
Methyl red	Red	4.4–6.2	Yellow
Bromothymol blue	Yellow	6.0–7.6	Blue
Phenol red	Yellow	6.8–8.4	Red

Using this information which indicator would be suitable for both titrations?

(A) Thymol blue
(B) Methyl red
(C) Bromothymol blue
(D) Phenol red

Question 52
A strong base is used to titrate a solution of a weak diprotic acid. The equivalence point is reached when:

(A) the indicator changes colour.
(B) equal moles of the base and acid have reacted.
(C) the molar ratio of acid to base is the same as that required by the chemical equation.
(D) the pH is 7.0.

The following information is referred to in Questions 53 and 54.

A student wishes to determine the concentration of ethanoic (acetic) acid in vinegar. The student titrates a 20.00 mL sample of a standard sodium hydroxide solution with a diluted vinegar solution from a burette. Four experiments were carried out and the following titration results were obtained: 21.65 mL, 22.35 mL, 22.30 mL, 22.35 mL.

Question 53
The discrepancy in the first titration could be due to the student washing:

(A) the conical flask with sodium hydroxide solution only.
(B) the pipette with water only.
(C) the burette with water only.
(D) the pipette with sodium hydroxide solution only.

Question 54
To make the solution of diluted vinegar, the student should:

(A) use a pipette to deliver a known volume of commercial vinegar into a volumetric flask and add water until it reaches the mark.
(B) use a measuring cylinder to deliver a known volume of commercial vinegar into a volumetric flask and add water until it reaches the mark.
(C) deliver a known volume of commercial vinegar from a burette into a measuring cylinder and add water until it reaches the mark.
(D) measure the volume of commercial vinegar from a pipette into a conical flask and then add a known volume of water from a burette.

Question 55
Dinitrogen pentoxide reacts with water to form nitric acid. The relevant equation is:

$$N_2O_5(s) + H_2O(l) \rightarrow 2HNO_3(aq)$$

Sodium hydroxide reacts with nitric acid as follows.

$$HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)$$

2.16 g of dinitrogen pentoxide is reacted with an excess of water. The resulting nitric acid is neutralised by reaction with 0.25 mol L^{-1} sodium hydroxide solution. The volume required is:

(A) 0.010 L **(B)** 0.080 L **(C)** 0.160 L **(D)** 6.25 L

Question 56
Which of the following is a conjugate acid–base pair?

(A) H_2O/OH^-
(B) H_3O^+/HCl
(C) H_3O^+/OH^-
(D) H_3O^+/O^{2-}

Question 57
Which acid/base pair could act as a buffer?

(A) H_3O^+/H_2O
(B) H_2O/OH^-
(C) HNO_3/NO_3^-
(D) $H_2PO_4^-/HPO_4^{2-}$

[BOS 2012 Q8]

Question 58
Which pieces of glassware should be used when preparing a primary standard solution?

(A) Pipette, burette and conical flask
(B) Dropper, watch glass and pipette
(C) Beaker, filter funnel and volumetric flask
(D) Measuring cylinder, stirring rod and conical flask

[BOS 2012 Q4]

Question 59
What mass of anhydrous sodium carbonate is required to neutralise 100.0mL of 0.500 mol L^{-1} acetic acid?

(A) 2.65 g **(B)** 5.30 g **(C)** 10.6 g **(D)** 53.0 g

[BOS 2012 Q19]

Question 60
A 25.0 mL sample of a 0.100 mol L^{-1} hydrochloric acid solution completely reacted with 23.4 mL of sodium hydroxide solution.

What volume of the same sodium hydroxide solution would be required to completely react with 25.0 mL of a 0.100 mol L^{-1} acetic acid solution?

(A) Less than 23.4 mL
(B) 23.4 mL
(C) More than 23.4 mL
(D) Unable to calculate unless the concentration of the sodium hydroxide solution is also known

[BOS 2013 Q17]

Question 61
The following equation represents a chemical system in equilibrium:

$$OCl^-(aq) + H_2O(l) \rightleftharpoons HOCl(aq) + OH^-(aq)$$

Which of the following is an acid/base conjugate pair?

(A) $H_2O/HOCl$
(B) $HOCl/OH^-$
(C) $HOCl/OCl^-$
(D) OCl^-/H_2O

[BOSTES 2014 Q10]

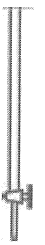
Question 62

Which type of glassware is used in a titration to deliver an accurate volume of a solution to a known volume of another solution?

(A) 

(B) 

(C) 

(D) 

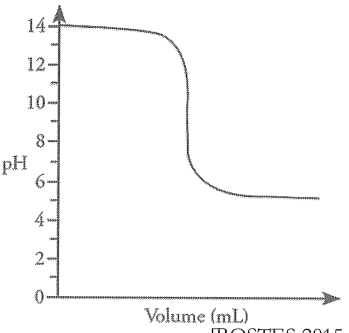
[BOSTES 2015 Q2]

Question 63

The graph shows the changes in pH during a titration.

Which pH range should an indicator have to be used in this titration?

(A) 3.1–4.4 (B) 5.0–8.0
(C) 6.0–7.6 (D) 8.3–10.0



[BOSTES 2015 Q14]

Question 64

Which of the following is the conjugate base of the $H_2PO_4^-$ ion?

(A) H_3PO_4 (B) H_3PO_3 (C) HPO_4^{2-} (D) HPO_3^{2-}

[BOSTES 2016 Q10]

Question 65

One litre of an aqueous solution is formed from mixing equal volumes of 0.2 mol L^{-1} hydrochloric acid and 0.2 mol L^{-1} sodium chloride.

How effective as a buffer is the aqueous solution formed?

(A) Ineffective, because HCl is a strong acid
(B) Effective, because Cl^- is the conjugate base of HCl
(C) Ineffective, because NaCl forms a neutral salt solution
(D) Effective, because the pH would change when a solution of NaOH is added

[NESA 2017 Q14]

Question 66

In an experiment, 30 mL of water is to be transferred into a conical flask.

Which piece of equipment would deliver the volume with the greatest accuracy?

(A) Burette (B) Beaker
(C) Test tube (D) Measuring cylinder

[NESA 2017 Q1]

Free-response questions

6.1 Properties of acids and bases

Question 1
Outline the characteristic properties of acids and bases in aqueous solution.

[4 marks]

Question 2
Complete the table below:

Compound name	*Formula*	*Compound name*	*Formula*
Potassium hydroxide		Ammonia	
Nitrous acid		Carbonic acid	
Sulfurous acid		Phosphoric acid	
Sulfuric acid		Barium hydroxide	
Hydrochloric acid		Sodium hydrogen carbonate	

[10 marks]

Question 3
An old remedy for heartburn was to drink a water mixed with bicarb soda (sodium hydrogen carbonate).

Write a net equation for this neutralisation reaction.

[2 marks]

Question 4
In coal-fired power stations, limestone slurry (calcium carbonate) is used to scrub acidic sulfur dioxide gas from effluent gases, as it is a pollutant.

Write a balanced equation to show this reaction and name the products.

[3 marks]

Question 5
Antacids products used for treating heartburn, caused by excessive acid (mainly hydrochloric acid) in the stomach, contain aluminium hydroxide and magnesium hydroxide.

Write balanced equations for the neutralisation reactions of the antacid.

[2 marks]

Question 6
The acid–base properties of oxides of elements depend on the position of the element in the periodic table.

Give examples to support this statement. Include acidic oxides, basic oxides and amphoteric oxides.

[4 marks]

Question 7
Effluents from electroplating contain sulfuric acid and is treated with lime, calcium oxide.

Write a complete and net equations for this reaction.

[2 marks]

Question 8

(a) Outline the experiment you have conducted to measure the enthalpy of neutralisation. [2 marks]

(b) Sketch an energy level diagram to show that the reaction was exothermic. [1 mark]

[Total = 3 marks]

Question 9

Some natural indicators (beetroot, blueberries, curry powder and red cabbage) were tested with a range of common solutions and the results are shown in the table below.

Solution	*Beetroot*	*Blueberries*	*Curry powder*	*Red cabbage*
Brick cleaner	Red	Red	Colourless	Orange
Vinegar	Red	Red/purple	Colourless	Pink
Rain water	Red	Purple	Colourless	Purple
Pure water	Red/purple	Green	Colourless	Blue
Baking soda	Purple	Green	Orange	Blue/green
Floor cleaner	Purple	Green	Red	Green
Oven cleaner	Purple	Green	Red	Green

Discuss the usefulness of each indicator regarding its ability to distinguish between the solutions used.

[3 marks]

Question 10

'The Brønsted–Lowry theory doesn't go against the Arrhenius theory in any way – it just adds to it.' https://www.chemguide.co.uk/physical/acidbaseeqia/theories.html

Explain this statement and include examples to support your answer.

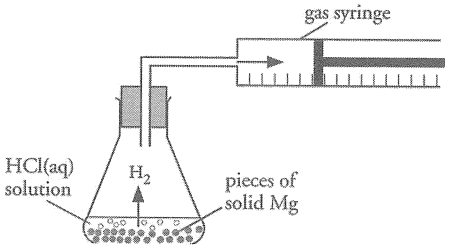
[4 marks]

Question 11

A student investigated how the volume hydrogen produced in the reaction between hydrochloric acid and magnesium depended on the mass of metal used.

For each mass of magnesium used the student measured the volume of hydrogen produced at 25°C, and 100 kPa. In each experiment 100 mL of 0.255 mol L^{-1} hydrochloric acid was used.

The equipment used is shown in the diagram below, and the student's results are in the following table.



Mass of Mg (g)	*Volume of H_2* (mL)	*Mass of Mg* (g)	*Volume of H_2* (mL)
0.105	107	0.285	291
0.135	120	0.335	316
0.190	194	0.350	316
0.235	240	0.395	316

(a) Using these results, plot a graph showing how the volume of hydrogen produced changed with increasing mass of magnesium. [3 marks]

(b) From the graph, what is the minimum mass of magnesium that produces the largest volume of hydrogen? [1 mark]

(c) Explain why the maximum volume of hydrogen produced is 316 mL? [2 marks]

(d) Calculate the volume of hydrogen gas expected to be produced at 25°C and 100 kPa by the reaction of 0.135 g of magnesium with the 100 mL of 0.255 mol L^{-1} hydrochloric acid. [2 marks]

[Total = 8 marks]

Question 12

Sodium ethanoate is used in the textile industry to neutralise sulfuric acid waste streams.

(a) Write an equation to describe the formation of sodium ethanoate from an acid–base reaction. Name the reactants. [3 marks]

(b) An acid–base reaction is known as neutralisation, yet the resulting salt solution is not always neutral. Explain the reason and include equations to support your answer. [3 marks]

(c) What is the pH of a 0.1 M sodium acetate solution? ($K_a = 1.86 \times 10^{-5}$) [1 mark]

[Total = 7 marks]

Question 13

Chemical spills are often potentially dangerous because of the hazardous or toxic nature of the chemical.

(a) Name one acid and one base produced in large quantities for industrial or domestic use. [2 marks]

(b) Spillages of acids and/or bases in any quantity can sometimes be dealt with using neutralisation reactions. Discuss how this process could be safely carried out and the potential difficulties to be overcome. [4 marks]

[Total = 6 marks]

Question 14

Investigations by various scientists over time have improved the accuracy and depth of knowledge about acids.

Analyse how this has led to the modern definition of an acid by considering the contributions of Lavoisier, Davy, Arrhenius, Brønsted and Lowry.

[5 marks]

Question 15

An indicator is placed in water. The resulting solution contains the green ion, Ind^-, and the red molecule, *HInd*. Explain why this solution can be used as an indicator. In your response, include a suitable equation that uses Ind^- and *HInd*.

[BOS 2013 Q25; 4 marks]

Question 16

(a) Outline a suitable method to prepare a natural indicator. [2 marks]

(b) How could a natural indicator be tested? [2 marks]

[BOSTES 2015 Q21; Total = 4 marks]

Question 17

(a) A solution of hydrochloric acid has a concentration of 0.350 mol L^{-1}. Calculate the pH of this solution. [1 mark]

(b) 50.0 mL of 0.025 mol L^{-1} barium hydroxide solution is added to 50.0 mL of 0.350 mol L^{-1} hydrochloric acid.

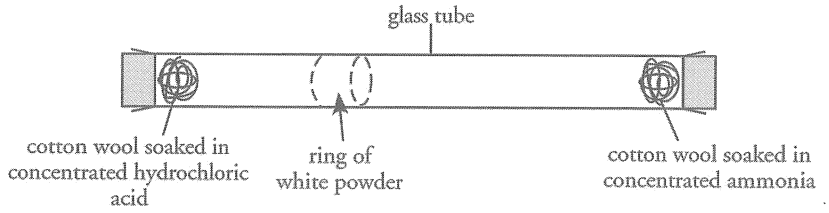
(i) Write a balanced equation for the reaction that occurs. [1 mark]

(ii) Calculate the pH of the resulting solution. [3 marks]

[Total = 5 marks]

Question 18

The equipment shown is set up. After some time, a ring of white powder is seen to form on the inside of the glass tube.

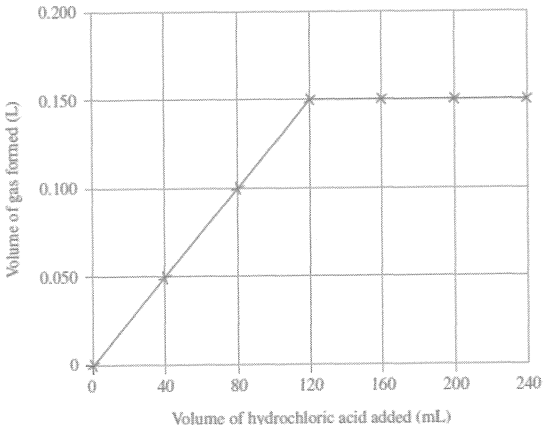


(a) Why would this NOT be an acid–base reaction according to Arrhenius? [1 mark]

(b) Explain why this would be considered a Brønsted–Lowry acid–base reaction. Include an equation in your answer. [2 marks]

[BOSTES 2015 Q28; Total = 3 marks]

Question 19
The volume of gas formed at 25°C and 100 kPa as hydrochloric acid was added to a pure sample of aluminium is shown in the graph.



Calculate the original mass of the aluminium sample used in the reaction.
[BOSTES 2016 Q27; 4 marks]

6.2 Using Brønsted–Lowry theory

Question 20
The water in Lake Barga, Queensland, is very acidic due to the presence of natural organic acids from plant material. The concentration of H^+ was measured at 25°C to be 7.1×10^{-5}.
Calculate the pH and pOH of the lake's water.
[2 marks]

Question 21
Write ionic equations for the following reactions:

(a) $2HCl(aq) + Na_2CO_3(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$ [1 mark]

(b) $Al_2O_3(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2O(l)$ [1 mark]
[Total = 2 marks]

Question 22
Using the hydrogen phosphate ion (HPO_4^{2-}), explain what is meant by the term *amphiprotic*. Give relevant equations to support your answer.
[3 marks]

Question 23
Identify the two acid–base pairs for the following reaction:
$HSO_4^-(aq) + PO_4^{3-} \rightarrow SO_4^{2-}(aq) + HPO_4^{2-}(aq)$
[2 marks]

Question 24
Write an equation for the hydrogen sulfate ion reacting with water as:
(a) a base **(b)** an acid.
[2 marks]

Question 25
The hydroxide concentration, at 25°C, in a potassium hydroxide solution was measured to be 0.0026 mol L^{-1}. What is the pH of the solution?

[1 mark]

Question 26
The soil in the south coast of Australia is rich in calcium carbonate. When the soil is moist, the pH is in the range of 7–8.2. The pH of a sample of wet soil was measured to be 8.14.

(a) What is the $[H^+]$ for this sample? [1 mark]

(b) Is the soil acidic or basic? [1 mark]

[Total = 2 marks]

Question 27
Beryllium hydroxide is amphiprotic. Briefly describe chemical tests that could be conducted to confirm this property.

[2 marks]

Question 28
The relative strengths of acids in water solution can be compared by measuring the pH of 0.1 mol L^{-1} solutions of the acids. Some data are given in the following table.

Acid	*pH of 0.1 mol L^{-1} solution of acids*
Hydrobromic acid, HBr	1.0
Hydrofluoric acid, HF	2.1
Formic acid, HCOOH	2.4
Hydrogen sulfide, H_2S	4.0

(a) Calculate the $H^+(aq)$ concentration of 0.1 mol L^{-1} formic acid solution. [1 mark]

(b) From the data in the table, predict which of the four acids is the weakest. Explain your answer. [3 marks]

[Total = 4 marks]

Question 29
Hydrogen sulfide is a highly poisonous gas and stringent precautions are required in its handling.

(a) Briefly explain why hydrogen sulfide is considered an acid according to the Brønsted–Lowry theory. [2 marks]

(b) Write a balanced equation for an acid–base reaction between hydrogen sulfide and water and indicate the conjugate acid–base pairs involved. [3 marks]

[Total = 5 marks]

Question 30
A sample of HCl has a pH of 1.5.

(a) Calculate $[H^+]$ in this solution. [1 mark]

(b) 10.0 mL of this solution is made up to 1.00 L with distilled water. Calculate the pH of the new solution. [1 mark]

[Total = 2 marks]

Question 31

(a) 0.01 mol L^{-1} solutions of sodium carbonate and ammonia were prepared and the pH of each of these solutions was measured. It was found that sodium carbonate had a higher pH.

Which is the stronger base? Explain your answer. [2 marks]

(b) If an aqueous solution of a base has a pH of 9, determine the hydroxide concentration of the solution. [1 mark]

(c) Write the conjugate base of the hydrogen carbonate ion. [1 mark]

[Total = 4 marks]

Question 32

To what volume must 30.0 mL of 0.520 mol L^{-1} sulfuric acid be diluted so that the new concentration is 0.100 mol L^{-1}?

[1 mark]

Question 33

A student has 200 mL of a solution of barium hydroxide. The pH of this solution is 13.

(a) What is the concentration of $OH^{-1}(aq)$ ions in this solution? [1 mark]

The student then adds 0.40 mol L^{-1} hydrochloric acid to neutralise the barium hydroxide solution.

(b) Write a balanced ionic equation for the reaction. [1 mark]

(c) What volume of the hydrochloric acid would be needed for complete neutralisation? [1 mark]

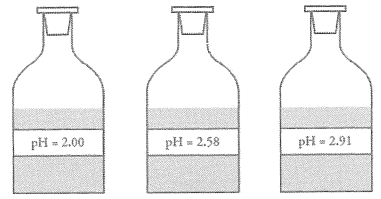
[Total = 3 marks]

Question 34

Write two equations showing the amphiprotic nature of the hydrogen carbonate ion. [2 marks]

Question 35

The diagram below shows three reagent bottles containing acids.



(a) 50.0 mL of 0.010 mol L^{-1} hydrochloric acid solution is added to 4.95 L of distilled water. Calculate the pH of the resulting solution. [1 mark]

(b) Fumaric acid is used as a food additive and methanoic acid is used as a preservative. Explain why these substances have these uses. [2 marks]

(c) The three acidic solutions shown above have the same concentration but different pH values. Explain how this can occur. [2 marks]

[Total = 5 marks]

Question 36

The pH of some 0.10 mol L^{-1} solutions are given in the table below.

Solution	*pH*
0.10 mol L^{-1} sodium hydrogen sulfate, $NaHSO_4$	1.57
0.10 mol L^{-1} sodium dihydrogen phosphate, NaH_2PO_4	4.1
0.10 mol L^{-1} disodium hydrogen phosphate, Na_2HPO_4	10.1

Use chemical equations to explain the pH of the three solutions in the above table.

[3 marks]

Question 37

The owner of a swimming pool decides that there are two choices for chlorinating a pool: either a solution of chlorine, Cl_2, or a solution of sodium hypochlorite, NaOCl, could be added. When these substances are added to water HOCl, which is partially responsible for killing bacteria, is produced.

(a) For each substance, write an equation for its reaction with water. [2 marks]

(b) For each substance, explain how the pH of a swimming pool will affected if it is added to the pool. [2 marks]

[Total = 4 marks]

Question 38

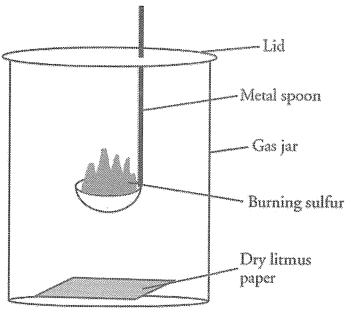
A solution was made by mixing 75.00 mL of 0.120 mol L^{-1} hydrochloric acid with 25.00 mL of 0.200 mol L^{-1} sodium hydroxide. What is the pH of the mixture?

[BOS 2012 Q28; 3 marks]

Question 39

An experiment was performed to model the formation of acid rain.

A sample of sulfur was burned on a metal spoon. While alight, it was placed in a gas jar with some dry litmus paper.



When a fine mist of water was sprayed into the jar, the litmus paper turned red.

Assess the suitability of this experiment as a model for the formation of acid rain.

[BOSTES 2014 Q29; 5 marks]

Question 40

Draw diagrams to illustrate the difference between strong, weak, concentrated and dilute acids and bases.

[10 marks]

6.3 Quantitative analysis

Question 41

20.00 mL of a solution of sodium hydrogen carbonate, $NaHCO_3$, was titrated with a 0.254 mol L^{-1} standard solution of sulfuric acid. The results from four titrations are shown in the table below. In each case, the same indicator colour was obtained at the endpoint.

Titration	*Volume of sulfuric acid used* (mL)
1	23.62
2	21.45
3	21.54
4	21.51

(a) Write a balanced chemical equation for the reaction between sulfuric acid and sodium hydrogen carbonate. [1 mark]

(b) Suggest a reason for the higher result in titration 1. [1 mark]

(c) Calculate the concentration of the sodium hydrogen carbonate solution. [3 marks]

[Total = 5 marks]

Question 42

(a) Potassium hydrogen phthalate, $KH(C_8H_4O_4)$, is a monoprotic acid that is used to prepare solutions of accurately known concentration. Briefly describe the procedure that would be used to prepare a standard solution of potassium hydrogen phthalate from the solid. [3 marks]

(b) Substances such as potassium hydrogen phthalate as called 'primary standards'. Give two properties of primary standards. [2 marks]

(c) Calculate the mass of potassium hydrogen phthalate required to make 250 mL of a 0.150 mol L^{-1} solution. [2 marks]

[Total = 7 marks]

Question 43

The manufacturer of antacid tablets claims they contain 99.9% magnesium carbonate ($MgCO_3$). A student used the following procedure to check this claim.

- A tablet was weighed and then placed in a conical flask. The mass of the tablet was 0.747 g.
- Using a pipette, the student added 20.00 mL of 0.996 mol L^{-1} hydrochloric acid to the tablet in the conical flask.
- When the reaction between the tablet and hydrochloric acid had stopped, the mixture was boiled gently for 10 minutes. 10 mL of water was added to the liquid in the conical flask.
- Phenolphthalein indicator was then added to the flask and the liquid was titrated with 0.110 mol L^{-1} sodium hydroxide solution to neutralise the excess hydrochloric acid.
- The volume of sodium hydroxide solution required to change the colour of the indicator was 22.39 mL.

(a) Write a balanced equation for the reaction between hydrochloric acid and the magnesium carbonate in the tablet. [1 mark]

(b) Suggest a reason for boiling the liquid in the conical flask for 10 minutes. [1 mark]

(c) Calculate the amount of hydrochloric acid, in moles, added to the tablet. [1 mark]

(d) Calculate the amount of hydrochloric acid, in moles, that remained in the flask after the reaction with the magnesium carbonate. [1 mark]

(e) Calculate the mass of magnesium carbonate in the antacid tablet. [2 marks]

(f) Calculate the percentage of magnesium carbonate in the antacid tablet and compare this value with the manufacturer's claim. [2 marks]

[Total = 8 marks]

Question 44

Anhydrous sodium carbonate may be used as a primary standard base in volumetric procedures.

In an experiment to determine the concentration of a hydrochloric acid solution, a standard solution of sodium carbonate was prepared by dissolving 2.73 g in water and making up the volume to 250 mL.

In a titration, it was found that 20.5 mL of the hydrochloric acid solution was required to react completely with exactly 25.0 mL of the sodium carbonate solution. Methyl orange was used as the indicator.

(a) Calculate the concentration of the hydrochloric acid. [1 mark]

(b) Draw a diagram of the apparatus used in the titration step only. Indicate in the diagram the location of the sodium carbonate, hydrochloric acid and the indicator solution. [4 marks]

(c) Describe the apparatus and procedure used to obtain exactly 25.0 mL of the standard base solution. [2 marks]

[Total = 7 marks]

Question 45

The concentration of hydrochloric acid is determined by titration against a standard base. The standard base solution is prepared by the following procedure:

- Weighing accurately an amount of the solid base on an analytical balance;
- Dissolving completely that amount in distilled water in a beaker;
- Transferring the solution quantitively to a 250 mL volumetric flask;
- Adding distilled water until the total volume of solution is 250 mL.

(a) Two bases are available, sodium hydroxide and sodium carbonate. Which one of the bases should be used? Explain your answer. [2 marks]

(b) How would you ensure that the transfer of solution from the beaker to the flask is quantitative? [2 marks]

(c) If it is necessary to rinse the volumetric flask, what would be used? [1 mark]

(d) What procedure must be followed to ensure the solution in the volumetric flask is of uniform concentration? [1 mark]

(e) Sketch a volumetric flask, showing its essential features. [1 mark]

[Total = 7 marks]

Question 46
A buffer solution was prepared by mixing:
$[CH_3COOH] = 0.090$ M and $[CH_3COONa] = 0.11$ M
Calculate the pH of this buffer solution at 25°C. K_a (CH_3COOH) = 1.8×10^{-5}.
[2 marks]

Question 47
Solution A consists of a 0.050 M aqueous solution of benzoic acid, C_6H_5COOH, which is a weak acid, at 25°C. Calculate the pH of Solution A. The pK_a of benzoic acid is 4.20.
[2 marks]

Question 48
The pK_a of formic acid, HCO_2H, is 3.77.

(a) What is the pH of a 0.20 M solution of formic acid? [2 marks]

(b) Write the equation for the reaction of formic acid with solid sodium hydroxide.
[1 mark]
[Total = 3 marks]

Question 49
Calculate the pH of a 0.001M solution of calcium hydroxide.
[1 mark]

Question 50
Using a specific example, describe why a buffer is important in a natural system.
Give all relevant equations to the equilibrium reactions of the buffer.
[3 marks]

Question 51
Give one example of acid/base analysis techniques used by indigenous Australian and one example where it is used in industry and briefly explain the techniques employed.
[4 marks]

Question 52
A chemist analysed aspirin tablets for quality control. The initial step of the analysis was the standardisation of a NaOH solution. Three 25.00 mL samples of a 0.1034 mol L^{-1} solution of standardised HCl were titrated with the NaOH solution. The average volume required for neutralisation was 25.75 mL.

(a) Calculate the molarity of the NaOH solution. [2 marks]

Three flasks were prepared each containing a mixture of 25 mL of water and 10 mL of ethanol. An aspirin tablet was dissolved in each flask. The aspirin in each solution was titrated with the standardised NaOH solution according to the following equation.

$$C_9H_8O_4(aq) + NaOH(aq) \rightarrow C_9H_7O_4Na(aq) + H_2O(l)$$

The titration results shown below were obtained.

Tablet	*Volume (mL)*
1	16.60
2	16.50
3	16.55

(b) (i) Calculate the average mass (mg) of aspirin per tablet. [3 marks]

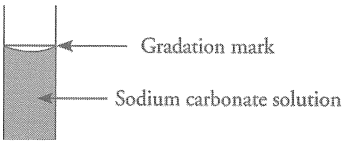
(ii) Why was it necessary to include the ethanol in the mixture? [1 mark]

[BOS 2012 Q30; Total = 6 marks]

Question 53

A student attempted to determine the concentration of a hydrochloric acid solution. The steps shown below were performed.

Step 1: A conical flask was rinsed with water.
Step 2: A 25.0 mL pipette was rinsed with water.
Step 3: The student filled the pipette with a standard sodium carbonate solution to the level shown in the diagram.



Step 4: The standard sodium carbonate solution in the pipette was transferred to the conical flask. The student ensured that all of the sodium carbonate solution was transferred to the conical flask by blowing through the pipette. Three drops of an appropriate indicator were added to the conical flask.
Step 5: A burette was rinsed with the hydrochloric acid solution and then filled with the acid. The student then carried out a titration to determine the concentration of the hydrochloric acid solution.

In steps 2, 3 and 4 above, the student did not follow acceptable procedures.

(a) Identify the mistake the student made in step 4 and propose a change that would improve the validity of the result. [2 marks]

(b) Explain the effect of the mistakes made in steps 2 and 3 on the calculation of the concentration of the hydrochloric acid solution. [3 marks]

[BOS 2013 Q28; Total = 5 marks]

Question 54

A batch of dry ice (solid CO_2) was contaminated during manufacture. To determine its purity, the following steps were carried out.

Step 1: A 0.616 gram sample of the contaminated dry ice was placed in a clean, dry flask.

Step 2: 50.00 mL of 1.00 mol L^{-1} sodium hydroxide was added to the flask. The sodium hydroxide was in excess.

Step 3: The flask was sealed to prevent loss of carbon dioxide gas and the reaction allowed to reach completion, according to this equation:

$$2NaOH(aq) + CO_2(s) \rightarrow Na_2CO_3(aq) + H_2O(l)$$

Step 4: The remaining sodium hydroxide was titrated against a 1.00 mol L^{-1} solution of hydrochloric acid. The average volume of HCl used was 27.60 mL.

(a) Calculate the number of moles of NaOH added in Step 2. [1 mark]

(b) Calculate the percentage purity by mass of this batch of dry ice. [4 marks]

[BOSTES 2014 Q30; Total = 5 marks]

Question 55

A sodium hydroxide solution was titrated against citric acid ($C_6H_8O_7$) which is triprotic.

(a) Draw the structural formula of citric acid (2-hydroxypropane-1,2,3-tricarboxylic acid). [1 mark]

(b) How could a computer-based technology be used to identify the equivalence point of this titration? [2 marks]

(c) The sodium hydroxide solution was titrated against 25.0 mL samples of 0.100 mol L^{-1} citric acid. The average volume of sodium hydroxide used was 41.50 mL.

Calculate the concentration of the sodium hydroxide solution. [4 marks]

[BOSTES 2015 Q26; Total = 7 marks]

Question 56

(a) Explain why the salt, sodium acetate, forms a basic solution when dissolved in water. Include an equation in your answer. [2 marks]

(b) A solution is prepared by using equal volumes and concentrations of acetic acid and sodium acetate. Explain how the pH of this solution would be affected by the addition of a small amount of sodium hydroxide solution. Include an equation in your answer. [3 marks]

[BOSTES 2015 Q24; Total = 5 marks]

Question 57

A solution of hydrochloric acid was standardised by titration against a sodium carbonate solution using the following procedure.

- All glassware was rinsed correctly to remove possible contaminants.
- Hydrochloric acid was placed in the burette.
- 25.0 mL of sodium carbonate solution was pipetted into the conical flask.

The titration was performed, and the hydrochloric acid was found to be 0.200 mol L^{-1}.

(a) Identify the substance used to rinse the conical flask and justify your answer.

[2 marks]

(b) Seashells contain a mixture of carbonate compounds. The standardised hydrochloric acid was used to determine the percentage by mass of carbonate in a seashell using the following procedure.

- A 0.145 g sample of the seashell was placed in a conical flask.
- 50.0 mL of the standardised hydrochloric acid was added to the conical flask.
- At the completion of the reaction, the mixture in the conical flask was titrated with 0.250 mol L^{-1} sodium hydroxide. The volume of sodium hydroxide used in the titration was 29.5 mL.

Calculate the percentage by mass of carbonate in the sample of the seashell.

[4 marks]

[BOSTES 2016 Q29; Total = 6 marks]

Question 58

A solution of sodium hydroxide was titrated against a standardised solution of acetic acid which had a concentration of 0.5020 mol L^{-1}.

(a) The endpoint was reached when 19.30 mL of sodium hydroxide solution had been added to 25.00 mL of the acetic acid solution.
Calculate the concentration of the sodium hydroxide solution. [3 marks]

(b) Explain why the pH of the resulting salt solution was not 7. Include a relevant chemical equation in your answer. [2 marks]

[NESA 2017 Q24; Total = 5 marks]

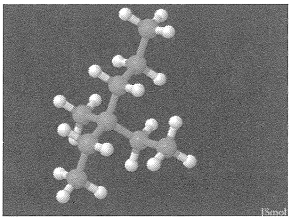
Chapter 3
Module 7: Organic Chemistry
Multiple-choice questions

7.1 Nomenclature

Question 1
The correct name for $CH_3CH{=}CHCH_2CH_3$ is:

(A) pent-1-ene. **(B)** pent-2-ene. **(C)** pent-3-ene. **(D)** pent-2,3-ene.

Question 2
What is the correct IUPAC systematic name for the compound shown on the right?



(A) 3,3-dimethylhexane
(B) 3,3-diethylhexane
(C) 4,4-ethyl-methylhexane
(D) 3-ethyl-3-methylhexane

Question 3
How many structural isomers, each containing one double bond, have the molecular formula C_5H_{10}?

(A) 3 **(B)** 4 **(C)** 5 **(D)** 6

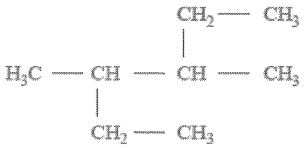
Question 4
Which of the following hydrocarbons does not belong to the same homologous series as the others?

(A) CH_4 **(B)** C_6H_{12} **(C)** C_4H_{10} **(D)** C_7H_{16}

Question 5
In a homologous series:

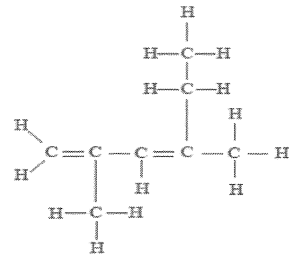
(A) with the addition of a carbon atom, the molecular mass increases by 14.
(B) all compounds have the same empirical formula.
(C) with the addition of a carbon atom, three hydrogen atoms are added.
(D) all alkanes have the formula C_nH_{2n}.

Question 6
What is the systematic name of this hydrocarbon?



(A) 3,4-dimethylhexane
(B) 2,3-diethylbutane
(C) 2, 3-ethyl-methylpentane
(D) 2,4-dimethylheptane

Question 7
The structural formula on the right represents a compound.
The IUPAC systematic name for this compound is



(A) 3,5-dimethyl-3,5-hexene.
(B) 2,4-dimethyl-1,3-hexadiene.
(C) 2-methyl-4-ethyl-1,3-pentadiene.
(D) 2-ethyl-4-methyl-2,4-pentadiene.

Question 8
Which of the following pairs of substances are NOT isomers?

(A) 3-methylpentane and hexane
(B) 2-methylpropene and but-2ene
(C) 3-methylhexane and 2,2,3-trimethylbutane
(D) Butanoic acid and 2,3-butanediol

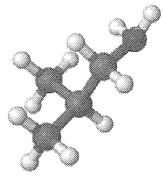
Question 9
Which of the following compounds has an isomer?

(A) CH_3CH_3
(B) $CH_2{=}CH_2$
(C) $CH_3CH_2CH_3$
(D) $CHCl{=}CHCH_3$

Question 10
Which of the following hydrocarbons could be an alkyne?

(A) C_5H_{10} **(B)** C_4H_8 **(C)** C_7H_{14} **(D)** C_8H_{14}

Question 11
Below is a model of an amine compound.

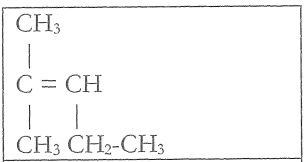


The name of the amine is:
(A) 3-butylamine
(B) 2-methylpropan-1-amine
(C) 2-methylpropan-3-amine
(D) 2,2-dimethylethan-1-amine

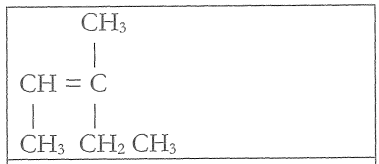
Question 12

Which of the following hydrocarbons is an isomer of 2-methylpent-2-ene?

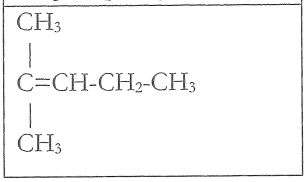
(A)



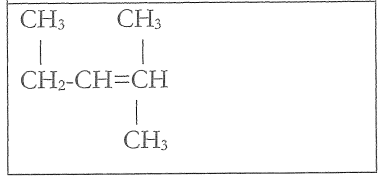
(B)



(C)



(D)



Question 13

Which of the following alcohols have been classified correctly?

	Names of alcohols and their classification		
	Primary, 1°	**Secondary, 2°**	**Tertiary, 3°**
(A)	Propan-2-ol	Butan-2-ol	Pentan-3-ol
(B)	Butan-2-ol	2-methylpropan-1-ol	2-methylpropan-2-ol
(C)	2,2-dimethylpropan-1-ol	Butane-1,4-diol	Ethanol
(D)	Propan-1-ol	Pent-3-ol	2-methylpropan-2-ol

Question 14

Which of the following hydrocarbons have the molecular formula $C_5H_{10}O$?

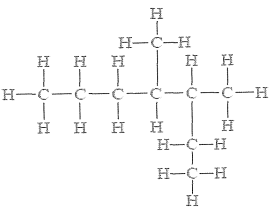
I. Pentanoic acid
II. Pentan-3-ol
III. Pentanal
IV. Pentan-3-one

(A) I, II and III
(B) I, III and IV
(C) IV only
(D) III and IV

Question 15

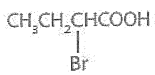
What is the correct IUPAC systematic name for the compound shown below?

(A) 2-ethyl-3-methylhexane
(B) 4-methyl-5-ethylhexane
(C) 4,5-dimethylheptane
(D) 3,4-dimethylheptane



Question 16

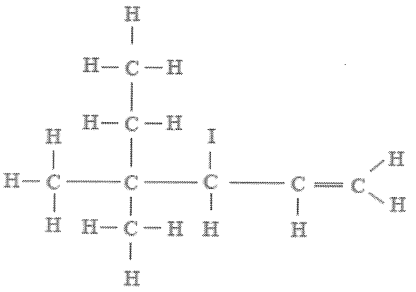
IUPAC names for the following compounds are:

I	$ClCH_2CH_2CH_2COOH$	II	

(A) I. 3-chloroproponoic acid and II. 2-bromoproponoic acid
(B) I. 1-chlorobutanoic acid and II. 2-bromobutanoic acid
(C) I. 4-chlorobutanoic acid and II. 2-bromobutanoic acid
(D) I. 4-chlorobutanal and II. 3-bromobutanal

Question 17

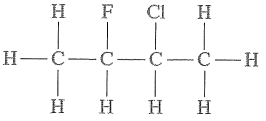
The IUPAC systematic name for the compound whose structure is given here is:



(A) 3-iodo-4,4-dimethyl-1-hexene.
(B) 2-ethyl-3-iodo-2-methyl-4-pentene.
(C) 4-dimethyl-3-iodo-1-hexene.
(D) 4-ethyl-3-iodo-4-methyl-1-pentene.

Question 18

What is the correct IUPAC name for the following compound?

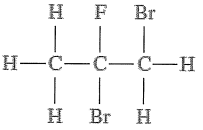


(A) 2-fluoro-3-chlorobutane
(B) 2-chloro-3-fluorobutane
(C) 3-fluoro-2-chlorobutane
(D) 3-chloro-2-fluorobutane

[BOS 2012 Q12]

Question 19

What is the IUPAC name of the following compound?

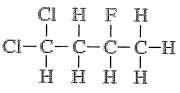
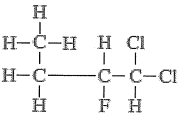
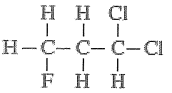
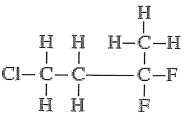


(A) 1,2-dibromo-2-fluoropropane
(B) 2,3-dibromo-2-fluoropropane
(C) 2-fluoro-2,3-dibromopropane
(D) 2-fluoro-1,2-dibromopropane

[BOSTES 2014 Q2]

Question 20

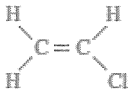
Four compounds, W, X, Y and Z, are represented below. Which of the following is a pair of isomers?

 Compound W	 Compound X	 Compound Y	 Compound Z

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

[BOSTES 2014 Q9]

Question 21
What is the name of this compound?



(A) Styrene **(B)** Ethylene
(C) Chloroethane **(D)** Vinyl chloride

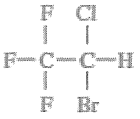
[BOSTES 2016 Q1]

Question 22
What is the molecular formula of pentanoic acid?

(A) C_5H_9O **(B)** $C_5H_{10}O$ **(C)** $C_5H_{10}O_2$ **(D)** $C_5H_{11}O_2$

[BOSTES 2016 Q3]

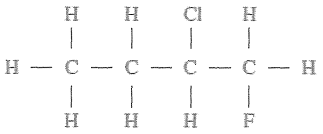
Question 23
What is the IUPAC name of the following compound?



(A) 1-bromo-1-chloro-2,2,2-trifluoroethane
(B) 1-chloro-1-bromo-2,2,2-trifluoroethane
(C) 2-chloro-2-bromo-1,1,1-trifluoroethane
(D) 2-bromo-2-chloro-1,1,1-trifluoroethane

[BOSTES 2016 Q11]

Question 24
What is the name of this compound?



(A) 2-chloro-1-fluorobutane
(B) 3-chloro-4-fluorobutane
(C) 1-fluoro-2-chlorobutane
(D) 4-fluoro-3-chlorobutane

[NESA 2017 Q3]

7.2 Hydrocarbons

Question 25
Name the following type of reaction.

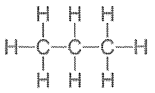
$$2Cl_2(g) + CH_4(g) \rightarrow 2HCl(g) + CH_2Cl_2(l)$$

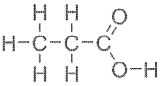
(A) Addition **(B)** Substitution
(C) Neutralisation **(D)** Displacement

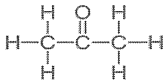
Question 26
Which of the following compounds would have the highest boiling point?

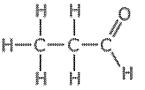
(A) $CH_3CH_2CH_2CH_3$ **(B)** CH_3NH_2
(C) CH_3OH **(D)** CH_2F_2

Question 27
The formula for hydrocarbon X is C_3H_8
The structural formula for hydrocarbon X is:

(A) 

(B) 

(C) 

(D) 

Question 28
Which of these hydrocarbons belongs to the same group as hydrocarbon X in Q27?

(A) C_4H_8 **(B)** C_5H_{10} **(C)** C_6H_{10} **(D)** C_7H_{16}

Question 29
Which of the following hydrocarbons has a higher boiling point than pentane?

I. pent-1-ene
II. hex-1-ene
III. pent-2-yne
IV. 2-methylbutane

(A) II only **(B)** IV only **(C)** I only **(D)** II and III

Question 30
The following table contains information about three experiments. In each experiment 0.1 mol of a hydrocarbon was burned completely and all the energy released was used to heat 250 mL of water which was initially at 20°C.

Experiment	*Hydrocarbon*	*Molar heat of combustion* (kJ mol^{-1})
I	Methane	–889
II	Methanol	–725
III	Butane	–2874

In which experiment(s) will the water be heated to its boiling temperature?

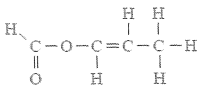
(A) III only **(B)** I and III **(C)** II and III **(D)** I, II and III

Question 31
A student was given the task of identifying a liquid organic compound that contains only carbon, hydrogen and oxygen. The following tests were carried out.

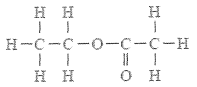
	Procedure	*Result*
Test 1	Some brown $Br_2(aq)$ was added to a sample of the compound.	A reaction occurred and a colourless product formed.
Test 2	Some $Na_2CO_3(s)$ was added to a sample of the compound	A reaction occurred and a colourless gas was evolved.

Based on the test results above, the compound could be:

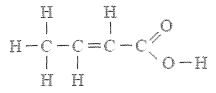
(A)



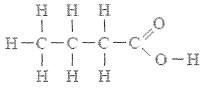
(B)



(C)



(D)



Question 32
Which of the following hydrocarbons is infinitely miscible in water?

(A) Butan-2-ol **(B)** Ethanol **(C)** Ethylene **(D)** Octane

Question 33
The approximate H–C–H bond angle in methane is

(A) 101.4° **(B)** 109.5° **(C)** 117.3 **(D)** 180°

Question 34
The approximate H–C–C bond angle in but-2-yne is

(A) 101.4° **(B)** 109.5° **(C)** 117.3 **(D)** 180°

Question 35
LPG is a very important automotive fuel. A tank vehicle must have design approval from the EPA before it can be licensed to carry LPG.
The reason/s for this design approval requirement is due to:

(A) ensure the vehicle is fit for purpose.
(B) minimise accidents and spills.
(C) protect human health and the environment.
(D) All of the above.

Question 36
Homologous series of organic compounds share common characteristics; including:

(A) the intermolecular forces in the series are the same.
(B) similar chemical properties.
(C) contain the same functional group.
(D) all of the above.

Question 37
Low boiling point liquid hydrocarbons are often classified as being volatile. This means that:

(A) they can ignite, even without an ignition source.
(B) they can easily change to a gas at normal temperature.
(C) their products of combustion are toxic.
(D) they all give out the same amount of energy when combusted.

Question 38
Safety procedures for the safe handling of organic products should include:

(A) wearing full breathing apparatus.
(B) have a safety plan in case of any mishap.
(C) hosing any spilt product to sewage.
(D) working only in cool conditions to ensure low flammability limits.

7.3 Products of reactions involving hydrocarbons

Question 39
Which compound can form when bromine water reacts with but-2-ene?

(A) 1-bromobutane
(B) 2-bromobutane
(C) 1,1-dibromobutane
(D) 2,3-dibromobutane

Question 40
An alkene undergoes an addition reaction with HCl. Only one product is formed. The alkene could be

(A) $CH_3CH{=}CHCH_3$.
(B) $CH_3CH_2CH{=}CH_2$.
(C) $(CH_3)_2C{=}CH_2$.
(D) $CH_3CH{=}CH_2$.

Question 41
How many isomers can be formed by the halogenation of $CH_3CH_2CH_2CH_3$ with Cl_2 in the presence of light?

(A) 2 **(B)** 4 **(C)** 5 **(D)** 6

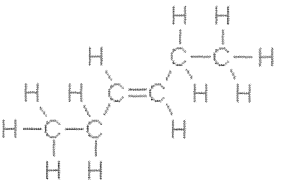
Question 42
A student performs two tests on an organic compound. In the first test, 2 mol of the compound was completely reacted with oxygen and 6 mol of carbon dioxide were produced. In the second test, a few drops of bromine water were added to the compound. The compound did **not** react rapidly with bromine. The formula of the compound is likely to be:

(A) C_2H_4 **(B)** C_2H_6 **(C)** C_3H_8 **(D)** C_6H_{14}

Question 43

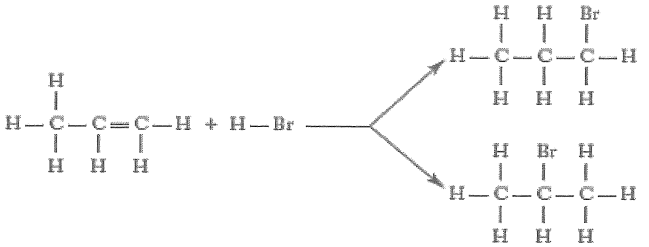
Name the compound formed when the hydrocarbon below reacts rapidly with bromine water.

(A) 1,2-dibromo-1,2-diethylethane
(B) 3,4-dibromohexane
(C) 3-bromohexane
(D) 3,4-dibromo-3-hexene



Question 44

When propene undergoes an addition reaction with hydrogen bromide, two products are formed.



Which of the following alkenes will also produce only two products when it undergoes an addition reaction?

(A) Ethene
(B) But-1-ene
(C) But-2-ene
(D) Hex-3-ene

Question 45

Hydrocarbon X, when reacted with concentrated sulfuric acid, produces a compound that decolourises bromine water. What is the formula of hydrocarbon X?

(A) C_6H_{12} **(B)** C_6H_{14} **(C)** $C_6H_{11}OH$ **(D)** $C_5H_{11}COOH$

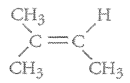
Question 46

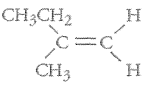
Under certain condition, when chlorine reacts with methane, $HCl(g)$ is produces. This reaction is classified as a/an:

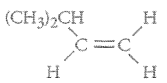
(A) addition.
(B) substitution.
(C) displacement.
(D) neutralisation.

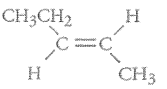
Question 47

An alkene has the molecular formula C_5H_{10}. When it is reacted with hydrogen in the presence of a catalyst, 2-methylbutane is formed. Which one of the following could **not** be the structure of the alkene?

(A) 

(B) 

(C) 

(D) 

Question 48
Which of the following hydrocarbons would change blue litmus red and liberate gas when added to a carbonate?

(A) ethanol **(B)** hexane **(C)** acetic acid **(D)** cyclohexane

Question 49
Hydration of an alkyne with suitable catalyst will produce:

(A) an alcohol, which rapidly becomes a ketone.
(B) an aldehyde.
(C) a polymer.
(D) a stable alcohol.

Question 50
Which row of the table correctly matches the reactant and the product of an addition reaction?

	Reactant	*Product*
(A)	$CH_3-CH_2-CH_2-CH_2-OH$	$CH_3-CH_2-CH=CH_2$
(B)	$CH_3-CH_2-CH_2-\underset{\displaystyle OH}{\underset{\vert}{CH}}-CH_3$	$CH_3-CH_2-CH=CH-CH_3$
(C)	$CH_3-CH=CH-CH_2-CH_3$	$CH_3-CH_2-\underset{\displaystyle Cl}{\underset{\vert}{CH}}-CH_2-CH_3$
(D)	$CH_3-C(=O)-OH$	$CH_3-C(=O)-O-CH_3$

[BOSTES 2014 Q5]

Question 51
The table lists some properties of the straight-chained carbon compounds W, X, Y and Z. Which row of the following table best identifies the compounds W, X, Y and Z?

Compound	*Reactivity in bromine water*	*Solubility in water*
W	Rapidly decolourises	Insoluble
X	Unreactive	Insoluble
Y	Unreactive	Soluble
Z	Unreactive	Partly soluble

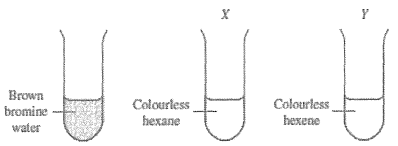
	W	*X*	*Y*	*Z*
(A)	C_3H_6	C_3H_8	CH_3OH	C_4H_9OH
(B)	C_3H_8	C_3H_6	CH_3OH	C_4H_9OH
(C)	C_3H_6	C_3H_8	C_4H_9OH	CH_3OH
(D)	C_3H_8	C_3H_6	C_4H_9OH	CH_3OH

[BOSTES 2016 Q15]

Question 52
The halogenation of a 2-methyl-2-butene with iodine will produce:

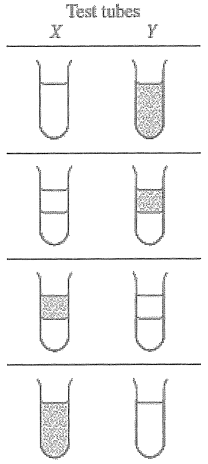
(A) 1,2-iodo-2 methylbutane
(B) 2,3-diiodo-2-methylbutane
(C) 2,3-iodo-2-methylbutane
(D) 2,3-diiodopentane

Question 53



Three test tubes were set up as shown.
Bromine water was added to X and Y in the absence of UV light.

Which of the following best represents the changes in test tubes X and Y?

(A)


(B)

(C)

(D)

[NESA 2017 Q7]

7.4 Alcohols

Question 54
Both ethanol, C_2H_5OH, and methanol, CH_3OH, have been suggested as alternative fuels for transport vehicles. The equations describing the complete combustion of ethanol and methanol are

$$C_2H_5OH(g) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l); \qquad \Delta H = -1368 \text{ kJ mol}^{-1}$$

$$CH_3OH(g) + 3/2O_2(g) \rightarrow CO_2(g) + 2H_2O(l); \qquad \Delta H = -726 \text{ kJ mol}^{-1}$$

Separate experiments are conducted in which 1 mol of ethanol and 2 mol of methanol undergo complete combustion. In these experiments:

(A) the combustion of methanol produces more carbon dioxide.
(B) more heat energy is released from the combustion of ethanol.
(C) more water is formed in the combustion of ethanol.
(D) the two experiments consume the same amount of oxygen.

Question 55

Which one of the following reactions involving ethanol is a dehydration reaction?

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

(B) $C_2H_5OH(l) + 5O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

(C) $C_2H_5OH(g) \rightarrow C_2H_4(g) + H_2O(g)$

(D) $C_2H_5OH(g) + O_2(g) \rightarrow 2CH_3COOH(g) + H_2O(g)$

Question 56

Many compounds can be used as fuels. The heat of combustion, in kJ g^{-1}, for four compounds are given in the table below.

Fuel	*Heat of combustion* (kJ g^{-1})
Ethanol	29.7
Petrol (octane)	47.9
Butane	49.5
Propane	50.3

Identify the fuel whose heat of combustion is 2876 kJ mol^{-1}.

(A) Ethanol **(B)** Petrol **(C)** Butane **(D)** Propane

Question 57

The reversible reaction to form ethanol from ethylene is represented:

$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_6O(g)$; ΔH = -45 kJ/mol

Identify the INCORRECT statement.

(A) The highest yield of ethanol is achieved at low temperature.

(B) The dehydration of ethanol is an endothermic reaction.

(C) The highest yield of ethanol is achieved when excess $H_2O(g)$ is present in the reaction vessel.

(D) Sulfuric acid acts as a catalyst for both the backward and forward reactions.

Question 58

Using a suitable catalyst, ethanol can be dehydrated to produce ethylene. Similarly, ethylene will undergo an addition reaction to form ethanol. These reactions are shown in the equations below.

$$\text{ethanol} \xrightarrow{\text{catalyst I}} \text{ethylene}$$

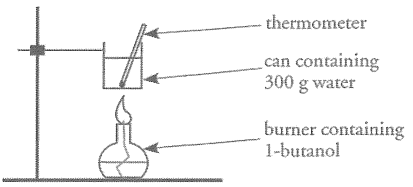
$$\text{ethylene} \xrightarrow{\text{catalyst II}} \text{ethanol}$$

The best examples of catalyst I and catalyst II are

	Catalyst I	*Catalyst II*
(A)	Dilute HCl	Concentrated HCl
(B)	Dilute H_2SO_4	Dilute H_2SO_4
(C)	Concentrated H_2SO_4	Dilute HCl
(D)	Concentrated H_2SO_4	Concentrated H_3PO_4

Question 59

To determine the heat of combustion of 1-butanol, a student used the apparatus shown.



Some of the results obtained by the student are given below.

Mass of water heated = 300 g
Mass of 1-butanol burnt = 1.50 g
Initial temperature of water = 20.7°C

The student calculates that the molar heat of combustion of 1-butanol is 1530 kJ mol^{-1}.

What was the final temperature of the water measured by the student?

(A) 24.7°C **(B)** 28.1°C **(C)** 37.2°C **(D)** 45.4°C

Question 60

Using a data table, a student finds that the heat of combustion of 1-propanol is 2021 kJ mol^{-1}. What value would the student calculate for the heat of combustion of 1-propanol in kJ g^{-1}?

(A) 23.0 **(B)** 27.3 **(C)** 33.7 **(D)** 43.9

Question 61

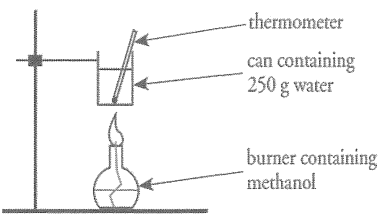
Which of the following is a balanced equation representing the fermentation of glucose?

(A) $C_6H_{12}O_6(aq) \rightarrow 2C_3H_6O_3(aq)$
(B) $C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$
(C) $C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$
(D) $C_6H_{12}O_6(aq) + 3O_2(g) \rightarrow C_2H_5OH(aq) + 4CO_2(g) + 3H_2O(l)$

[BOS 2012 Q5]

Question 62

To determine the heat of combustion of methanol, a student used the apparatus shown.



The following results were obtained.

Mass of burner at the start, g	125.58
Mass of burner at the end, g	124.38
Temperature of water at the start, °C	20.6
Temperature of water at the end, °C	36.6

From this data, the student calculates the molar heat of combustion of methanol to be:

(A) 446 kJ mol^{-1} **(B)** 535 kJ mol^{-1} **(C)** 574 kJ mol^{-1} **(D)** 2140 kJ mol^{-1}

Question 63

The heat of combustion of propan-1-ol is 2021 kJ mol^{-1}. Combustion takes place according to the equation

$$2C_3H_7OH(l) + 9O_2(g) \rightarrow 6CO_2(g) + 8H_2O(l)$$

What mass of water is formed when 1539 kJ of energy is released?

(A) 3.4 g **(B)** 14 g **(C)** 55 g **(D)** 144 g

[BOS 2012 Q17]

Question 64

Butan-1-ol burns in oxygen according to the following equation.

$$C_4H_9OH(l) + 6O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$$

How many moles of CO_2would form if two moles of butan-1-ol were burnt in excess oxygen?

(A) 2 **(B)** 4 **(C)** 8 **(D)** 10

[BOS 2013 Q4]

Question 65

An experimental car using ethanol as a fuel source requires 2270 kJ of energy for every kilometer travelled. Given that the heat of combustion of ethanol is 1360 kJ mol^{-1}, what is the maximum distance that the car can travel on 1.0 kilogram of ethanol?

(A) 1.7 km **(B)** 13 km **(C)** 28 km **(D)** 36 km

[BOSTES 2014 Q19]

Question 66

The table below shows the heat of combustion for four compounds.

Compound	*Heat of combustion* (kJ mol^{-1})
CO	233
CH_4	890
C_2H_2	1300
C_2H_6	1560

Which of these compounds would produce the greatest amount of energy if 1.00g of each is burnt?

(A) CO **(B)** CH_4 **(C)** C_2H_2 **(D)** C_2H_6

[BOS 2013 Q11]

Question 67

Which of the following statements best explains the solubility of ethanol in octane?

(A) Ethanol and octane are both non-polar.
(B) Ethanol forms hydrogen bonds with octane.
(C) Ethanol forms dispersion forces with octane.
(D) Ethanol forms dipole-dipole bonds with octane.

[BOSTES 2015 Q8]

Question 68

The table shows the heat of combustion of four straight chain alkanols.

Number of C atoms in straight chain alkanol	*Heat of combustion* (kJ mol^{-1})
1	726
3	2021
5	3331
7	4638

What is the mass of water that could be heated from 20°C to 45°C by the complete combustion of 1.0 g of heptan-1-ol?

(A) 0.032 kg **(B)** 0.044 kg **(C)** 0.36 kg **(D)** 0.38 kg

[BOSTES 2015 Q20]

Question 69

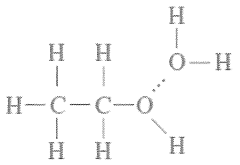
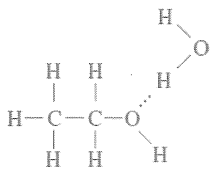
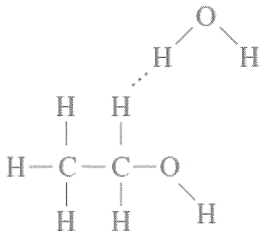
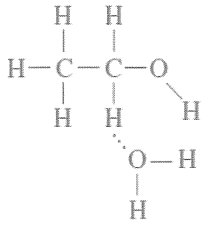
What volume of carbon dioxide will be produced if 10.3 g of glucose is fermented at 25°C and 100 kPa?

(A) 1.30 L **(B)** 1.42 L **(C)** 2.57 L **(D)** 2.83 L

[BOSTES 2015 Q17]

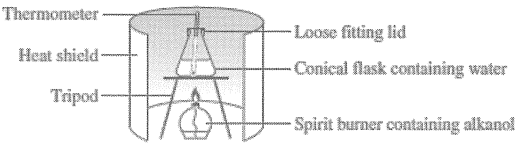
Question 70

Which of the following diagrams best represents the bonding between molecules of water and ethanol?

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

[BOSTES 2016 Q5]

Question 71
The following equipment was set up to measure the heat of combustion of an alkanol.



Black deposits were observed on the bottom of the conical flask and the heat of combustion measured was lower than the theoretical value. Which of the following equations could account for these observations?

(A) $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$
(B) $C_3H_8O(g) + 4O_2(g) \rightarrow CO_2(g) + CO(g) + 4H_2O(g)$
(C) $2C_4H_{10}O(g) + 3O_2(g) \rightarrow 8C(s) + 2H_2(g) + 8H_2O(g)$
(D) $2C_2H_6O(g) + 4O_2(g) \rightarrow 2CO_2(g) + 2C(s) + 6H_2O(g)$

[NESA 2017 Q9]

7.5 Reactions of organic acids and bases

Question 72
A hydrocarbon containing the elements carbon, hydrogen, and oxygen, has the following chemical properties:
i) neutral to litmus AND **ii)** when reacted with acidified $KMnO_4$, the new product turned litmus red. The hydrocarbon could be:

(A) propane. **(B)** 2-propanol. **(C)** 1-propanol. **(D)** propanoic acid.

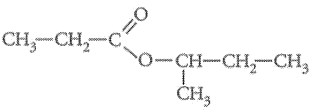
Question 73
Propan-1-ol can be reacted with propanoic acid to produce propyl propanoate. This type of reaction is best classified as:

(A) condensation. **(B)** hydrolysis. **(C)** acid/base. **(D)** oxidation.

Question 74
To produce ethyl pentanoate the compounds that should be reacted together are:

(A) ethanol and hexanoic acid. **(B)** ethanol and pentanoic acid.
(C) pentan-1-ol and ethanoic acid. **(D)** pentane and ethanoic acid.

Question 75
A compound has the structure shown at right.



Hydrolysis of this compound would produce:

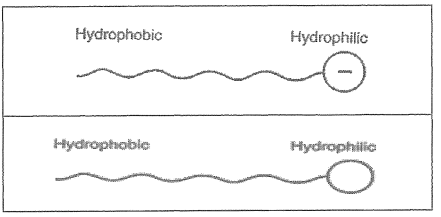
(A) butan-1-ol and propanoic acid.
(B) propan-1-ol and butanoic acid.
(C) propan-1-ol and 2-methylbutanoic acid.
(D) butan-2-ol and propanoic acid.

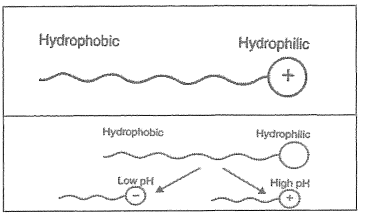
Question 76
Sodium lauryl sulfate is an inexpensive and effective foaming agent; with good cleaning properties. This surfactant ionises in water to carry a negative charge.

Which of the following best describes the class of surfactants it belongs to?

(A) Anionic **(B)** Cationic **(C)** Non-ionic **(D)** Amphoteric

Question 77
Which of the following molecules shows an anionic surfactant?

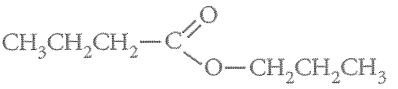
(A)


(B)


(C)

(D)

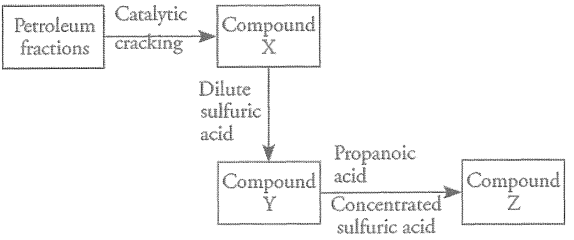
Question 78
What are the reactants used to make this compound?



(A) Butan-1-ol and butanoic acid
(B) Butan-1-ol and propanoic acid
(C) Propan-1-ol and butanoic acid
(D) Propan-1-ol and propanoic acid

[BOSTES 2015 Q9]

Question 79
Consider the following series of reactions.



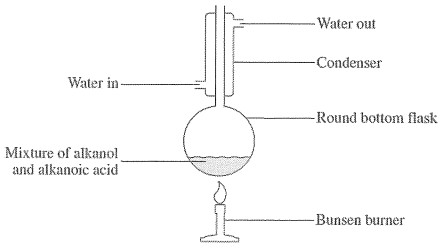
Which row in the table below correctly identifies compounds X, Y and Z?

	Compound X	*Compound Y*	*Compound Z*
(A)	Propene	Propan-1-ol	Ethyl propanoate
(B)	Propene	Ethanol	Propyl ethanoate
(C)	Ethanol	Ethylene	Propyl ethanoate
(D)	Ethylene	Ethanol	Ethyl propanoate

[BOS 2013 Q18]

Question 80

Esterification can be carried out in a school laboratory using the equipment shown.



How could the safety of the process shown be improved?

(A) Place a stopper on top of the condenser.
(B) Add concentrated sulfuric acid to the flask.
(C) Change the direction of water flow through the condenser.
(D) Replace the Bunsen burner with an electric heating mantle.

[NESA 2017 Q4]

7.6 Polymers

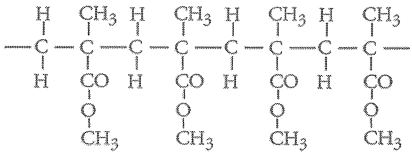
Question 81

Polypropene is made by the polymerisation of propene, $CH_3CH{=}CH_2$. One sample of this polymer is found to have a molar mass of approximately 1.05×10^5 g mol^{-1}.
The number of carbon atoms in one molecule of this polymer would be closest to

(A) 2500 **(B)** 2900 **(C)** 7500 **(D)** 8750

Question 82

Perspex is a hard, transparent plastic made by polymerisation of methyl methacrylate. A section of the polymer is shown.



What is the molecular formula of the monomer from which this polymer is made?

(A) $C_4H_6O_2$ **(B)** $C_5H_8O_2$ **(C)** C_2H_4 **(D)** $C_4H_8O_3$

Question 83
Ethylene may be converted into polyvinyl chloride (PVC) by a series of reactions as shown in the sequence below.

$$C_2H_4 + Cl_2 \xrightarrow{\text{step 1}} C_2H_4Cl_2 \xrightarrow{\text{step 2}} CH_2{=}CHCl \xrightarrow{\text{step 3}} PVC$$

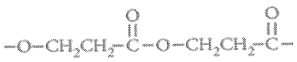
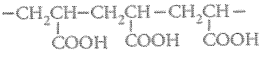
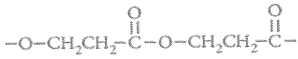
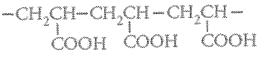
The steps in this process are best described as

	Step 1	Step 2	Step 3
(A)	Addition	Elimination	Polymerisation
(B)	Addition	Reduction	Condensation
(C)	Chlorination	Substitution	Polymerisation
(D)	Condensation	Elimination	Addition

Question 84
Ethylene is a very important industrial chemical. The most important industrial source of ethylene is:

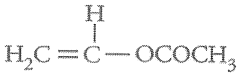
(A) ethanol. **(B)** crude oil. **(C)** chloroethane. **(D)** polyethylene.

Question 85
Acrylic acid, $CH_2{=}CHCOOH$, can be polymerised to make acrylic resins. The type of polymerisation it undergoes and a section of the resulting polymer would be:

	Type of reaction	*Section of polymer*
(A)	Condensation	
(B)	Condensation	
(C)	Addition	
(D)	Addition	

Question 86

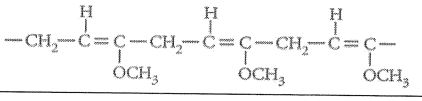
Polyvinyl acetate is a component of PVA glue. Polyvinyl acetate is made from vinyl acetate.



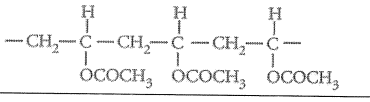
vinyl acetate

The structure of the polymer is most likely to be:

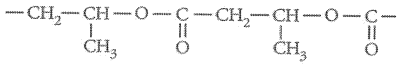
(A)



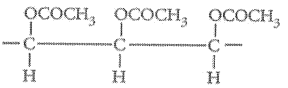
(B)



(C)



(D)



Question 87

Which of the following is the monomer used in the manufacture of the polymer, polyvinyl chloride (PVC)?

(A) Carbon tetrachloride
(B) Chloroform
(C) Chloroethane
(D) Chloroethene

Question 88

Lactic acid, $CH_3CH(OH)COOH$, can be polymerised to form polylactic acid (PLA). In one experiment the polymer chains had an average of 1000 monomer units per polymer chain. The approximate molar mass, in g mol^{-1}, of the polymer was

(A) 54 000. **(B)** 72 000. **(C)** 81 000. **(D)** 90 000.

Question 89

When a condensation polymer is formed, the other product is often:

(A) water. **(B)** hydrogen. **(C)** oxygen. **(D)** chlorine.

Question 90

Cellulose can be converted into ethylene by the following sequence of reactions.

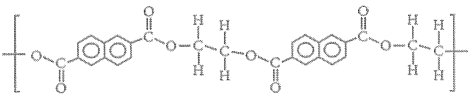
cellulose $\xrightarrow{\text{step 1}}$ glucose $\xrightarrow{\text{step 2}}$ ethanol $\xrightarrow{\text{step 3}}$ ethylene

The steps in this process are best described as

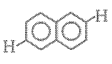
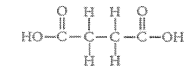
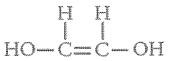
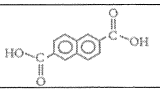
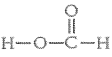
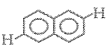
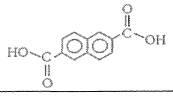
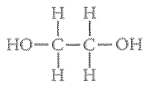
	Step 1	*Step 2*	*Step 3*
(A)	Hydrolysis	Oxidation	Dehydration
(B)	Polymerisation	Fermentation	Addition
(C)	Hydrolysis	Fermentation	Dehydration
(D)	Fermentation	Substitution	Condensation

Question 91

The polymer PEN (polyethylenenapthalate) is a condensation polymer used to make high quality bottles and high-performance sailcloth. A section of the structure of PEN is shown below.



The two monomers used to produce this polymer are

	Monomer 1	*Monomer 2*
(A)		
(B)		
(C)		
(D)		

Question 92

Synthetic biopolymers are likely to become more important in the future because when compared to current synthetic polymers:

(A) their physical properties make them more useful.
(B) they are more easily broken down into simpler molecules.
(C) their chemical properties make them more useful.
(D) they are cheaper to produce.

Question 93

C_2H_4 → X → polymer

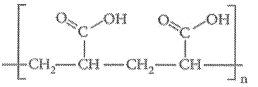
Which one of the following compounds is represented by X in the flow chart?

(A) Cellulose **(B)** Ethanol **(C)** Glucose **(D)** Styrene

[BOS 2012 Q2]

Question 94

A portion of a resin made from acrylic acid (CH_2=CHCOOH) is shown.



Which type of reaction results in the formation of this polymer?

(A) Addition **(B)** Condensation **(C)** Dehydration **(D)** Esterification

[BOS 2013 Q9]

Question 95

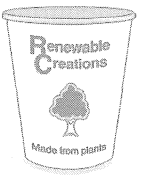
Which row of the table correctly matches the reactant and the product of an *addition reaction*?

	Reactant	*Product*
(A)	CH_3–CH_2–CH_2–CH_2–OH	CH_3–CH_2–CH=CH_2
(B)	CH_3–CH_2–CH_2–CH(OH)–CH_3	CH_3–CH_2–CH=CH–CH_3
(C)	CH_3–CH=CH–CH_2–CH_3	CH_3–CH_2–CH(Cl)–CH_2–CH_3
(D)	CH_3–C(=O)–OH	CH_3–C(=O)–O–CH_3

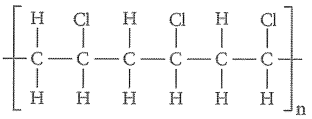
[BOSTES 2014 Q5]

Question 96

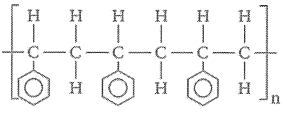
What is the structure of the polymer most likely to have been used in the manufacture of the cup shown?



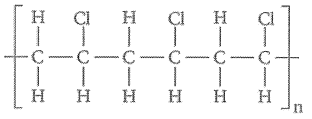
(A)



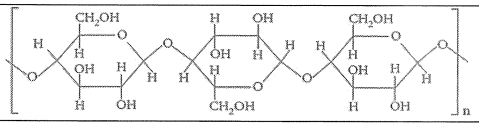
(B)



(C)



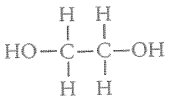
(D)

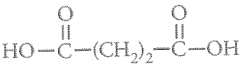


[BOS 2013 Q13]

Question 97

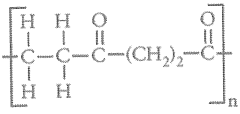
Two monomers are shown.



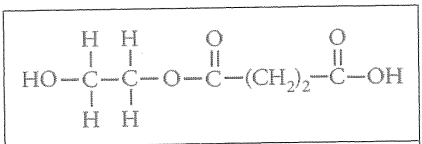


Which of the following shows a condensation polymer that could be formed from the monomers?

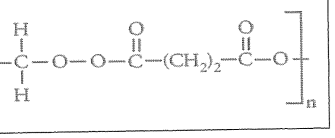
(A)



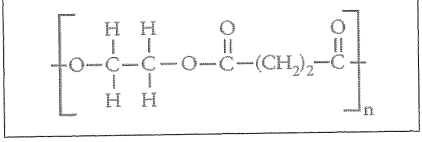
(B)



(C)



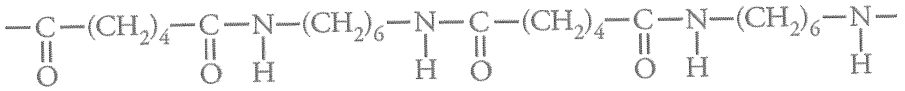
(D)



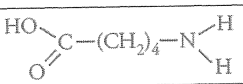
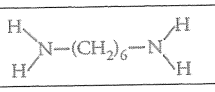
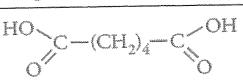
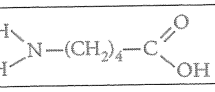
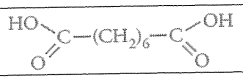
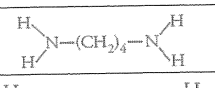
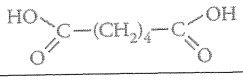
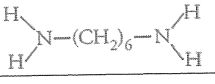
[BOSTES 2015 Q11]

Question 98

Below is a representation of a segment of the polymer nylon 6,6.



Which of the following represents the two monomers that are used to produce nylon 6,6?

	Monomer 1	*Monomer 2*
(A)		
(B)		
(C)		
(D)		

[BOSTES 2014 Q18]

Question 99

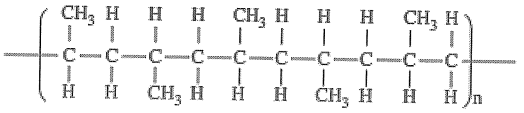
Which row of the table correctly identifies an application of polystyrene and the reason for its suitability for that application?

	Application	*Reason for suitability*
(A)	Shopping bags	Rigidity
(B)	Shopping bags	Flexibility
(C)	Scewdriver handle	Rigidity
(D)	Screwdriver handle	Flexibility

[BOSTES 2016 Q4]

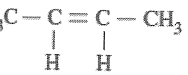
Question 100

A polymer has the following structure.

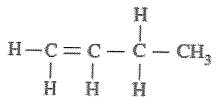


Which of the following represents the monomer from which this polymer can be produced?

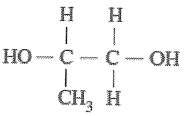
(A)



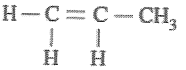
(B)



(C)



(D)

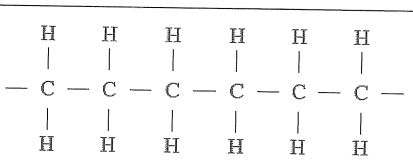


[BOSTES 2016 Q17]

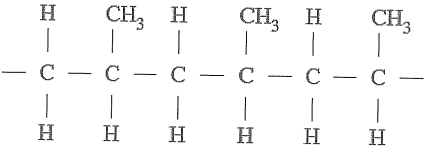
Question 101

What is the product when propene undergoes addition polymerisation?

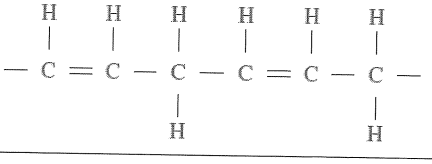
(A)



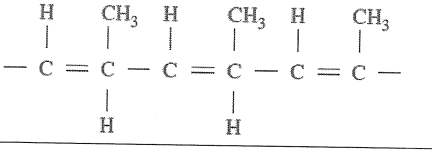
(B)



(C)



(D)



[NESA 2017 Q12]

Free-response questions

7.1 Nomenclature

Question 1
Draw structural formulae for a compound of molecular formula C_3H_7NO that contains an aldehyde and a primary amine.

[1 mark]

Question 2
A sample of standard grade petrol was found to have the components, as shown in the table below.

Name	*Formula*
Butane	C_4H_{10}
Hexane	C_6H_{14}
Benzene	C_6H_6
Methylhexane	C_7H_{16}
Trimethylpentane	C_8H_{18}
Methylheptane	C_8H_{18}

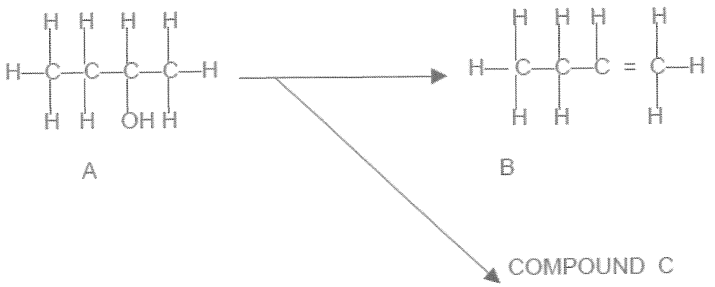
(a) Two of the identified compounds are isomers. Name the two compounds and explain your choice. [2 marks]

(b) One of the above compounds is NOT an alkane. Identify this compound and give a reason for your choice. [2 marks]

(c) When these compounds burn in an engine, the products are carbon dioxide and water. Write a balanced equation for the combustion of methylhexane. [2 marks]

[Total = 6 marks]

Question 3
Alkenes can be made by dehydrating alkanols, as shown below.



(a) What homologous series does compound B belong to? [1 mark]

(b) Compound C belongs to the same homologous series as compound B. Draw a possible structure for compound C. [1 mark]

[Total = 2 marks]

Question 4
Draw the structural formula and give the systematic name for the isomer of heptane with the most side chain branching.

[2 marks]

Question 5
Draw and name an isomer of 2-amino-2-methylbutane.

[2 marks]

7.2 Hydrocarbons

Question 6
Outline one physical and one chemical property that differs for ethanoic acid and methyl ethanoate.

[2 marks]

Question 7
Ethanoic acid and methyl methanoate both have the molecular formula $C_2H_4O_2$. Which compound would be expected to have the higher boiling point? Explain your choice.

[2 marks]

Question 8
The following compounds have similar molecular weights

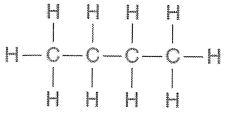
(1) $CH_3CH{=}O$ **(2)** CH_3OCH_3 **(3)** C_2H_5OH **(4)** $CH_3CH_2CH_3$

Identify the compound with the highest boiling point and explain the reason/s for this choice.

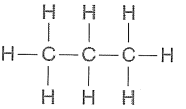
[2 marks]

Question 9
Which of the following compounds would you expect to have the higher boiling point? Give reasons for your answer.

[2 marks]



butane, C_4H_{10}



propane, C_3H_8

Question 10
Identify and explain the trend in boiling points as carbon chain length increases in alkanes and alkenes.

[2 marks]

Question 11
Ethanol is related to ethene. Compare the physical properties of both substances at standard conditions and account for any differences observed.

[3 marks]

Question 12

'Environmental issues have become a major source of concern in oil and gas exploration and production because of current exploration and production practices and the use of modern technology and materials (toxic in nature) in the discovery and exploitation of oil reserves.'

Adebayo and Tawabini, *J Pet Environ Biotechnol* 2012, 3:3

Evaluate this statement and include the sociocultural implications if oil and gas exploration and production was to cease.

[6 marks]

Question 13

The following three alkane isomers do not have same boiling point.

hexane, 2,2-dimethylbutane and 2-methylpentane

Place them in ascending order and give reasons for your answers.

[4 marks]

Question 14

Intermolecular forces play an important role in determining the properties of substances.

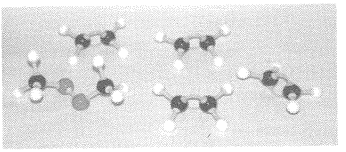
Name at least three properties which are influenced by intermolecular forces and name which of the major intermolecular forces are acting on each of these physical properties.

[3 marks]

Question 15

A student created the following models to demonstrate a chemical process.

I



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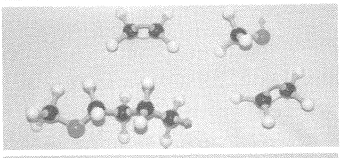
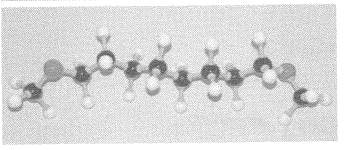


III



(a) What is the chemical process being modelled? [1 mark]

(b) Why are models such as these useful? [2 marks]

[BOS 2012 Q22; Total = 3 marks]

Question 16

The boiling points and molar masses of three compounds are shown in the table.

Compound	*Boiling point* °C	*Molar mass,* g/mol
Acetic acid	118	60
Butan-1-ol	117	74
Butyl acetate	116	116

Acetic acid, butan-1-ol and butyl acetate have very different molar masses but similar boiling points. Explain why in terms of the structure and bonding of the three compounds.

[NESA 2017 Q27; 5 marks]

7.3 Products of reactions involving hydrocarbons

Question 17

Ethene, C_2H_4, is an important starting material for the production of many materials. For example, it can be converted into ethanol, C_2H_5OH.

$$C_2H_4(g) + H_2O(g) \xrightarrow{\text{catalyst}} C_2H_5OH(g)$$

(a) What is the name given to this type of reaction? [1 mark]

(b) Give two more examples of reactions of ethene. In each case, include an equation in your answer. [4 marks]

[Total = 5 marks]

Question 18

Alkanes and alkenes are two important classes of organic compounds.

(a) Describe the difference in structure between alkanes and alkenes. [2 marks]

(b) Describe the experiments you could carry out to distinguish between an alkane and an alkene. Include in your description any potential hazards and how they may be avoided. [3 marks]

[Total = 5 marks]

Question 19

Propene, C_3H_6, and ethene, C_2H_4, are used to make a wide range of materials.

(a) Draw the structures of ethene and propene. [2 marks]

(b) Both propene and ethene can be made from butane, C_4H_{10}, in reactions that involve breaking one of the carbon to carbon bonds of butane. In each case the alkene and one other product are formed. Give separate, balanced equations showing how butane can be converted into these two alkenes. [2 marks]

(c) In the presence of a suitable catalyst propene will react to produce a polymer. Give an equation for this process and draw the structure of the product. [2 marks]

(d) When propene undergoes a reaction with HBr two products are possible. Draw the structures of these two products. [2 marks]

[Total = 8 marks]

Question 20

Hydrocarbon A, molecular formula C_6H_{12}, reacts with chlorine to form B, molecular formula $C_6H_{12}Cl_2$, and with HCl to form hydrocarbon C, molecular formula $C_6H_{13}Cl$.

(a) State the systematic names and structural formulae of substances A, B and C. [3 marks]

(b) Identify two isomers of substance A and state their systematic names and structural formulae. [2 marks]

[Total = 5 marks]

Question 21

Hydrocarbon $C_3H_6O_2$ has the following chemical properties:

- Is soluble in water
- Dissolves readily in NaOH solution
- Reacts with ethanol and a trace of sulfuric acid to form a sweet-smelling liquid.

Suggest the structure of the hydrocarbon and the reason for reaching this answer. [4 marks]

Question 22

Two known alcohols, 2-methyl-2-pentanol and 3-methyl-2-pentanol, are in reagents bottles; have their labels missing.

(a) Show the structural formulae for the two alcohols. [2 marks]

(b) Outline and give the results of a chemical test to distinguish between these two alcohols. [2 marks]

[Total = 4 marks]

7.4 Alcohols

Question 23

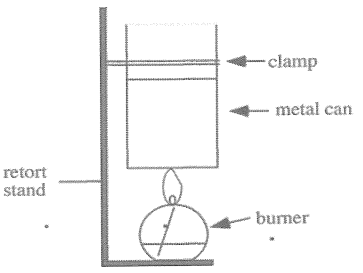
(a) Propan-1-ol will undergo complete combustion in air. Write a balanced chemical equation for this reaction. [1 mark]

(b) Calculate the volume of carbon dioxide produced at 25°C and 100 kPa when 85.0 g of propan-1-ol is completely burnt in air. [2 marks]

[Total = 3 marks]

Question 24

A student determines the heat of combustion of methanol, CH_3OH, using the apparatus shown. 300 mL of water is placed in the metal can. The temperature of the water is measured before and after heating by the methanol burner. The burner is weighed before and after heating the water.



The student obtains the results shown.

- mass of burner and methanol before combustion, g = 35.674
- mass of burner and methanol after combustion, g = 34.396
- temperature of water in can before heating, °C = 16.3
- temperature of water in can after heating, °C = 28.1

(a) Why was a metal can used rather than a glass container? [1 mark]

(b) How many mol of methanol was burnt? [2 marks]

(c) Calculate the heat given to the water in the can if the specific heat of water is 4.18 $J°C^{-1}$ g^{-1} and its density is 1.0 g mL^{-1}. [1 mark]

(d) From parts **(b)** and **(c)** above, calculate the heat of combustion of methanol in kJ mol^{-1}. [1 mark]

(e) The accepted value for the heat of combustion of methanol is 725 kJ mol^{-1}. Suggest two reasons why the value determined in part **(d)** is different from this value. [2 marks]

[Total = 7 marks]

Question 25

A camper uses methylated spirits, which is mostly C_2H_5OH, as a source of energy to boil his drinking water.

(a) Write a balanced equation for the reaction of methylated spirits with oxygen. [1 mark]

(b) If 1 mol of methylated spirits releases 1364 kJ when it is completely burnt in excess oxygen, calculate the amount of energy released when 1.0 g of methylated spirits is burnt. [1 mark]

(c) A camping stove that uses methylated spirits as its fuel heats a small kettle containing 950 mL of water at 12°C. What mass of methylated spirits must be burnt to heat the water to its normal boiling temperature? Assume that 4.2 J will raise the temperature of 1.00 mL of water by 1.00°C and that only 40% of the energy provided by the combustion of the methylated spirits is used to heat the water. [4 marks]

[Total = 6 marks]

Question 26

There are four possible isomers of alcohol $C_4H_{10}O$. Draw the structural formulae of the four isomers.

[4 marks]

Question 27

Ethanol, C_2H_5OH, is used in many parts of the world as an alternative transport fuel to hydrocarbons, such as petrol. The table shows some of the properties of these two fuels.

Property	*Ethanol*	*Petrol*
Sources	Fermentation of carbohydrates	Distillation/cracking of crude oil
Boiling temperature (°C)	78.3	27 – 240
Flash point (°C)	+13	–43
Energy of combustion (kJ g^{-1})	29.7	46.0
Octane number	113	91 – 97
Energy density (MJ L^{-1})	23.4	34.0

Use these data to assess the suitability of ethanol as a transport fuel.

[5 marks]

Question 28
Ethanol, C_2H_5OH, is an alternative fuel to octane, C_8H_{18} for motor vehicles.

(a) Write an equation for the complete combustion of each of these fuels in oxygen. [2 marks]

(b) **(i)** If the density of octane is 0.698 g mL^{-1}, calculate the mass of octane in a 50.0 L tank of the fuel.

(ii) What mass of ethanol will be present in 50.0 L if the density of ethanol is 0.785 g mL^{-1}? [2 marks]

The heats of combustion of octane and ethanol are 5464 kJ mol^{-1} and 1364 kJ mol^{-1} respectively.

(c) For each fuel, calculate the energy that can be obtained from the complete combustion of a 50.0 L of the fuel. [4 marks]

(d) For each fuel, calculate the mass of carbon dioxide formed when 1000 kJ of energy is released. [2 marks]
[Total = 10 marks]

Question 29
A student studied the mass changes that occurred during the fermentation of glucose for eight days. Glucose, yeast and water were added to a flask, the neck of which contained some cotton wool. The mass of the flask and contents for each of the eight days are recorded in the table below.

Day	*Mass of flask + contents* (g)	*Day*	*Mass of flask + contents* (g)
1	421.62	5	412.52
2	418.57	6	411.90
3	416.05	7	411.86
4	413.99	8	411.84

(a) Write a balanced equation for the fermentation of glucose. [1 mark]

(b) Calculate the total amount of CO_2, in moles, released during this experiment. [1 mark]

(c) Calculate the mass of ethanol produced during this fermentation experiment. [2 marks]
[Total = 4 marks]

Question 30
Define the term *molar heat of combustion.*
[1 mark]

Question 31
It is possible to get two different products from the oxidation of ethanol.

(a) Write equations for the two reactions and name the hydrocarbon products. [2 marks]

(b) Explain why you get a different product by changing the conditions. [2 marks]

(c) Butan-2-ol oxidation only yields one product. Name the product and explain why only one product is produced regardless of the conditions. [2 marks]
[Total = 6 marks]

Question 32

The first three alcohols are soluble in water, butanol and pentanol are slightly soluble and the rest are insoluble.

(a) Explain the solubility of this group of compounds. [1 mark]

(b) Explain the decline in solubility with the increasing numbers of carbon atom. [2 marks]

[Total = 3 marks]

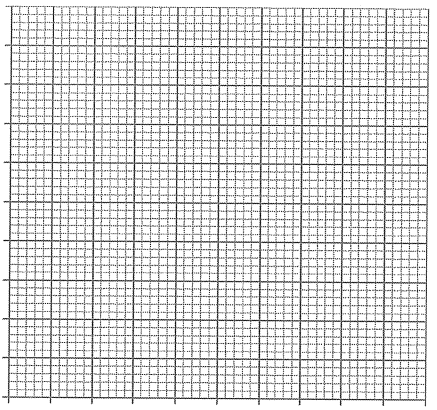
Question 33

A spirit burner containing ethanol was used to heat water in a conical flask for three minutes to measure the molar heat of combustion of ethanol. The results from the investigation are shown.

Time, min	0	0.5	1.5	2.0	2.5	3.0	3.5	4.5	5.0
Temperature of water, °C	18.5	20.5	25.0	27.0	29.5	31.0	30.5	28.5	27.5

(a) On the grid, draw a line graph to represent the data contained in the table. [3 marks]

(b) The following values were also recorded during the investigation:
Initial mass of spirit burner = 236.14 g
Final mass of spirit burner = 235.56 g
Calculated experimental molar heat of combustion of ethanol = –827 kJ mol^{-1}.



Using information from part **(a)** and the above values, determine the mass of water that was in the conical flask. [3 marks]

[BOSTES 2016 Q23; 6 marks]

Question 34

Petroleum and sugar cane are both raw materials used for the production of ethanol.

(a) Construct separate flow diagrams for the production of ethanol from each raw material.

petroleum ——>

sugar cane ——> [5 marks]

(b) Compare the environmental sustainability of producing ethanol from these two raw materials. [3 marks]

[BOS 2012 Q26; Total = 8 marks]

Question 35

The boiling points of some alkanols are given in the table.

Alkanol	*Boiling Point (°C)*	*Alkanol*	*Boiling Point (°C)*
Methanol	65	Pentan-1-ol	138
Ethanol	79	Hexan-1-ol	157
Propan-1-ol	97	Heptan-1-ol	176

(a) Using the data provided, construct a graph that shows the relationship between carbon chain length and boiling point. [3 marks]

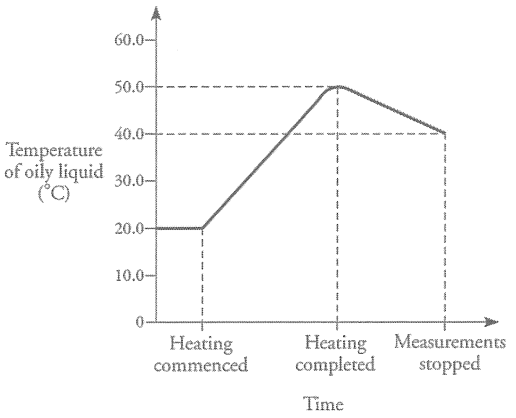
(b) Using the graph, predict the boiling point of butan-1-ol. [1 mark]

(c) What is the intermolecular force responsible for the trend shown in the graph? [1 mark]

[BOS 2012 Q31; Total = 5 marks]

Question 36

A 0.259 g sample of ethanol is burnt to raise the temperature of 120 g of an oily liquid, as shown in the graph. There is no loss of heat to the surroundings.

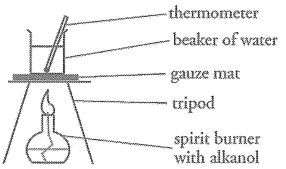


Using the information shown on the graph, calculate the specific heat capacity of the oily liquid. The heat of combustion of ethanol is 1367 kJ mol^{-1}.

[BOS 2013 Q27; 4 marks]

Question 37

A student performed a first-hand investigation to determine the quantitative relationship between heat of combustion and molecular mass of alkanols. The student did this by burning different alkanols to heat water as shown in the diagram.



The calculated heats of combustion for four of the alkanols are given in the table below.

Alkanol	*Molecular mass* ($g\ mol^{-1}$)	*Calculated heat of combustion* ($kJ\ mol^{-1}$)	*Theoretical heat of combustion* ($kJ\ mol^{-1}$)
Methanol	32	150	726
Ethanol	46	950	1367
Propan-1-ol	60	1500	2021
Butan-1-ol	74	2250	2676

(a) On the graph paper, graph both the calculated and the theoretical heat of combustion against the molecular mass of the alkanols. [3 marks]

(b) Discuss the validity of the student's investigation. [3 marks]

[BOSTES 2014 Q22; Total = 6 marks)

Question 38

With reference to the underlying chemistry and with relevant equations, assess the impacts on society of TWO uses of ethanol.

[BOSTES 2014 Q31; 7 marks]

Question 39

In recent years many scientific research groups have investigated biopolymers. In terms of their likely impact on society and the environment discuss why biopolymers have attracted this interest.

[4 marks]

Question 40

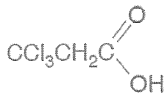
(a) Outline TWO advantages and TWO disadvantages of using ethanol as an alternative fuel for motor vehicles [4 marks]

(b) The molar heat of combustion (ΔH_c) for ethanol is 1360 kJ mol^{-1}. Calculate the energy generated per kg of CO_2 released by the combustion of ethanol. [3 marks]

[NESA 2017 Q28; Total = 7 marks]

7.5 Reactions of organic acids and bases

Question 41
Name the compound below and its salt, when reacted with NaOH.



[2 marks]

Question 42
(a) Write a balanced chemical equation, using structural formulae, for the formation of ethyl butanoate. [2 marks]

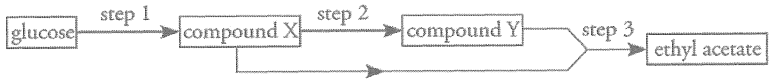
(b) Common safety precautions in school laboratories include the use of safety glasses, gloves and lab coats. Justify the use of another safety precaution specifically required to safely make ethyl butanoate. [2 marks]

[BOS 2012 Q21; Total = 4 marks]

Question 43
An ester and an acid are both listed as additives on a food label.
Explain, on a labelled diagram, why reflux is used to produce an ester.

[BOS 2013 Q21b; 4 marks]

Question 44
Ethyl acetate (ethyl ethanoate) is an ester used as a solvent in some paints, glues and nail polish remover. The flow chart below shows how ethyl acetate could be produced from glucose.



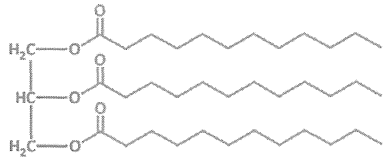
(a) Identify compounds X and Y. [2 marks]

(b) Describe the chemistry involved in each of the steps 1, 2 and 3. Include in your answer relevant equations. [6 marks]

(c) Describe the procedure needed to produce pure compound X in step 1. [1 mark]

[Total = 9 marks]

Question 45
The diagram below represents a typical fat.



(a) How could soap be produced from a typical fat, as shown above? [1 mark]

(b) With reference to the chemical structure, briefly explain the action of soap. [2 marks]

[Total = 3 marks]

Question 46

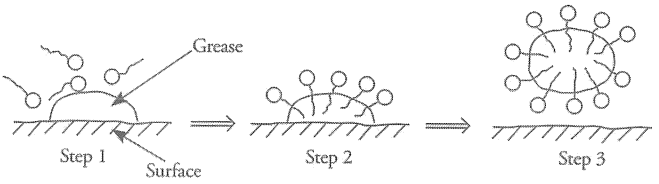
(a) Describe the chemical nature of a typical fat/oil which may be used in the soap making process. [1 mark]

(b) Write an equation to show the saponification of a typical fat. [2 marks]

[Total = 3 marks]

Question 47

The diagram shows a sequence of steps in the removal of grease from a surface. Explain the process shown in these steps.



[BOS 2013 Q32a; 3 marks]

Question 48

A first-hand investigation to produce an ester is to be carried out in a school laboratory, using an alkanol, an alkanoic acid and a suitable catalyst.

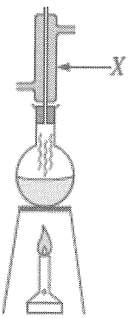
(a) Name an ester that could be produced in a school laboratory. [1 mark]

(b) Describe how potential hazards associated with the three chemicals required for this investigation could be addressed. [5 marks]

[BOSTES 2014 Q26; Total = 6 marks]

Question 49

This apparatus was set up to produce methyl butanoate.



(a) Identify a safety issue in this experiment. [1 mark]

(b) Using structural formulae, write the equation for the production of methyl butanoate. [2 marks]

(c) Justify the use of apparatus X in this experiment. [2 marks]

[BOSTES 2016 Q22; Total = 5 marks]

Question 50
A haloalkane, A, on analysis gave the following percentage composition:

Element	*Percentage composition, %*
Carbon	63.1
Hydrogen	11.9
Bromine	25.0

Hydrolysis of this substance gave a compound, B, which was readily oxidised to an alkenone, C.

(a) Construct a flow chart for the production of C, showing all the additives in the process. [5 marks]

(b) Name A, B, and C. [3 marks]

[Total = 8 marks]

7.6 Polymers

Question 51
Fill in the table below.

Monomers		*Polymers*		
Common Name	*Systematic name*	*Name*	*Properties*	*Use*
Ethylene		LDPE		
		HDPE		
Vinyl chloride				
Styrene				

[4 marks]

Question 52
Using full structural formulae, show the monomer units for vinyl chloride and styrene and demonstrate the formation of their respective polymers showing at least three monomer units in the polymer chain.

[4 marks]

Question 53
Explain why and how the chlorine and benzene side chain significantly affect the nature of the polymer in terms of its properties and uses.

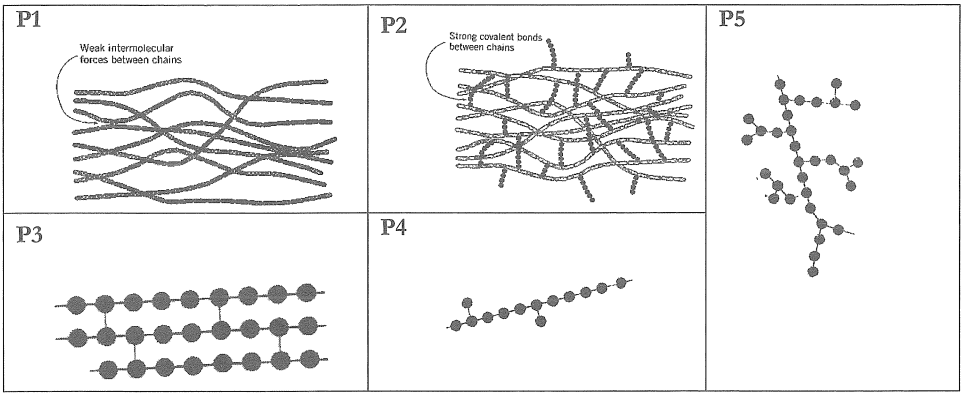
[2 marks]

Question 54

Answer these questions in relation to the diagram below.

(a) Identify the type of polymer and list some everyday polymer which has this structure. [2 marks]

(b) Describe the relationship between the structure, properties and use of this plastic. [3 marks]



[Total = 5 marks]

Question 55

Each of the properties below affects the nature of the polymer. For each, explain its significance in the polymer.

(a) Length of chain

(b) Chain arrangement.

(c) Degree of branching

(d) Cross linking between polymer chains

(e) Inclusion of additives

[5 marks]

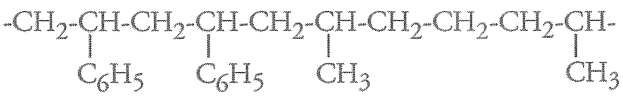
Question 56

(a) The monomer vinyl chloride, CH_2=CHCl, is used to make the polymer polyvinyl chloride by passing it over a catalyst.

(i) Draw a partial structure of polyvinyl chloride by showing how three monomer units would be linked together in the polymer. [2 marks]

(ii) What name is given to the reaction undergone by the vinyl chloride? [1 mark]

(b) The diagram below represents a small section of a co-polymer, that is, a polymer made from more than one monomer.

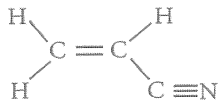


Draw the structures of the monomers from which this polymer is made. [3 marks]

[Total = 6 marks]

Question 57

Acrylonitrile is the monomer used to make polyacrylonitrile (PAN). The structure of the monomer is shown below.



PAN is used to make 'Orlon' fibres, which are used to make rugs, blankets and clothing.

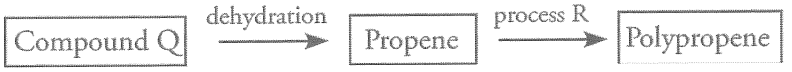
(a) Draw the structure of the polymer PAN. [1 mark]

(b) The properties of polymers are very important in determining their uses. Discuss the properties expected for polyacrylonitrile. [3 marks]

[Total = 4 marks]

Question 58

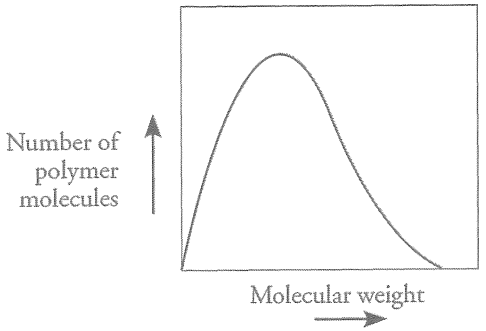
The flow chart shown below describes the production of polypropene.



(a) Give the name of compound Q and draw its structure. [2 marks]

(b) Describe process R. [3 marks]

Process R was used to produce a sample of polypropene. The molecules of polypropene in the sample have different molecular weights and this distribution is shown in the graph below.



(c) Why do all the molecules of polypropene not have the same molecular weights? [1 mark]

[Total = 6 marks]

Question 59

(a) Describe the steps involved in the process of *addition polymerisation.* [3 marks]

(b) Explain the uses of polyethylene and polystyrene in terms of their structures and properties. [4 marks]

[BOSTES 2015 Q25; Total = 7 marks]

Chapter 4
Module 8: Applying Chemical Ideas
Multiple-choice questions

8.1 Analysis of inorganic substances

Question 1
Industrial chemists must monitor the emissions produced by industrial chemical processes. Which one of the following would be the LEAST harmful when released into the environment?

(A) Nitrogen
(B) Steam
(C) Sulfur dioxide
(D) Carbon monoxide

Use this information to answer Questions 2 and 3.

A sample of pond water from a contaminated site was analysed to determine the concentration of lead ions using the following procedure.

- A measuring cylinder was used to collect 50 mL sample from the pool.
- A sample was placed in a clean dry beaker.
- 25.0 mL of 0.200 mol L^{-1} sodium chloride solution was added to the sample.
- The precipitate of lead(II) chloride that formed was filtered, dried and weighed. It had a mass of 0.13 g.

Question 2
How could the reliability of the analysis of the pond water be improved?

(A) Analyse more samples from the same pond.
(B) Use 50 mL of distilled water as a control sample.
(C) Analyse samples from different ponds on the site.
(D) Remove other contaminants from the sample before the analysis.

Question 3
What was the concentration of lead ions in the sample?

(A) 5.0×10^{-3} mol L^{-1}
(B) 5.8×10^{-3} mol L^{-1}
(C) 9.3×10^{-3} mol L^{-1}
(D) 10.7×10^{-3} mol L^{-1}

[BOSTES 2015 Q18 & 19]

Question 4

Drinking water is regularly tested to ensure that it is safe for consumption. Which of the following test results indicates the highest drinking-water quality?

	Dissolved oxygen (mg/L)	*Nitrate* (mg/L)	*Total dissolved solids* (mg/L)	*Turbidity* (NTU)
(A)	2	0.1	50	50
(B)	8	0.1	50	2
(C)	2	2	200	2
(D)	8	2	200	50

[BOSTES 2014 Q6]

Question 5

To determine the concentration of dissolved solids in a sample of creek water the method used is partially summarised below.

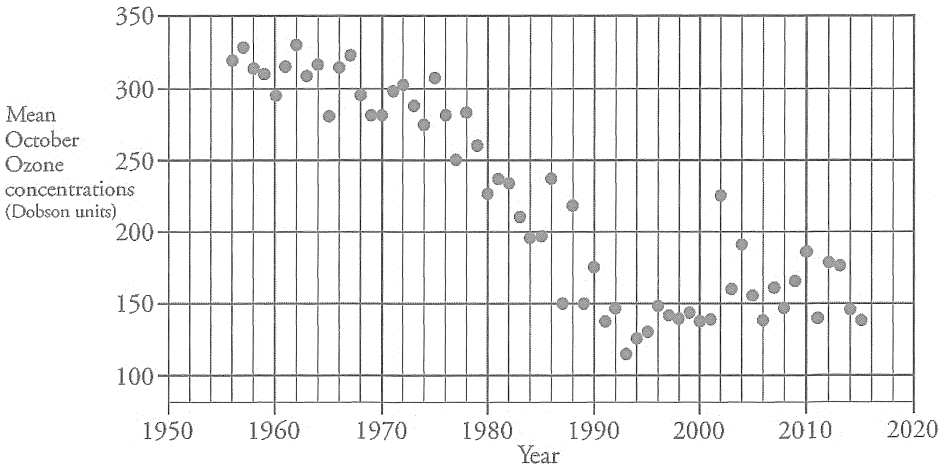
- Filtration of the creek water
- Washing the residue.
- Evaporation of the filtrate to dryness
- Weighing the solids

Several important steps are missing from the summary. Which one of the following steps need not be added to the method?

(A) Weigh the solid residue obtained after filtration.
(B) Weigh the evaporating basin before the filtrate is added.
(C) Dry the solids to constant mass.
(D) Measure the initial volume of the creek water.

The following information should be used to answer Questions 6 and 7.

The concentration of ozone above the British Antarctic Survey station at Halley Bay in Antarctica has been measured each October since 1956. The results are shown in the graph below.



Question 6

Using only this information, which of the following statements is correct?

(A) The ozone concentration will be greater in 2018 than it was in 2010.
(B) The decrease in ozone concentration from the 1960s to the 1990s was caused by an increase in the concentration of CFC in the atmosphere.
(C) The ozone concentration was lower in 1989 than in 2009.
(D) Changes in the atmospheric CFC concentration cause changes in the ozone concentration.

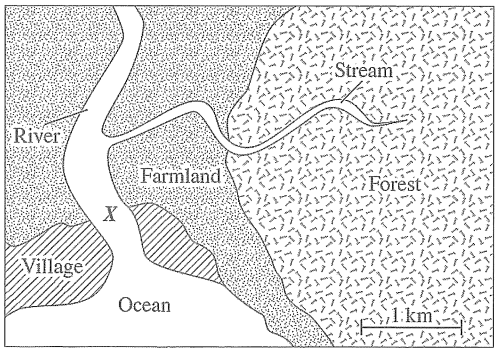
Question 7

The mean October ozone concentration in 2020 will be:

(A) ~150 Dobson units.
(B) ~200 Dobson units.
(C) ~250 Dobson units.
(D) difficult to predict from this data.

Question 8

Part of a water catchment is shown in the diagram.



A sample of river water taken from point *X* is analysed. Which row of the table shows the most likely results?

	Results of water analysis at X			
	Turbidity (NTU)	*BOD* (ppm)	*pH*	*Total dissolved solids* (ppm)
(A)	400	18	6.5	22000
(B)	22	3	8.5	17
(C)	5	18	6.5	22000
(D)	400	3	8.5	17

[BOSTES 2015 Q15]

Question 9

Which of the following gases can cause major depletion of the ozone layer?

(A) O_3 **(B)** CCl_3F **(C)** CO **(D)** NO_x

Question 10
What is the main environmental problem associated with chlorofluorocarbon compounds?

(A) Acid rain
(B) Eutrophication
(C) Global warming
(D) Ozone depletion

[BOS 2013 Q3]

Question 11
Jet engines produce small amounts of nitric oxide, NO. Emissions from aircraft flying in the stratosphere are thought to cause the removal of ozone by the following reaction:

$$NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$$

If 0.84 g of $O_3(g)$ is mixed with 0.15 g $NO(g)$ at 0°C and 100 kPa what volume of $O_3(g)$ would remain?

(A) 0.11 L **(B)** 0.28 L **(C)** 0.31 L **(D)** 0.40 L

Question 12
Which of the following is a measure of the clarity of water?

(A) Hardness
(B) Turbidity
(C) Total dissolved solids
(D) Biochemical oxygen demand

[BOS 2012 Q1]

Question 13
Which of the following is the most suitable replacement for CFCs in terms of reducing their environmental impact?

(A) CH_4 **(B)** CH_2F_2 **(C)** CH_2ClF **(D)** $CHCl_2CCl_2F$

[BOSTES 2015 Q6]

Question 14
Sodium fluoride, NaF, or sodium fluorosilicate, Na_2SiF_6, are often added to town water supplies. The most important reason for doing this is to

(A) remove harmful metal ions are their insoluble fluorides.
(B) kill harmful microorganisms.
(C) help harden tooth enamel.
(D) adjust the pH of the water.

Question 15
The measurement taken by an atomic absorption spectrometer is:

(A) volume. **(B)** concentration. **(C)** mass. **(D)** absorbance.

Question 16
The purpose of the flame in flame atomic absorption spectroscopy is to:

(A) desolvate and atomise the analyte atoms in a sample.
(B) purify the sample.
(C) ionise the analyte atoms.
(D) excite the analyte atoms.

Question 17
Which of the following is the principle of atomic absorption spectroscopy?

(A) Radiation is absorbed by non-excited atoms in vapour state and are excited to higher states.
(B) Medium absorbs radiation and transmitted radiation is measured.
(C) Colour is measured.
(D) Colour is simply observed.

Question 18
In atomic absorption spectroscopy, which of the following is the generally used radiation source?

(A) Xenon mercury and lamp
(B) Hydrogen discharge lamp
(C) Hollow cathode lamp
(D) Magnesium lamp

Question 19
Each of the lists below contains four cations. If a dilute solution of sodium hydroxide were added separately to a dilute solution of the chloride of each ion, in which one of the lists would precipitates be least likely to form?

(A) Ba^{2+}, Ca^{2+}, Cu^{2+}, Ni^{2+}
(B) Al^{3+}, Cr^{3+}, Fe^{3+}, Ni^{3+}
(C) Ag^{+}, Li^{+}, K^{+}, Na^{+}
(D) Li^{+}, K^{+}, Na^{+}, Rb^{+}

Question 20
Sodium hydroxide solution is added to a solution containing a certain cation. A green precipitate forms which turns red brown on standing. The precipitate is most likely to be the hydroxide of

(A) Fe^{2+} which is then oxidised to Fe^{3+}.
(B) Fe^{3+} which is then reduced to Fe^{2+}.
(C) Cu^{+} which is then oxidised to Cu^{2+}.
(D) Cu^{2+} which is then reduced to Cu^{+}.

Question 21
Which one of the anions below will produce a precipitate with each of the solutions I, II and III?

I silver nitrate solution
II barium nitrate solution
III copper nitrate solution

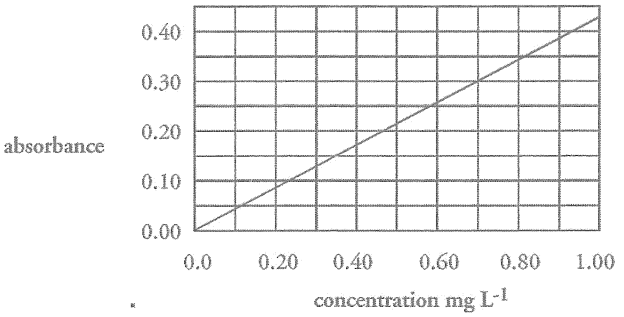
(A) CO_3^{2-} **(B)** SO_4^{2-} **(C)** Cl^{-} **(D)** OH^{-}

Question 22
Aqueous solutions containing nickel(II) salts are usually green.

Which of the following techniques would be most suitable to determine low concentrations of nickel ions in solution?

(A) Atomic absorption spectroscopy
(B) Gravimetric analysis
(C) Volumetric analysis
(D) A flame test

Question 23
The relationship between absorbance and the concentration of copper ions (Cu^{2+}) in aqueous solution was determined using atomic absorption spectroscopy (AAS). The results are shown in the graph below.



The amount of Cu^{2+} in a soft drink sample was determined using the same technique. A 10.0 mL sample was diluted to 250 mL with water and the absorbance observed in an AAS experiment was 0.25.

The concentration of Cu^{2+} in mg L^{-1}, in the undiluted soft drink was
(A) 2.5 **(B)** 6.0 **(C)** 15 **(D)** 150

Question 24
Samples of a solution of barium nitrate were independently tested with chloride ions, with sulfate ions and also for flame colour. Which row of the table below would represent the results?

	Chloride	*Sulfate*	*Flame test*
(A)	No precipitate	No precipitate	Red
(B)	No precipitate	Precipitate	Green
(C)	Precipitate	Precipitate	Green
(D)	Precipitate	No precipitate	Red

[BOS 2012 Q10]

Question 25
All the lead ions present in a 50.0 mL solution were precipitated by reaction with excess chloride ions. The mass of the dried precipitate was 0.595 g. What was the concentration of lead in the original solution?

(A) 8.87 g L^{-1}
(B) 10.2 g L^{-1}
(C) 11.9 g L^{-1}
(D) 16.0 g L^{-1}

[BOS 2012 Q20]

Question 26
What flame colour do copper ions produce when heated?

(A) Brick red
(B) Blue-green
(C) Pale purple
(D) Yellow-orange

[BOSTES 2015 Q3]

Question 27
A dilute solution of barium nitrate is added to a dilute solution of an unknown salt and a white precipitate form. The anion present in the salt could **not** be:

(A) sulfate.
(B) chloride.
(C) carbonate.
(D) phosphate.

Question 28
Which is NOT a step in atomic absorption spectroscopy?

(A) The adsorption of particles on a stationary phase
(B) The construction of a calibration curve
(C) Atoms absorb light
(D) The vaporisation of a solution.

Question 29
Which row of the table correctly matches an ion with its flame colour during a flame test?

	Ion	*Flame colour*
(A)	Barium	Orange-red
(B)	Calcium	Blue-green
(C)	Carbonate	Orange-red
(D)	Copper	Blue-green

[NESA 2017 Q2]

Question 30
There are two unlabelled solutions. One is barium nitrate and the other lead nitrate. Which of the following could be added to the two unlabelled solutions to distinguish between them?

(A) Sodium sulfate
(B) Sodium nitrate
(C) Sodium chloride
(D) Sodium carbonate

[NESA 2017 Q8]

Question 31

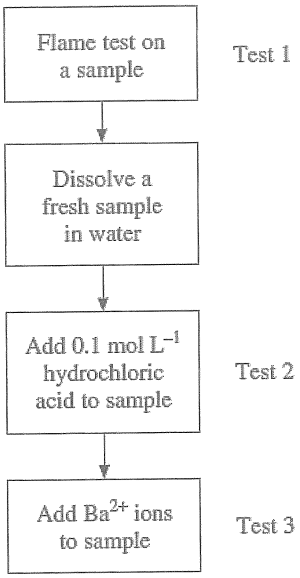
Excess barium nitrate solution is added to 200 mL of 0.200 mol L^{-1} sodium sulfate. What is the mass of the solid formed?

(A) 4.65 g **(B)** 8.69 g **(C)** 9.33 g **(D)** 31.5 g

[BOSTES 2016 Q19]

Question 32

The flow chart shows the steps used to identify a sample of a substance.



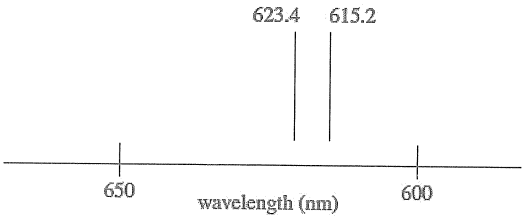
If the substance is sodium sulfate, what should have been observed in Tests 1, 2 and 3?

	Test 1	*Test 2*	*Test 3*
(A)	Bright orange flame	No bubbles	White precipitate formed
(B)	Bright orange flame	Bubbles	No precipitate formed
(C)	Blue-green flame	No bubbles	No precipitate formed
(D)	Blue-green flame	Bubbles	White precipitate formed

[BOSTES 2016 Q13]

Question 33

A section of the emission spectrum of a mercury lamp is shown.



Light at 623.4 nm and 615.2 nm from the mercury lamp was passed through a sample of water containing mercury, and the intensities were then measured by a detector.

I (x nm) = Intensity of light at a wavelength of x nm from the lamp

I_d (x nm) = Intensity of light at a wavelength of x nm at the detector

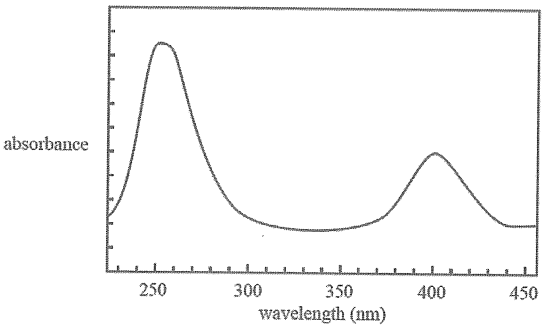
Which of the pairs of intensities on the following page can be used in the determination of the amount of mercury in the water sample using atomic absorption spectroscopy (AAS)?

(A) I (615.2 nm) and I_d (615.2 nm)
(B) I (615.2 nm) and I_d (623.4 nm)
(C) I (615.2 nm) and I (623.4 nm)
(D) I_d (615.2 nm) and I_d (623.4 nm)

[BOSTES 2016 Q20]

Question 34

The UV–visible spectrum of a solution of a certain compound is shown below.



Consider the following statements about this compound and its UV–visible spectrum.

I. The amount of light absorbed by a solution of this compound depends on its concentration.
II. The amount of light absorbed by a solution of this compound depends on the wavelength of light used.
III. The spectrum is a result of electrons falling back from higher to lower electronic energy levels.
IV. The concentration of a solution of this compound can only be determined by UV–visible spectroscopy at 250 nm.

Which of the above statements are true?

(A) I and II
(B) II and III
(C) I, II and III
(D) I, II and IV

Question 35
The main mineral present in high concentration in regions where underground caves are found is:

(A) sodium chloride.
(B) mercury chloride.
(C) calcium carbonate.
(D) sodium carbonate.

Question 36
Which of the following is considered a heavy metal?

(A) Sodium
(B) Mercury
(C) Potassium
(D) Magnesium

Question 37
Which of the following is an example of qualitative analysis?

(A) Measuring the fat content in a liquid
(B) Determining the concentration of chemicals in a domestic cleaner
(C) Detecting the presence of a chemical in a water supply
(D) Finding the % of a salt in a household substance

Question 38
Which of the following reactions is most likely to be part of a gravimetric analysis?

(A) $2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$
(B) $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
(C) $AgNO_3(aq) + LiBr(aq) \rightarrow AgBr(s) + LiNO_3(aq)$
(D) $2HCl(aq) + Na_2CO_3(aq) \rightarrow 2NaCl(aq) + CO_2(g) + H_2O(l)$

Question 39
A student determines the percentage of sodium chloride in a food sample by the following procedure. The food sample is dissolved in water and the chloride ion is precipitated by adding an excess of silver nitrate solution. The precipitate is washed and dried. If the food sample had a mass of 20.0 g and the final precipitate a mass of 0.376 g.

What is the percentage of sodium chloride in the food?

(A) 0.220% **(B)** 0.465% **(C)** 0.767% **(D)** 1.88%

Question 40
Which one of the following is not part of the gravimetric analysis procedure to determine the sodium chloride content of a food sample?

(A) Dissolve sample in water.
(B) Titrate the solution of the sample.
(C) Add silver nitrate solution.
(D) Filter and weigh the precipitate.

Question 41

Listed below are some properties of solids.

I. White and partly soluble
II. Maintains its composition when heated
III. High formula mass
IV. Known formula
V. Low solubility and unreactive towards other substances

Which properties are desirable for the precipitate obtained in a quantitative gravimetric procedure?

(A) I, II, III, IV and V
(B) II, III, IV and V
(C) II, IV and V
(D) I, III and IV

8.2 Analysis of organic substances

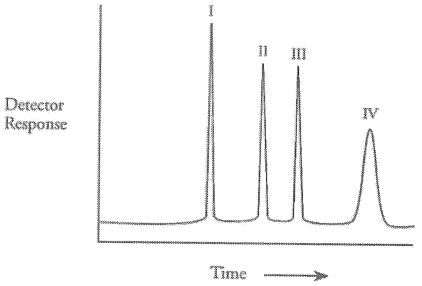
Question 42

Which of the following statements accurately describes the molecular vibrations characteristic of IR spectroscopy?

(A) Stretching frequencies are lower than corresponding bending frequencies.
(B) Triple bonds have lower stretching frequencies than corresponding double bonds, which in turn have lower frequencies than single bonds.
(C) Bonds to hydrogen have higher stretching frequencies than those to heavier atoms.
(D) Stretching frequencies appear mostly in the fingerprint region.

Question 43

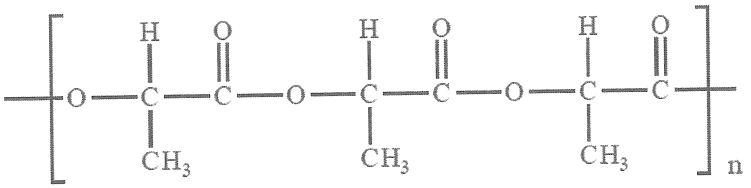
Gas liquid chromatography is used to identify compounds present in a mixture. Compounds leave the column in order of increasing molecular weight, i.e. the compound with the smallest molecular weight reaches the detector first. A mixture of alkanes was analysed using GLC. The diagram below shows the result obtained.



The compounds I, II, III and IV could be

	Compound I	*Compound II*	*Compound III*	*Compound IV*
(A)	Hexane	Pentane	Butane	Propane
(B)	Pentane	Hexane	Heptane	Octane
(C)	Methanol	Ethanol	Propan-1-ol	Butan-1-ol
(D)	Butane	Ethane	Hexane	Propane

Question 44
The polymer polylactic acid, PLA, shown below, is used to make soluble stitches which are absorbed by the body following surgery.



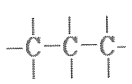
Other than the peak given by the TMS reference, the monomer from which PLA is formed would give:

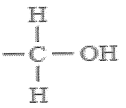
(A) one set of peaks in the ^{1}H NMR.
(B) two sets of peaks in the ^{1}H NMR.
(C) three sets of peaks in the ^{1}H NMR.
(D) four sets of peaks in the ^{1}H NMR.

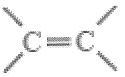
Question 45
Certain chemical tests were performed on the pain-relief drug ibuprofen. The results of these tests are given in the table below.

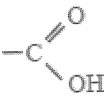
Test	*Result*
Aqueous sodium carbonate	Effervescence
Bromine water	Remained orange
Acidified potassium dichromate(VI) and heat	Remained orange

From the results, ibuprofen contains which functional group?

(A) 

(B) 

(C) 

(D) 

Question 46
In the common naming convention for carboxylic acids, what is the correct Greek letter used for the carbon adjacent to the carboxyl group?

(A) α **(B)** an ester **(C)** the alcohol **(D)** micelle

Question 47
Which of the following statements is wrong?

(A) UV spectra provide information about valence electrons.
(B) NMR spectrometers use radiofrequency electromagnetic radiation.
(C) UV absorption is attributable to electronic transitions.
(D) IR absorption is attributable to transitions between rotational energy levels of whole molecules.

Question 48
Which of the following statements regarding IR spectroscopy is wrong?

(A) Infrared radiation is higher in energy than UV radiation.
(B) Molecular vibrations are due to periodic motions of atoms in molecules, and include bond stretching, torsional changes, and bond angle changes.
(C) Infrared spectra give information about bonding features and functional groups in molecules.
(D) Infrared spectra record the transmission of IR radiation.

Question 49
Which of the following statements regarding NMR spectroscopy is wrong?

(A) A hydrogen signal splits in $n + 1$ peaks by spin-spin coupling when the number of equivalent hydrogen atoms on adjacent atom(s) is n, and other neighbouring atoms are involved.
(B) NMR signals towards the left on the spectral chart correspond to larger chemical shifts.
(C) Chemical shifts are larger when shielding effects are greater
(D) Chemical shifts are larger when the frequencies of the radiation which includes the nuclear transitions are higher.

Question 50
Which of the following statements regarding mass spectroscopy is wrong?

(A) Only cations can be detected by a normal mass spectrometer.
(B) Molecular ion peaks always have an even-numbered values of mass charge ratio (m/z).
(C) In a normal mass spectrometer, electron impact causes a molecule to lose an electron and become a molecular radical cation which decomposes into fragment cations and radicals.
(D) A compound whose molecules contain just one bromine atoms shows two molecular ion peaks of similar intensity, one at +1 and one at –1 of the average m/z value.

Question 51
Which of the following statements is wrong?

(A) Water is a good solvent for recording UV spectra of water-soluble compounds.
(B) Water is a good solvent for recording IR spectra of water-soluble compounds.
(C) The wavelength of a band in an IR spectrum is directly proportional to the frequency of the associated molecular vibration.
(D) Hydrogen bonding in hydroxy compounds leads to the broadening of spectral bands which are attributed to vibrations of O-H.

Question 52
Infrared spectroscopy provides valuable information about:

(A) melting point.
(B) functional groups.
(C) molecular weight.
(D) conjugation.

Question 53
A strong signal at 1700 cm^{-1} in an IR spectrum indicates the presence of a(n):

(A) ether. **(B)** amine. **(C)** alcohol. **(D)** carbonyl.

Question 54
A strong signal at 3400 cm^{-1} in an IR spectrum indicates the presence of a(n):

(A) ether. **(B)** amine. **(C)** alcohol. **(D)** carbonyl.

Question 55
What is the exact molecular mass (in amu) of the molecule C_3H_8O?

(A) 58.078 **(B)** 60.00 **(C)** 60.09 **(D)** 34.00

Question 56
How many signals does the aldehyde $(CH_3)_3CCH_2CHO$ have in ^1H and ^{13}C NMR spectra?

(A) three ^1H and four ^{13}C NMR
(B) five ^1H and six ^{13}C NMR
(C) five ^1H and four ^{13}C NMR
(D) three ^1H and six ^{13}C NMR

Question 57
Which of the following statements is wrong?

(A) A mass spectrum does not show signals due to uncharged radicals.
(B) A conventional mass spectrometer employs high energy UV radiation.
(C) A conventional mass spectrometer does not employ a spectrophotometric detector.
(D) Conventional mass spectrometry does not always require samples of high purity.

Question 58
Which of the following statements regarding mass spectroscopy is false?

(A) The molecular ion of carbonyl compounds with a –C-H readily undergoes elimination of an alkene to give a relativity stable enol radical cation.
(B) The base peak of a simple ketone is usually attributable to an acylium ion.
(C) The molecular ion peak of some alcohols is very weak because it readily loses an alkyl radical to give a relatively stable oxonium ion.
(D) Structurally isomeric alkanes cannot be distinguished by low resolution mass spectroscopy.

8.3 Chemical synthesis and design

Question 59
Choose the LEAST appropriate answer.
A chemical industry such as ammonia production should be located:

(A) close to supplies of raw materials.
(B) in an urban area.
(C) close to transport facilities for removing the product.
(D) where workers can easily access the site.

Question 60
Fossil fuel powered generation plants are ideally located:

(A) close to the source of the fossil fuel as it is the most expensive commodity.
(B) near a river system to access water.
(C) in the proximity of towns to access workforce.
(D) All of the above are important for the operation of a power plant.

Free-response questions

8.1 Analysis of inorganic substances

Question 1

(a) Choose an industrial production area, such as fossil fuel power plant or an ammonia or fertiliser plant, and state 3–4 sources of possible pollutant and reasons for the need to monitor them. [4 marks]

(b) Choose one of the pollutant from your answer in part **(a)** and analyse how and why it requires monitor. [2 marks]

[Total = 6 marks]

Question 2
Some insecticides contain dieldrin, $C_{12}H_8Cl_6O$ (M_r = 381), as the active ingredient. When burnt in oxygen the only products of combustion of dieldrin are carbon dioxide, hydrogen chloride (HCl) and water. If the products of combustion are bubbled through a solution of silver nitrate ($AgNO_3$), then a white precipitate of silver chloride (AgCl) is formed.

$$AgNO_3(aq) + HCl(g) \rightarrow AgCl(s) + HNO_3(aq)$$

In a typical experiment, 2.26 g of the insecticide was burnt in oxygen. The white solid was collected, washed and dried. The mass of silver chloride obtained was 3.28 g.

(a) Write the equation for the combustion of dieldrin in oxygen. [2 marks]

(b) How many mole of silver chloride was formed? [1 mark]

(c) Calculate the number of mole of chlorine atoms in the sample. [1 mark]

(d) Calculate the percentage purity of the insecticide. [3 marks]

(e) If the precipitate was not thoroughly washed before it was dried, what effect would this have on the calculated percentage? Explain your answer. [2 marks]

[Total = 9 marks]

Question 3

A scientist wishes to determine the concentration of copper ions in a sample of drinking water by using atomic absorption spectroscopy. The scientist first measures the absorbance of solutions containing known concentrations of copper ions by spraying the solutions into the flame. The results obtained are given in the table below.

Concentration of Cu^{2+} (M)	*Absorbance (arbitrary units)*
1.25×10^{-5}	0.080
1.86×10^{-5}	0.120
4.06×10^{-5}	0.270
6.04×10^{-5}	0.400

The scientist then measures the absorbance of the drinking water and obtains a reading of 0.315.

(a) Plot a graph of 'Absorbance' against 'Concentration of copper ions'. [2 marks]

(b) Use your graph to determine the concentration of copper ions in the drinking water. [1 mark]

(c) What assessment can be made concerning the reliability of the result obtained in part **(b)**? [2 marks]

(d) What absorbance reading would be expected for a sample of water that contains 1.35 mg L^{-1} of Cu^{2+}? [3 marks]

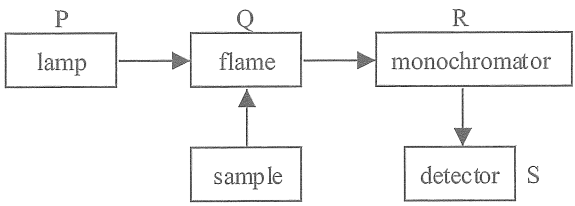
(e) What mass of copper sulfate, $CuSO_4.5H_2O$, would be needed to make 1.00 L of a solution with a copper ion concentration of 6.04×10^{-5} M? [2 marks]

(f) How would you prepare the solution mentioned in part **(d)** if the only balance available reads to ± 0.1 g? [1 mark]

[Total = 11 marks]

Question 4

Shown below is a simplified diagram of an atomic absorption spectrometer. Explain what happens at the points labelled P, Q, R and S.



[Total = 5 marks]

Question 5

Atomic absorption spectroscopy has been used to determine the amount of mercury in various seafoods. Calibration of the apparatus was carried out by spraying samples of standard solutions containing known amounts of mercury into a flame. The results are given in the table below.

Absorbance	*Mercury concentration (mg L^{-1})*	*Absorbance*	*Mercury concentration (mg L^{-1})*
0.013	1.00	0.038	3.00
0.026	2.00	0.051	4.00

The mercury content of a sample of flathead was determined by taking 10.00 g of the fish and heating it with 10 mL of nitric acid in a closed container. The resulting liquid was filtered and sprayed into the flame. The absorbance reading obtained was 0.031.

(a) Plot a graph of absorbance against mercury concentration. [2 marks]

(b) Calculate the concentration of mercury in the fish in ppm (g per 10^6 g fish). [3 marks]

(c) Comment on the reliability of the result obtained regarding its applicability to the mercury content of fish in general. [2 marks]

[Total = 7 marks]

Question 6

A solution contains the carbonate, chloride and sulfate anions.

(a) What sequence of tests should be carried out to show that the solution contains all these ions? Give the names of the reagents used in any relevant equations. [3 marks]

(b) Explain why the order in which these tests are carried out is important. [3 marks]

[Total = 6 marks]

Question 7

If ground water contains small amounts of calcium and magnesium ions it is said to be 'hard'. The concentrations of these ions can be determined by titrating a sample of the water with a reagent called EDTA in the presence of a suitable indicator. The solution of the reagent usually contains the anion H_2EDTA^{2-} and the titration is carried out at about pH 10. Metal cations, such as Mg^{2+} and Ca^{2+}, react as follows.

$$Mg^{2+}(aq) + 2OH^-(aq) + H_2EDTA^{2-}(aq) \rightarrow Mg(EDTA)^{2-} + 2H_2O(l)$$
$$Ca^{2+}(aq) + 2OH^-(aq) + H_2EDTA^{2-}(aq) \rightarrow Ca(EDTA)^{2-} + 2H_2O(l)$$

If the pH is raised to ~13 then $Mg(OH)_2$ is precipitated and only the second reaction with Ca^{2+} ions occurs.

A student adjusts the pH of 100.00 mL of a ground water sample to 10 with dilute ammonia and then titrates the sample with a 0.0125 mol L^{-1} EDTA solution. The student repeats the procedure three times and obtains an average titre of 15.16 mL.

The pH of a second set of 100.00 mL samples of the ground water is adjusted to 13 and the titrations repeated. This time the average titre is 12.45 mL.

(a) Calculate the concentrations of Mg^{2+} and Ca^{2+} ions in the ground water in mol L^{-1}. [4 marks]

The hardness of a water sample is often expressed as the equivalent mass of calcium carbonate (in mg) in 1.00 litre.

(b) Calculate the hardness of the ground water sample in mg ($CaCO_3$) L^{-1}. [2 marks]

[Total = 6 marks]

Question 8

Many vitamin and mineral tablets used to supplement diets contain zinc. A chemist uses the following procedure to determine the amount of zinc in some tablets. A tablet is dissolved in dilute nitric acid and the volume of solution is made up to 250 mL. Three separate tablet solutions are prepared in this way. The chemist also prepares five standard solutions of zinc. Atomic absorption spectroscopy is used to measure the absorbances of the tablet samples solution and the standard solutions. The results are given in the table below.

Standard zinc solutions (mg L^{-1})	*Absorbance*
0.00	0.000
0.50	0.100
1.50	0.280
2.50	0.480
3.50	0.670
Three tablet samples	0.535, 0.525, 0.530

(a) Plot a calibration curve for the standard zinc solutions. [3 marks]

(b) Calculate the mean absorbance of the tablet samples. [1 mark]

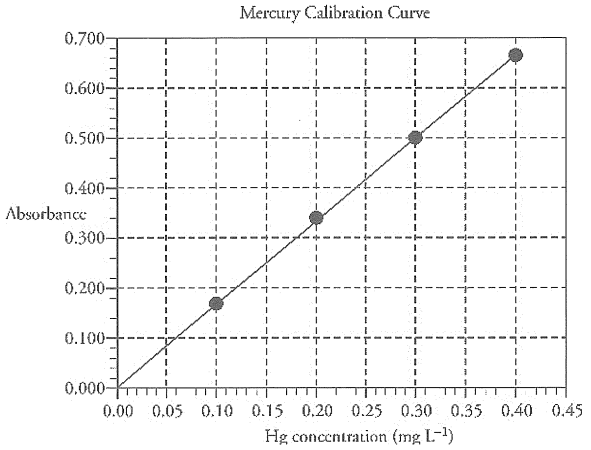
(c) Calculate the mean amount of zinc per tablet in mg. [2 marks]

[Total = 6 marks]

Question 9

The mercury concentration of a certain fish species was determined by atomic absorption spectroscopy. The sample data is shown below.

Mass of fish (g)	18.6
Final sample volume (mL)	25.0
Absorbance (mean)	0.280

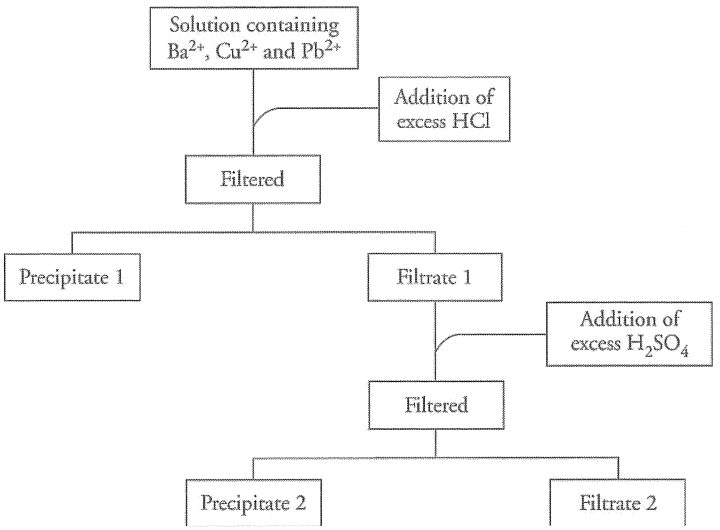


A consumer wants to avoid eating fish with a mercury concentration greater than 0.5 mg/kg of fish. Calculate the concentration of mercury in the fish sample and state whether the consumer can eat this fish species.

[BOS 2012 Q32; Total = 3 marks]

Question 10

A solution contains three cations, Ba^{2+}, Cu^{2+} and Pb^{2+}. The flow chart below indicates the plan used to confirm the identity of these cations.



(a) Name precipitate 2. [1 mark]

(b) Write a balanced net ionic equation for the formation of precipitate 1. [2 marks]

(c) Suggest a test and the expected result that would confirm the identity of the metal cation remaining in filtrate 2. [2 marks]

[BOS 2013 Q22; total = 5 marks]

Question 11

A solution contains carbonate, chloride and sulfate ions. Describe a sequence of tests that could be used to confirm the presence of each of these ions. Include ONE relevant chemical equation.

[BOSTES 2014 Q24; 5 marks]

Question 12

Under conditions of low oxygen levels, octane can undergo incomplete combustion according to the following chemical equation:

$$2C_8H_{18}(l) + 17O_2(g) \rightarrow 6C(s) + 4CO(g) + 6CO_2(g) + 18H_2O(l)$$

(a) Explain the need to monitor this process. [2 marks]

(b) Calculate the mass of soot ($C(s)$) produced if 4.2 moles of octane are combusted in this way. [2 marks]

[BOSTES 2014 Q25; total = 4 marks]

Question 13

The procedure of a first-hand investigation conducted in a school laboratory to determine the percentage of sulfate in a lawn fertiliser is shown.

- 2.00 g of a sample of fertiliser was ground up and placed in a beaker.
- It was dissolved in about 200 mL of 0.1 mol L^{-1} hydrochloric acid, stirred and filtered.
- Excess barium chloride solution was quickly added to this beaker and a precipitate formed.
- The precipitate was then allowed to settle, filtered using filter paper and the residue collected.
- The residue was dried and weighed and had a mass of 2.23 g.

(a) Suggest modifications that could be made to the procedure to improve the results of this investigation. Justify your suggestions. [4 marks]

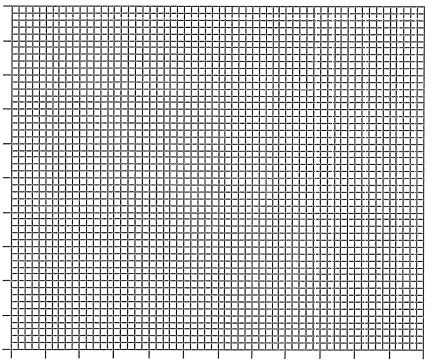
(b) Calculate the percentage of sulfate in the original fertiliser sample. [3 marks]

[BOSTES 2015 Q29; Total = 7 marks]

Question 14

Atomic absorption spectroscopy was used to determine the concentration of zinc in a water sample. The absorbance of a series of standard solutions of known concentration of zinc was measured. The results are shown in the table.

Zinc concentration, ppm	0.00	1.00	2.00	3.00	4.00	5.00
Absorbance	0.00	0.17	0.34	0.48	0.65	0.83



(a) Plot the data on the grid and draw a line of best fit. [3 marks]

(b) In order for water to be considered safe for drinking, the concentration of zinc must be less than 2.80 ppm

The absorbance of the water sample was 0.58. Explain whether this water is safe for drinking. [2 marks]

[NESA 2017 Q22]

Question 15

(i) Outline a test that can be carried out to observe the flame colour of ONE metal ion. Include a safety precaution in your answer. [2 marks]

(ii) Account for the flame colour that should be observed in part **(i)**. [3 marks]

[NESA 2017 Q34a; Total = 5 marks]

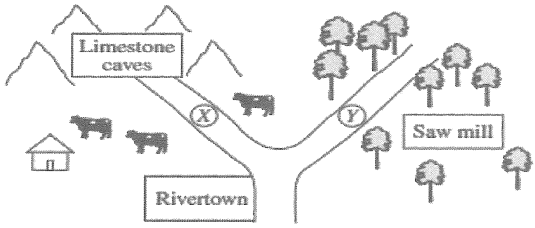
Question 16

Explain why ions of this element (strontium^{2+}) produce a characteristic flame colour when heated strongly.

[BOSTES 2016 Q34a(ii); 3 marks]

Question 17

Rivertown sits at the junction of two rivers.



A simple water purification system has been purchased for the town water supply. It consists ONLY of a sedimentation tank, pH control, sand filters and a chlorination facility.

The system is to draw water either from Site *X* or Site *Y*. A water chemist has obtained the following data from each site.

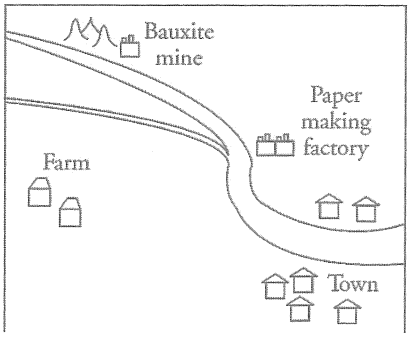
Factor	*X*	*Y*
Turbidity (NTU)	2	400
pH	7.3	6.0
Calcium (ppm)	120	5
Phosphate (ppm)	1.00	0.0001

With reference to the information provided, justify which of the sites, *X* or *Y*, would be the preferred water source for the town water supply.

[NESA 2017 Q 29; 4 marks]

Question 18

The diagram below shows part of the catchment area for a river.



(a) In what ways might the bauxite mine, the paper making factory and the farm pollute the river? [3 marks]

(b) How might the water need to be purified before being used in the town? [3 marks]

(c) What pollutants would the town add to the water? [1 marks]

[Total = 7 marks]

Question 19

(a) Two separate experiments are carried out on samples of water taken from the same river at the same time and place. In the first experiment formation of an insoluble precipitate is used to identify a cation present in the water. In the second experiment the concentration of the cation is determined.
State whether each experiment is qualitative or quantitative analysis.

Experiment 1 _____
Experiment 2 _____

[2 marks]

(b) Explain why the concentration of a metal cation might vary. [2 marks]

(c) Sodium carbonate solution is used to precipitate cations as their carbonates. State the likely identity of the cation if the precipitate is
(i) green **(ii)** white. [1 + 1 = 2 marks]
[Total = 6 marks]

Question 20

A river supplying water to a local community is thought to be contaminated with copper compounds. 750 mL of the water was filtered and the filtrate was heated to remove all of the water. The final mass of the solid was 0.45 g.

(a) Calculate the percentage of dissolved solids in the river water sample. [1 mark]

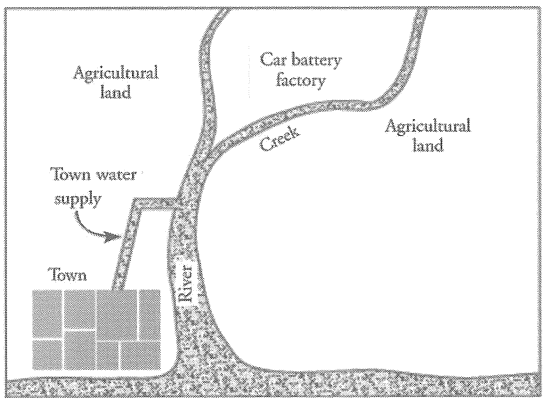
(b) Why was the river water sample filtered before heating? [1 mark]

(c) What chemical test could be used to show that copper compounds are present in the water? [1 mark]

(d) What instrumentation test could identify the metal ion or ions present in the water? [1 mark]
[Total = 4 marks]

Question 21

The diagram below shows a town situated near agriculture and industry. The town relies on the river for its water supply.



(a) Identify ONE chemical species that could be a contaminant of the water supply. [1 mark]

(b) Explain the need to monitor the levels of a contaminant in water supplies. [2 marks]
[BOSTES 2014 Q23; Total = 3 marks]

Question 22
Describe the process of monitoring waterways for eutrophication.
[BOS 2012 Q25; Total = 3 marks]

Question 23
Iron(II) and iron(III) ions can be identified, and their concentrations measured using AAS. Copper(II) ions can similarly be analytically tested, but not copper(I) ions. Explain the reason Cu^+ cannot be identified by AAS (or flame test).
[2 marks]

Question 24
Outline the factors and/or properties for gravimetric analysis to be successful as an analytical technique of substances.
[2 marks]

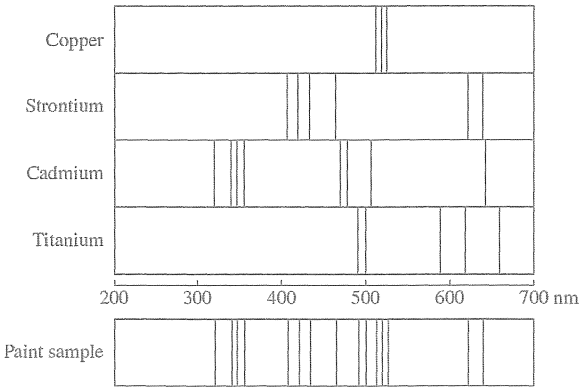
Question 25
Limestone ($CaCO_3$) contributes to the hardness of water by releasing Ca^{2+} ions in water. The chemical equation for this exothermic reaction is shown.

$$CaCO_3(s) + H_2O(l) + CO_2(g) \rightleftharpoons Ca^{2+}(aq) + 2HCO_3^-(aq)$$

(a) Explain why increasing the temperature of hard water would reduce its hardness.
[2 marks]

(b) Describe how atomic absorption spectroscopy (AAS) could be used to measure the effectiveness of heating water to reduce its hardness. [4 marks]
[BOSTES 2014 Q27; Total = 6 marks]

Question 26
The diagrams below show schematic representations of atomic emission spectra from a range of metals and an unknown mixture from a paint sample.

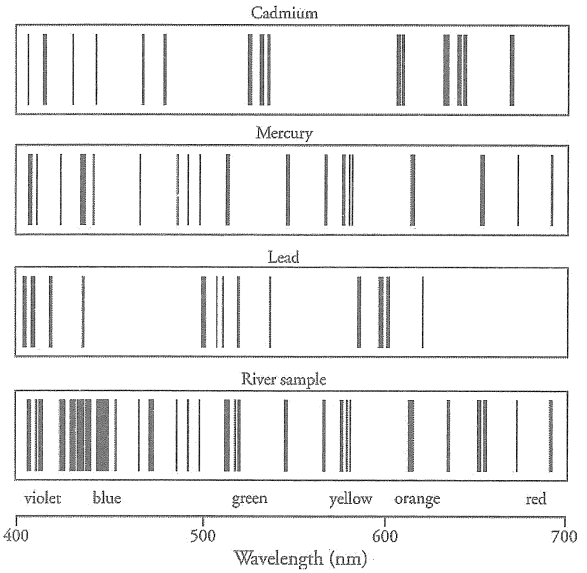


(i) Identify TWO of the metal ions present in the paint sample and justify your answer.
[3 marks]

(ii) Describe how atomic emission spectra are produced and used in forensic analysis.
[4 marks]
[BOSTES 2016 Q35c; Total 7 marks]

Question 27

A pesticide manufacturer is suspected of releasing waste water contaminated with heavy metal ions into a local river. Atomic emission spectroscopy is used to identify the possible pollutants.



(i) Use the emission spectra shown above, to identify a metal pollutant in the river. Justify your answer. [2 marks]

(ii) Outline a procedure that could be used in a school laboratory to safely produce and analyse the emission spectrum of an element. [3 marks]

[BOS 2013 Q36c; Total 5 marks]

8.2 Analysis of organic substances

Question 28

Describe the chemical tests that could be used to distinguish between alkenes, alkanols and alkanoic acids.

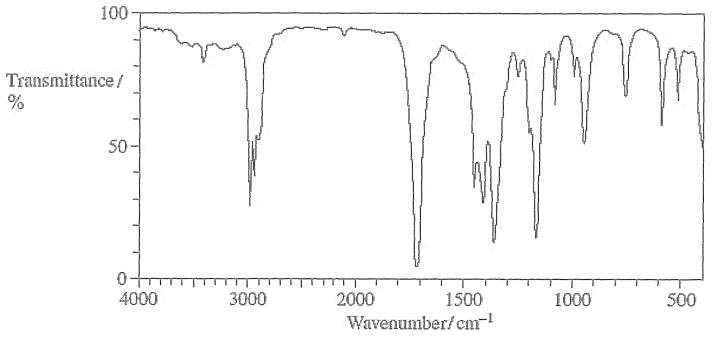
[3 marks]

Question 29

Butan-2-ol can be oxidised by acidified potassium dichromate(VI) to form butanone as shown by the following equation.

$$CH_3CH_2CH(OH)CH_3 + [O] \rightarrow CH_3CH_2COCH_3 + H_2O$$

The infrared spectrum shown on the following page is either that of butan-2-ol or that of butanone.



(a) Identify the compound to which this infrared spectrum refers. Explain your answer. [3 marks]

(b) Explain what is meant by the fingerprint region of an infrared spectrum and state how it is used to confirm the identity of organic molecules such as butan-2-ol or butanone. [4 marks]

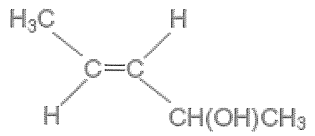
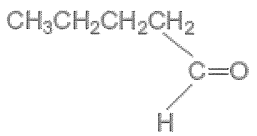
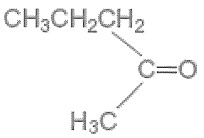
[Total = 7 marks]

Question 30

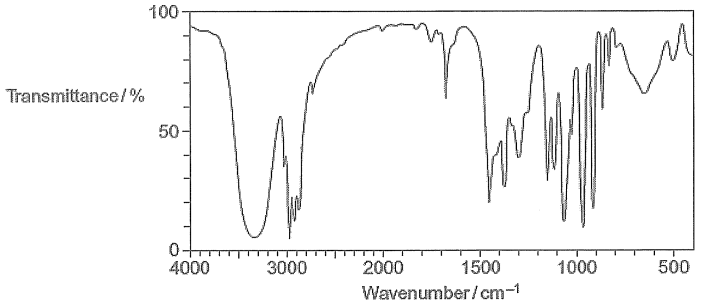
The table on the next page, shows the structures of three isomers with the molecular formula $C_5H_{10}O$.

(a) Name isomer 3. [1 mark]

(b) A chemical test can be used to distinguish between separate samples of *Isomer 2* and *Isomer 3*.
Identify a suitable reagent for the test and state what you would observe with *Isomer 2* and with *Isomer 3*. [3 marks]

Isomer 1 	pent-3-en-2-ol
Isomer 2 	pentanal
Isomer 3 	?

(c) The following is the infrared spectrum of one of the isomers 1, 2 or 3.



(i) Deduce which of the isomers (1, 2 or 3) would give this infrared spectrum. [1 mark]

(ii) Identify two features of the infrared spectrum that support your response in part **(i)** and in each case identify the functional group responsible. [2 marks]

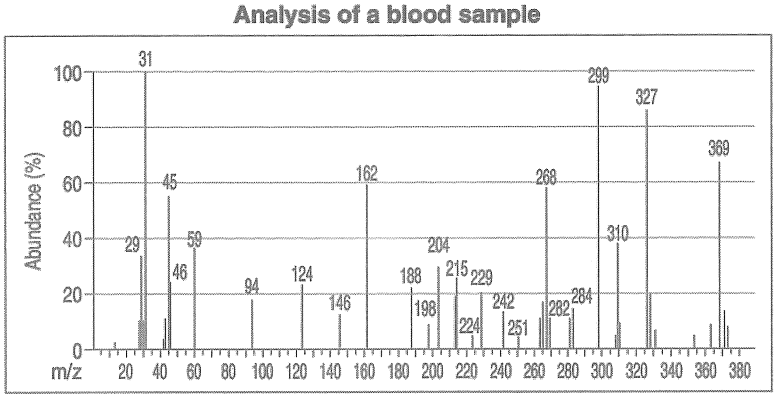
[Total = 7 marks]

Use the mass spectrometry graphs on this and the following page to answer Question 31.

Question 31

Mass spectrometry can be used to identify-drugs in a blood sample.

Below, is a spectrum obtained from the analysis of a blood sample.



With reference to the diagrams of the mass spectra of four substances (Diagrams 1 to 4 on the following page), deduce which of the substances are present in the blood sample. Justify your answer.

[NESA 2017 Q35c(iii); 2 marks]

Diagram 1 – Methoxyp.d

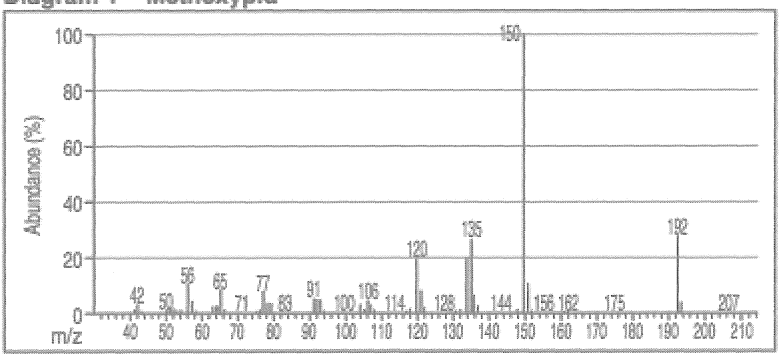


Diagram 2 – Trifluor.d

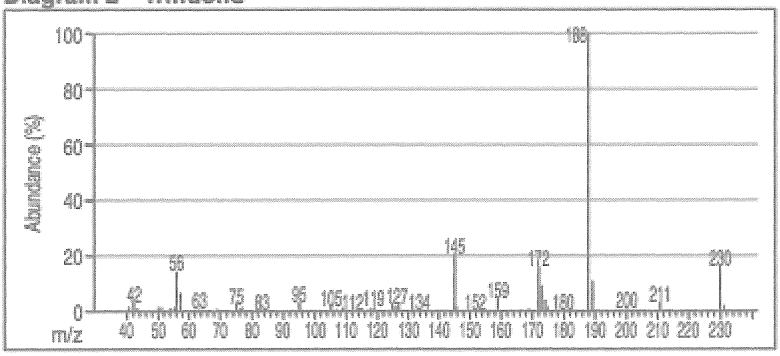


Diagram 3 – Heroin

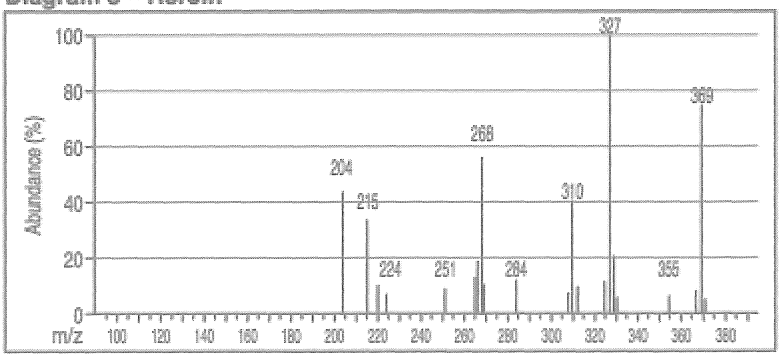
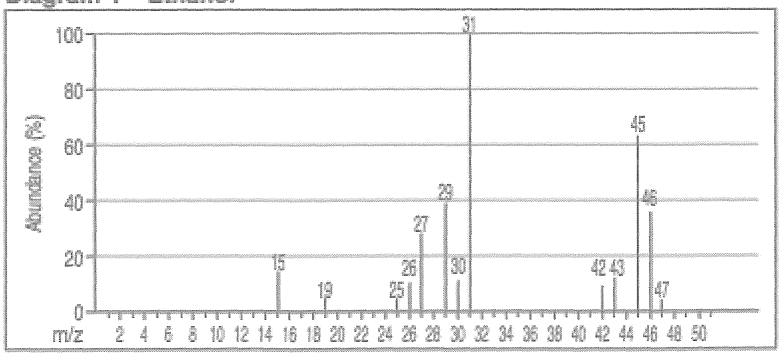
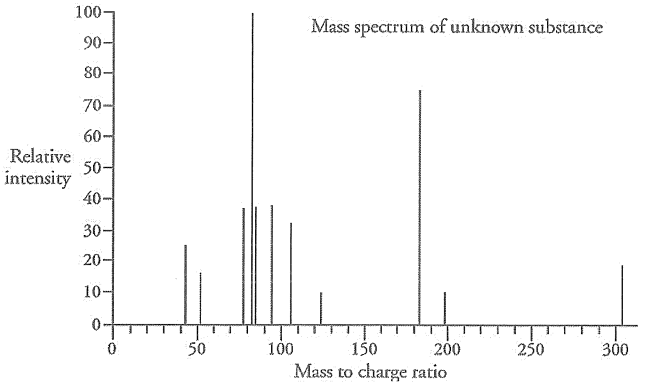


Diagram 4 – Ethanol



Question 32

An unknown substance was collected. It was analysed and its mass spectrum collected and is shown below.



The table below shows the mass to charge ratio of a selection of fragments in the mass spectrum for three compounds of interest in forensic investigations.

Compound name	*Significant fragments (mass to charge ratio)*
Caffeine	67 109 194
Cocaine	82 94 182
Paracetamol	43 109 151

(i) Using the information in the table, identify the unknown substance and justify your choice. [2 marks]

(ii) Describe how mass spectrometry can be useful for analysing forensic evidence. [3 marks]

[BOSTES 2014 Q36c; Total = 5 marks]

Question 33

Alkanes, alkenes, alkanols and alkanoic acids are four different classes of organic compounds.

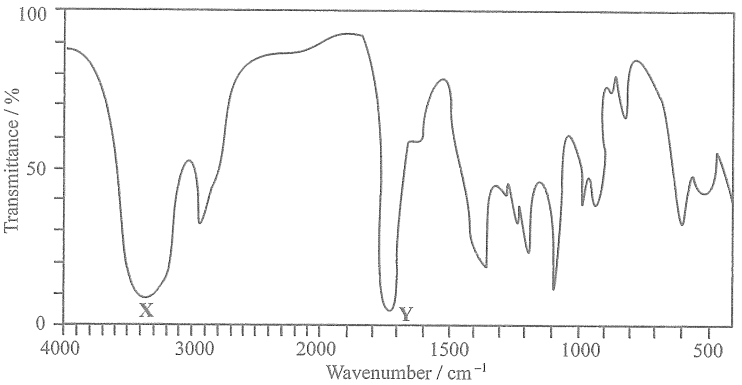
(i) Describe a simple test that would confirm that a compound is organic. [2 marks]

(ii) Describe a sequence of tests that could be used to distinguish between any THREE of the classes of organic compounds named above. [3 marks]

[BOS 2013 Q36d; Total = 5 marks]

Question 34

Below is an infrared spectrum of a compound, with the empirical formula $C_3H_6O_2$.



(a) Identify the functional groups of peaks X and Y. [2 marks]

(b) With reference to the infrared spectrum, draw the structure of two possible isomers for this compound? [2 marks]

[Total = 4 marks]

8.3 Chemical synthesis and design

Question 35

Choose a chemical synthesis process (such as fossil fuel power generation or an ammonia or a fertiliser production) and evaluate the factors to be considered by the company, including but not limited to, the location of the site, reaction conditions and environmental, social and economic issues.

[8 marks]

Question 36

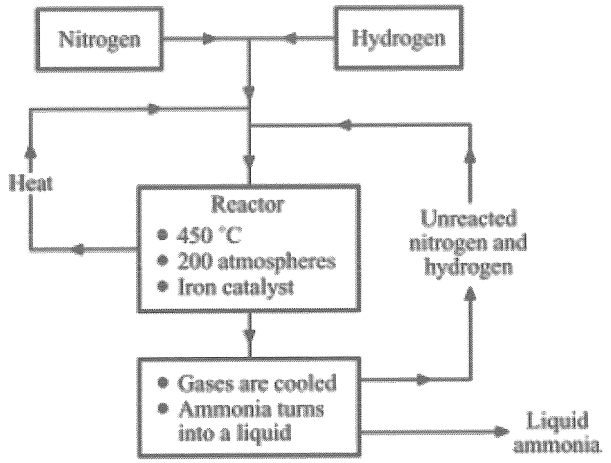
(a) The diagram on the next page is a simplified flow chart of the production of ammonia by the Haber process and a graph of the condition for its production. Evaluate how the process makes the best use of energy and materials. [4 marks]

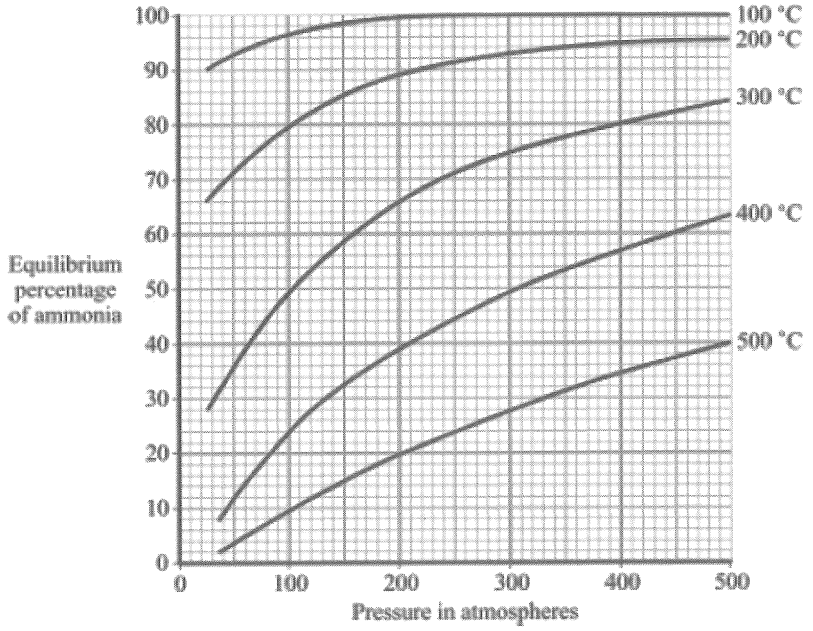
(b) Suggest three other factors that should be considered to produce ammonia, which may not be evident from the flow chart and give reasons for their importance. [6 marks]

[Total = 10 marks]

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \ (+ \text{heat})$$

Flow Chart for the Haber Process





Answers – Module 5: Equilibrium and Acid Reactions

Multiple-choice questions

Question	Answer	Comments
1.	A	Dehydration of cobalt(II) chloride is a reversible reaction and combustion of Mg is irreversible.
2.	B	A chemical equilibrium reaction is dynamic and the forward and backward reactions are occurring continuously.
3.	A	For a reaction to be dynamic, the forward and backward reactions are occurring continuously.
4.	A	For a reaction to be spontaneous ΔG must be negative; hence ΔG is just < 0. Hence if $\Delta G = \Delta H - T\Delta S$ then reaction becomes spontaneous when $T = \frac{\Delta H}{\Delta S}$. The units of enthalpy should be changed from kJ to J. $T = \frac{51 \times 10^3}{118.74} = 430$ K, i.e. the drug decomposes spontaneously at 430 K and is therefore stable at room temperature.
5.	D	Note: Square brackets represent the concentration. As Q2.
6.	B	For an exothermic reaction, the lower temperature will give the best yield. Since 2 mol of products is formed from 3 mol of reactants, increasing the pressure will result in more products being formed.
7.	C	Increasing the concentration of one of the reactants leads to the formation of more products. (A) would have no effect on the position of equilibrium because the number of moles on each side of the equation is equal. (B) would result in less CO_2 being formed. (D) would increase the rate of reaction but not the % conversion.
8.	B	From the graph, the yield increases with increasing temperature, hence the reaction is endothermic. Increasing the pressure reduces the yield which shows that moles (products) > moles (reactants).
9.	A	The lines for CO and H_2 will change in the same direction, i.e. they will both increase, or both decrease as the system moves to equilibrium. $[H_2]$ will change by *twice* the change for [CO]. $[CH_3OH]$ will change in the opposite direction from the other two lines. Hence before time T_1 the top (solid) line is due to CO, the middle line is due to H_2 and the lower line is CH_3OH.

10. **A** Catalysts provide an alternative reaction pathway with a lower activation. The rate of a catalysed reaction will be faster. Catalysts do **not** change the yield nor the heat of a reaction.

11. **C** Addition of a catalyst only increases the rate of reaction. Decreasing the volume causes the position of equilibrium to move to the left and addition of argon has no effect on the equilibrium position.

12. **B** Decreasing the volume of the chamber will initially increase the concentrations of all the gases. The system will partially oppose this change by moving to the side with the least number of particles, i.e. to the right. Hence there will be a further increase in $[NH_3]$.

13. **C** Since the L to R reaction is endothermic the yield of Z will be greatest at the higher temperature. However, increasing the pressure will move the position of equilibrium to the left since there are fewer moles on this side.

14. **B** The yield of N_2O_4 will increase with decrease in volume, since there are fewer moles on L side compared to R. Also decreasing the area for reaction will increase the collision rate, producing more N_2O_4.

15. **B** Adding OH^- will increasing the pH. To achieve equilibrium, the system will produce more acid to re-establish equilibrium. As there is 1 mole of product compared to 2 moles of reactants, the gas pressure will decrease.

16 **D** The kinetic energy of the particles increases with the temperature increase, resulting in more collisions. However, 'more collisions' is not the determining factor in increasing the rate of reaction, rather it is the increase in 'meaningful collisions' from the particles with greater energy than the activation energy. This is more significant than the increase in the frequency of collisions between faster-moving particles.

17. **D** Increasing the temperature decreases the yield of product Z. Hence the L to R reaction must be exothermic. Increasing the pressure increases the yield of Z, hence there are more moles of reactants than products.

18. **D** The reactant X is 1 mole as opposed to 2 moles of product, hence more products are formed at time *T* to re-establish equilibrium.

19. **B** This reaction is exothermic as the reactants contained more energy product. Net energy for the reaction = (product – reactant) and should not include the activation energy.

20. **D** This two-step reaction released energy in the first step, hence it is endothermic, and the activation energy required to achieve the product is X amount of energy.

21. **A** In endothermic reactions, heat energy is taken in from the surroundings, and turned into potential energy in the products. As a result, the enthalpy of the products is greater than the enthalpy of the reactants.

22. **D** Catalyst speeds the rate of the reaction which is enabled by all the factors in (A) to (C).

23. **A** For the reaction to re-establish equilibrium after addition of water, the Cl^- will decrease to overcome the change.

24. **B** With an increase in pressure, the equilibrium will move to the side that will reduce pressure – the side with the least number of moles of GAS. Hence, the syringe will change to colourless.

25. **B** The smaller the value of K_{eq} is indicative that the reaction has reached completion.

26. **C** To check the direction of the reaction, compare the reaction quotient (Q) with the equilibrium constant.

$$Q = \frac{[HF]^2}{[H_2][F_2]}$$

$$= \frac{0.500^2}{0.0120 \times 0.0200}$$

$$= 1042$$

Since $Q >> K$ (313), the reverse reaction dominates as Q decreases on the way to equilibrium. Hence, [HF] will be < 0.500 M at equilibrium. The selection of option (B) or (C) assumes that the forward reaction is dominating as the system moves to equilibrium.

27. **C**

$$K = \frac{[F_2]^3[Cl_2]}{[ClF_3]^2}$$

28. **C** As this reaction is exothermic, lowering the temperature favours the forward reaction and 0.150 mol ClF_3 reacts to produce the products.
Hence: (0.150 mol) $ClF_3 \rightarrow$ (0.225 mol) F_2 + (0.075 mol) Cl_2.

29. **B** K_{sp} is the product of the two ions: $MgCl_2 \rightleftharpoons Mg^{2+} + 2Cl^-$

30. **C** As Q24, $Sn(OH)_2 \rightleftharpoons Sn^{2+} + 2OH^-$

31. **A** K_{sp} of Ag_2CrO_4 is larger than Tl_2CrO_4 hence more soluble; 2 moles of Ag^+ in 1 mole Ag_2CrO_4, hence the most soluble compared to the other two compounds.

32. **C** Ba^{2+} and Pb^{2+} are insoluble in sulfates and carbonates, $BaCl_2$ is soluble but $PbCl_2$ is insoluble (sparingly soluble).

Free-response questions

5.1 Static and dynamic equilibrium

Question 1

(i) The following reaction can be used to model an equilibrium reaction.

$$W(aq) + X(aq) \rightleftharpoons Y(aq) + Z(aq)$$

Data showing how the concentrations of W and Y vary with time can be plotted to give concentration–time graphs.

More data at different temperatures can show the effect of temperature on the position of equilibrium and how the initial rates of the forward or reverse processes vary with temperature.

The concentration–time graphs obtained for this system would model those of real systems. [2 marks]

(ii) The following points can be made about this modelling exercise.

- When the concentrations no longer change, the system has reached equilibrium.
- The equilibrium constant, K, for the reaction can be calculated from the data at the various temperatures.
- The effect of changing the temperature can be seen. The system should reach equilibrium faster at higher temperatures.
- The sign of ΔH for the forward reaction can be deduced.
- The exercise gives no information about the rates of the forward and reverse processes at equilibrium.
- Equilibrium systems are dynamic. The forward and reverse reactions are still occurring even though the concentrations are not changing.

[3 marks]
[Total = 5 marks]

Question 2

The balanced chemical equation for the complete combustion of octane (C_8H_{18}) is as follows:

$$C_8H_{18}(l) + \frac{25}{2} O_2(g) \rightarrow 8CO_2(g) + 9H_2O(g)$$

We calculate $\Delta S°$ for the reaction using the (products – reactants) rule, where m and n are the stoichiometric coefficients of each product and each reactant:

$$\Delta S_{rxn} = \Sigma mS(\text{prod}) - \Sigma nS(\text{reacts}) = [8S(CO_2) + 9S(H_2O)] - [S(C_8H_{18}) + \frac{25}{2} S(O_2)]$$

$$= \{[8 \times 213.8] + [9 \times 188.8]\} - \{[1 \times 329.3)] + \frac{25}{2} \times 205.2]\} = 515.3 \text{ J/K}$$

$\Delta S°$ is positive, as expected for a combustion reaction in which one large hydrocarbon molecule is converted to many molecules of gaseous products, increase in 'disorder'.

[2 marks]

Question 3

Doubling the concentration of the organic compound, will double the chance of a collision between it and a hydroxide ion, hence doubling the rate of the reaction. If also doubling the concentration of the hydroxide ions, that will double the chance of a collision again. The overall effect will be to speed up the reaction rate four times.

[3 marks]

Question 4

Complete combustion of methane: $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

There are 3 moles of reactant gases and 1 mole of product gas. Hence, there is a decrease in entropy as the reactants are more 'disordered' (greater number of moles of gases) than the product.

[2 marks]

Question 5

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

ΔS = (products) – (reactants) = $(212 + 6 \times 205) - (6 \times 214 + 6 \times 70)$

= -262 J K^{-1} mol^{-1}. Total entropy change for the reaction without sunlight is negative, hence entropy decreases. This reaction cannot proceed spontaneously and therefore, must be driven by an external energy source – sunlight.

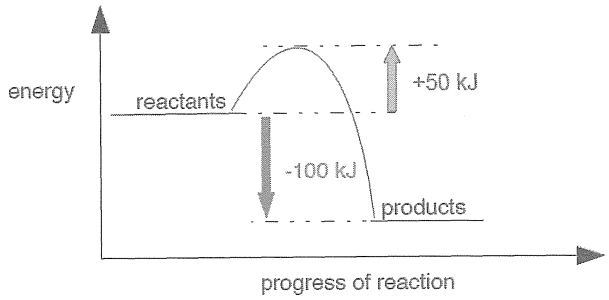
[4 marks]

5.2 Factors that affect equilibrium

Question 6

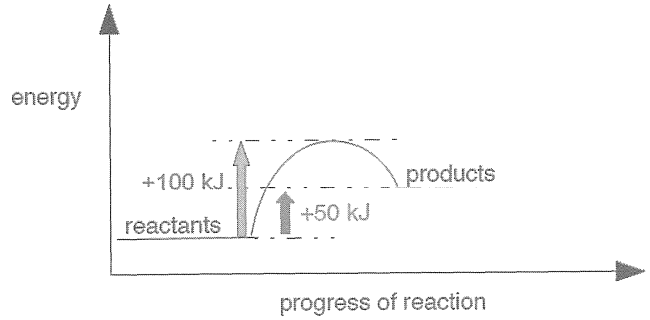
(a)

(i)



[1 mark]

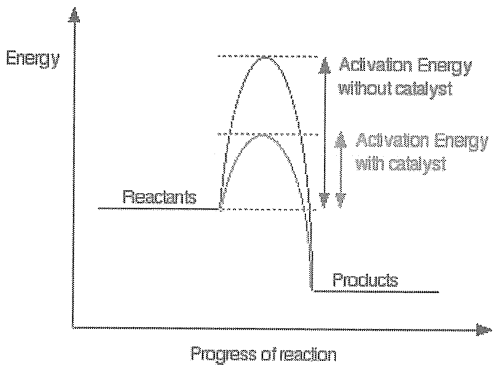
(ii)



[1 mark]

(b) For a reaction to occur, sufficient energy is required to break the bonds. In the exothermic reaction in part **(i)** the reactants had more energy than the product, but it is not sufficient for the reaction to proceed, hence the 50 kJ of activation energy was required for the reaction. [2 marks]

(c)

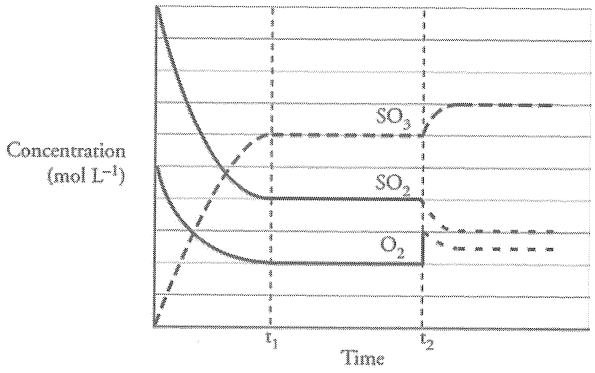


[1 mark]
[Total = 5 marks]

Question 7

(a) The reaction has reached equilibrium. The rates of formation of products and reactants are equal and opposite. [1 mark]

(b) (i)



[2 marks]

(ii) The equation for the reaction is: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$
When more O_2 is added the position of equilibrium moves to the right, i.e. more SO_3 is formed to partially compensate for the change (Le Chatelier's principle). Hence the concentrations of SO_2 and O_2 are reduced (in a 2:1 ratio).
[2 marks]
[Total = 5 marks]

Question 8

(a) At two minutes, since the concentrations have stopped changing. [2 marks]

(b) The decomposition of phosgene is endothermic. According to Le Chatelier's principle, if the temperature is increased, the system will try to overcome the changes to re establish a new equilibrium position. From the graph, $COCl_2$ concentration decreases, while CO and Cl_2 concentrations increase after the temperature increases, showing that the decomposition is endothermic, forcing the reaction to the right as heat is absorbed. [3 marks]
[Total = 5 marks]

Question 9

Carbon dioxide dissolves in water according to the following equilibrium:

$$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq) \qquad \Delta H = -ve$$

An increase in pressure will result in more CO_2 dissolving and an increase in solubility. An increase in temperature will encourage the endothermic process to take place. In this case, the reverse reaction results in production of CO_2 and lower CO_2 solubility.

[3 marks]

Question 10

Le Chatelier's principle states that when a system at equilibrium experiences a disturbance (such as concentration, temperature, or pressure changes), it will respond to restore a new equilibrium state.

[1 mark]

Question 11

(a) Higher percentage of ethanoic acid would be converted to the ester. If you disturb the equilibrium by adding more ethanol, Le Chatelier states that the position of equilibrium will move to remove it again. It can only do that by reacting it with ethanoic acid to make more ethyl ethanoate. [2 marks]

(b) Sulfuric acid is a catalyst to this slow reaction; hence it has no effect. A catalyst speeds up the forward and back reactions equally, and so there is no change in the position of equilibrium. [2 marks]

[Total = 4 marks]

Question 12

(a) The position of equilibrium would move to the right – more ammonia would be formed. According to Le Chatelier, an increase in pressure, will cause the system to respond by reducing it again. Pressure is caused by molecules hitting the sides of the container; fewer molecules, then the pressure will be lower. The forward reaction produces 2 molecules for every 4 of reactants and hence the forward reaction will cause the pressure to reduce. [2 marks]

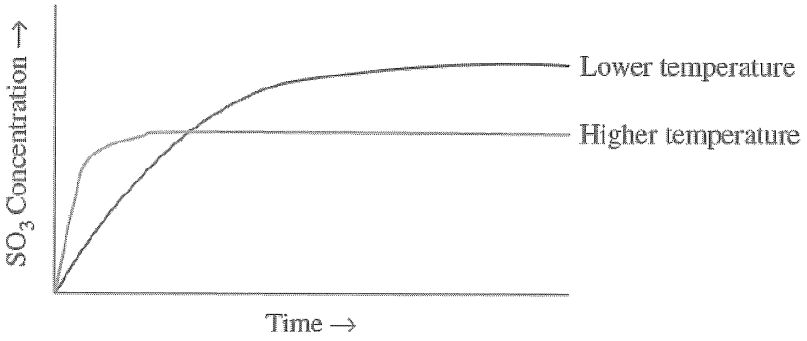
(b) Low temperature. Lowering the temperature, according to Le Chatelier, will cause the reaction to move in such a way as to increase it again. The forward reaction is exothermic, which means that it produces heat energy which would cause the temperature to increase again. [2 marks]

(c) N_2 and H_2 do not react at low temperatures, because the activation energy of the reaction is so high. Even at moderately raised temperatures, the reaction is very slow. Hence, although a low temperature might eventually produce high percentage conversion of N_2 and H_2 into NH_3, the reaction is very slow for it to reach equilibrium. From a manufacturer's point of view, this is not economically suitable. [2 marks]

[Total = 6 marks]

Question 13

(i)



[2 marks]

(ii) Concentration of gases in 1.0 L container, mol L^{-1}.

	Moles SO_2	*Moles O_2*	*Moles SO_3*
Initial	1.0	1.0	0
Used/made	0.70	0.35	0.70
Final	0.30	0.65	0.70

$$\frac{[SO_3]}{[SO_2].[O_2]^{\frac{1}{2}}}$$

$$= \frac{0.7}{0.3 \times 0.65^{\frac{1}{2}}} = 2.9$$

Since $2.9 \neq 12.1$, equilibrium has not been reached.

[4 marks]
[Total = 6 marks]

Question 14

(i) Initially, $[H_2]$ would drop as the volume of the container was suddenly increased. However, as there is a 3:1 ratio of gas particles in the equilibrium reaction, the reverse reaction would be favoured to increase pressure by increasing the number of particles, and so $[H_2]$ would then start to increase again until equilibrium was re-established.

[2 marks]

(ii)

	Moles H_2	*Moles CO*	*Moles CH_3OH*
Initial	0.5	1.00	2.50
Used/made	0.36	0.18	0.18
Final	0.86	1.18	2.32

equilibrium concentrations in the 2.00 L container

$[H_2] = 0.43$

$[CO] = 0.59$

$[CH_3OH] = 1.16$

$$K = \frac{[CH_3OH]}{[H_2]^2[CO]} = \frac{1.16}{0.43^2 \times 0.59} = 11$$

[3 marks]

[Total = 5 marks]

Question 15

In the Haber process, nitrogen and hydrogen, in a 1:3 ratio, are heated to 300 to 500°C, compressed to 150 to 250 atmospheres and passed over an iron catalyst. The product is ammonia.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g); \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

After passing over the catalyst ammonia is removed from the gases and the unreacted nitrogen and hydrogen are passed over the catalyst again.

The conditions used are a compromise between three factors:

- rate of reaction
- equilibrium yield
- economic concerns.

At room temperature. the rate of reaction is very low but in theory the yield is high. Increasing the temperature increases the rate of reaction, but since the reaction is exothermic the yield falls as the temperature rises. Since the reaction converts 4 moles of reactant into 2 moles of product increasing the pressure increases the yield of ammonia. However, high pressures require more costly equipment and it costs more to maintain the high pressures throughout the process. The conditions must be carefully monitored and maintained to produce ammonia in the most economical way.

The reactant gases must be pure and in a 1:3 ratio. Impurities such as CO_2, CO, H_2O or H_2S would poison the catalyst and reduce the yield of ammonia.

[6 marks]

Question 16

(a) CO_2 is present in the mixture. Before opening of the bottle, there is an equilibrium existing between the carbon dioxide present in the solution and that present in the empty space above. Carbon dioxide molecules keep going inside the mixture and coming out of it, thereby establishing equilibrium. When the bottle is opened, the closed system becomes an open system. Thus, the equilibrium is lost. As CO_2 is released the pH will increase. [2 marks]

(b) Addition of a slice of lemon, which is acidic, will decompose the carbonate in the drink, causing a release of CO_2; i.e. the reverse of equation. [2 marks]

(c) $$CO_2(g) \underset{\text{endothermic}}{\overset{\text{exothermic}}{\rightleftharpoons}} CO_2(aq)$$ [2 marks]

(d) As the gas escapes with time, the amount of carbonic acid is reduced, hence the pH will increase. [2 marks]

[Total = 8 marks]

5.3 Calculating the equilibrium constant K_{eq}

Question 17

(a) Homogeneous in an equilibrium reaction is where the reactants and products are present in a single solution, in the same phase. The chemical species involved can be molecules, ions, or a mixture of both. [1 mark]

(b) $K_c = \dfrac{[CH_3CH_2OH]}{[CH_2{=}CH_2][H_2O]}$ [2 marks]

[Total = 3 marks]

Question 18

$$K_{eq} = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$

[2 marks]

Question 19

(a) $K_{eq} = \dfrac{[Hb(O_2)_4]}{[Hb][O_2]^4}$ [1 mark]

(b) $Hb(O_2)_4(aq) + 4CO(g) \rightleftharpoons Hb(CO)_4(aq) + 4O_2(g)$ [2 marks]

(c) The equation is the reverse of (b);

[2 marks]
[Total = 5 marks]

Question 20

In the Haber process, ammonia is produced from nitrogen and hydrogen in the following exothermic reaction:

$$N(g) + 3H_2(g) \rightleftharpoons 2NH_3(g); \Delta H = -92 \text{ kJ}.$$

Being exothermic, yield is increased by lowering the temperature of the reaction mixture, which would drive the reaction to the right, as according to Le Chatelier's principle, the reaction would be favoured that produced heat. On the graph, this is clearly shown, as for each pressure, the yield increased at lower temperatures. Maximum yield could be obtained at very low temperatures; however, the rate of ammonia formation would be compromised at low temperatures, hence, in the Haber process, a temperature of about 450°C is used. This produces an acceptable yield. A catalyst of Fe_3O_4 is used to maintain an acceptable rate of reaction at this low industrial temperature. In the reaction above, there is a 4:2 ratio of gaseous reactants to products, so higher pressures will drive the reaction to the right to reduce moles of gas, which reduces the pressure. Ideally as shown on the graph, extreme pressures would increase the yield. However, in the Haber process, the cost of maintaining high-pressure reaction vessels is prohibitive, so a pressure of 300 atm is used, which is an acceptable compromise.

[6 marks]

Question 21

(a) Decreasing the volume of the reaction vessel will increase the pressure. This will drive the reaction to the right-hand side as there are fewer moles of gas on this side of the equation. [2 marks]

(b) Adding a catalyst to the equilibrium mixture will have no visible effect on the reaction mixture. This is because a catalyst will speed up the rate of both the forward and the reverse reactions. [2 marks]

[Total = 4 marks]

Question 22

$NH_4HS(s) \quad NH_3(g) + H_2S(g)$

$n NH_3 = 0.0328 = n H_2S$

$$[NH_3] = [H_2S] = \frac{0.0328}{3}$$

$$= 0.0109$$

$$K = [NH_3][H_2S]$$

$$= 0.0109 \times 0.0109$$

$$= 1.20 \times 10^{-4}$$

[4 marks]

Question 23

(a) $H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g) + \text{heat}$

$$K_{eq} = \frac{[HCl]^2}{[H_2][Cl_2]}$$

[2 marks]

(b) Heat added to the system would shift the equilibrium to the left, as the reaction would try to use up the added heat by producing more H_2 and Cl_2, thus using up HCl and heat, ΔH. The value of K_{eq} will get smaller; due to the, the [HCl] decreasing and both the $[H_2]$ and $[Cl_2]$ increasing. This makes the numerator smaller and the denominator larger. [2 marks]

[Total = 4 marks]

Question 24

(i) $COCl_2(g) \rightleftharpoons CO(g) + Cl_2(g)$

$[CO] = [Cl_2] = 0.028$ M [2 marks]

(ii) $[CO]\,[Cl_2] / [COCl_2]$ [1 mark]

(iii) $Kc = (0.028)^2 / 1 - 0.028 = 8.0 \times 10^{-4}$ [2 marks]

[Total = 5 marks]

Question 25

(i) As this is an exothermic reaction, temperature decrease would decrease the [HNO3], as the reaction would favour the RHS to increase the temperature.

[1 mark]

(iii) With the increase of zinc ion concentration; $[HNO_3]$ would increase

[1 mark]

(iii) Decrease of [NO] would decrease the $[HNO_3]$. [1 mark]

(iv) Increase in pH increases the production of $[HNO_3]$ to counteract the change and reduce the pH. [1 mark]

[Total = 4 marks]

Question 26

(i) $2NO(g) \rightleftharpoons N_2(g) + O_2(g)$ [1 mark]

(ii)

Gas	*Initial Conc mol/L*	*Equilibrium Conc mol/L*
NO	0.400	$0.4 - (2 \times 0.198) = 4.00 \times 10^{-3}$
N_2	0	0.198
O_2	0	0.198

$$K = \frac{0.198 \times 0.198}{(4.00 \times 10^{-3})^2} = 2.45 \times 10^3$$

The position of equilibrium is to the right ($K > 1$), i.e. it lies in favour of the products. [3 marks]

(iii) The value of K_{eq} can be changed by changing the temperature. If the temperature is constant, K_{eq} is constant. [1 mark]

[Total = 5 marks]

Question 27

(i) According to Le Chatelier's principle, increasing the temperature favours the endothermic reaction. Since the L to R process is endothermic, increasing the temperature will increase the yield of NO. [2 marks]

(ii) Since $[Cl_2] = 0.17$ mol L^{-1} ∴ $[NO] = 0.34$ mol L^{-1}

$$K = \frac{[NO]^2[Cl_2]}{[NOCl]^2} = 0.028 \text{ and } \therefore [NOCl]^2 = (0.34)^2 \times \frac{0.17}{0.028}$$

$[NOCl]^2 = 0.702$ and $[NOCl] = 0.838$, i.e. 0.84 mol L^{-1} [3 marks]

[Total = 5 marks]

Question 28

(i)

Decrease in volume (causes increase in pressure)	Decrease in temperature
• System adjusts to decrease pressure by Le Chatelier's principle • Equilibrium moves to reactant side as less moles of gas will reduce pressure • No change to K when equilibrium re-established	• Systems adjusts to increase temperature by Le Chatelier's principle • Equilibrium moves to reactant side to produce more heat • K will be lower when the new equilibrium is established

[3 marks]

(ii)

$$NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$$

$$nNH_3 = 0.0328 = nH_2S$$

$$[NH_3] = [H_2S] = \frac{0.0328}{3}$$

$$= 0.0109$$

$$K = [NH_3][H_2S]$$

$$= 0.0109 \times 0.0109$$

$$= 1.20 \times 10^{-4}$$

[4 marks]
[Total = 7 marks]

5.4 Solution equilibria

Question 29

$K_2CrO_4(aq) + Pb(NO_3)_2(aq) \longrightarrow 2\ KNO_3(aq) + PbCrO_4(s)$

$Pb^2(aq) + CrO_4^{2-}(aq) \longrightarrow PbCrO_4(s)$

K_{sp}: $PbCrO_4(s) \longrightarrow Pb^{2+}(aq) + CrO_4^{2-}(aq)$

$K_{sp} = [Pb^{2+}][CrO_4^{2-}]$

$c_1v_1 = c_2v_2$, (to determine the initial concentration of each species once mixed and before any reaction takes place).

(0.0020 M)(25.0 mL) = (c_2)(100.0 mL); c_2 for K_2CrO_4 = 0.00050 M

Similar calculation for the lead(II) nitrate yields:

c_2 for $Pb(NO_3)_2$ = 0.0000938 M

Calculate the reaction quotient Q, and compare to the value of K_{sp}.

Q = (0.0000938 M)(0.00050 M) = 4.69×10^{-8}

Q is greater than K_{sp}, so a precipitate of lead(II) chromate will form.

[2 marks]

Question 30

$Ag_2CrO_4 \longrightarrow 2Ag^+ + CrO_4^{2-}$ $\quad K_{sp} = [Ag^+]^2[CrO_4^{2-}]$

If solubility of Ag_2CrO_4 is sb: $\quad K_{sp} = (2sb)^2 \times sb = 4sb^3 = 1.1 \times 10^{-12}$

$\therefore$ sb(Ag_2CrO_4) = 6.5×10^{-5},

$[Ag^+] = 2 \times (6.5 \times 10^{-5}) = 1.3 \times 10^{-4}$ M; $\quad [CrO_4^{2-}] = 6.5 \times 10^{-5}$ M

[3 marks]

Question 31

The equilibrium expression for the dissolution of barium sulfate:

$K_{sp} = [Ba^{2+}][SO_4^{2-}]$ for $BaSO_4(s) \rightleftharpoons Ba^{2+}(aq) + SO_4^{2-}(aq)$

Let x represent the barium sulfate that dissolves in the sodium sulfate solution, expressed in moles L^{-1}.

	$BaSO_4(s)$	***$Ba^{2+}(aq)$***	***$SO_4^{2-}(aq)$***
Initial concentration	All solid	0	0.020 M (from Na_2SO_4)
Change in concentration	$-x$ dissolves	$+ x$	$+ x$
Equilibrium concentration	Less solid	x	0.020 M + x

Substitute into the equilibrium expression and solve for x. Assume that x is very small (the solubility is reduced in the presence of a common ion), the term '0.020 + x' is the same as '0.020'.

$1.1 \times 10^{-10} = [x][0.020 + x] = [x][0.020]$

$x = 5.5 \times 10^{-9}$ M; $\therefore$ $[Ba^{2+}] = 5.5 \times 10^{-9}$ M; and $[SO_4^{-2}]$ = 0.020 M

[2 marks]

Question 32

Each substance can be classified as an ionic solute or a nonionic solute. Ionic solutes are electrolytes, and nonionic solutes are nonelectrolytes.

1. Potassium chloride is an ionic compound; therefore, when it dissolves, its ions separate, making it an electrolyte.
2. Glucose is a molecular compound, it is nonionic and ∴ a nonelectrolyte.
3. Propan-2-ol is an organic molecule containing the alcohol functional group. The bonding in the compound is all covalent, so when it dissolves, it separates into individual molecules but not ions; ∴ it is a nonelectrolyte.
4. Magnesium hydroxide is an ionic compound, so when it dissolves it dissociates, ∴ it is an electrolyte.

[3 marks]

Question 33

NaCl is an ionic solute. When dissolved in a polar solvent, the ions become surrounded by particles of the solvent, carrying the ions from its associated crystal. Glucose is a molecular compound. When dissolved in a polar solvent, the compound forms individual neutral molecules without dissociation.

[2 marks]

Question 34

Volume of treated water: 1000 L + 10 L = 1010 L

Concentration of OH^- on addition to 1000 L of pure water:

$$= 4.0\ \text{M} \times \frac{10\ \text{L}}{1010\ \text{L}} = 0.040\ \text{M}$$

Initial concentration of Cd^{2+} in 1010 L of water:

$$(1.6 \times 10^{-5}\ \text{M}) \times \frac{100}{101} \approx 1.6 \times 10^{-5}\ \text{M}$$

Assume that all the Cd^{2+} precipitates.

Concentrations	$[Cd^{2+}]$ M	$[OH^-]$ M
initial	1.6×10^{-5}	0.04
change	-1.6×10^{-5}	-3.2×10^{-5}
final	0	$0.04 - 3.2 \times 10^{-5} \approx 0.04$

At equilibrium, find the concentration of Cd^{2+} that can exist in a 0.04 M OH^- solution:

Concentrations	$[Cd^{2+}]$ M	$[OH^-]$ M
initial	0	0.04
change	$+x$	$+2x$
at equilibrium	x	$0.04 + 2x \approx 0.04$

Substitute these values into the solubility product expression:

$K_{sp}(Cd(OH)_2) = [Cd^{2+}]\ [OH^-]^2 = 2.5 \times 10^{-14}$

$$\left[Cd^{2+}\right] = \frac{2.5 \times 10^{-14}}{1.6 \times 10^{-5}}$$

$$= 1.6 \times 10^{-13}\ \text{M}$$

Note that the effluent will now be very alkaline: pH = 14 + log 0.04 = 12.6, so to meet environmental standards, an equivalent quantity of strong acid must be added to neutralise the water before it is released.

[3 marks]

Answers – Module 6: Acid/Base Reactions

Multiple-choice questions

Question	Answer	Comments
1.	D	Acids have a sour taste, dissociates producing ions which allow electricity to flow, is a good preservative (vinegar), and indicated blue litmus red.
2.	C	Phosphoric acid is the common name for this compound.
3.	C	The anion commonly used is nitrate NO_3^-, one less O atom makes it NO_2^- – nitrite ion, hence its acid name has the suffix – *ous*. This applies for other acids too.
4.	C	Only methyl propanoate is not an indicator in the list, it is an ester.
5.	B	Acid and carbonate always produces $CO_2(g)$. The combining ratio in the balanced equation is 1:1 → 1 of $CO_2(g)$. M($NaHCO_3$) = 84.008 g mol^{-1}, n($NaHCO_3$) = 2/84.008 = 0.023 mol. n(HCl) = 0.45 mol L^{-1} × 0.1 L = 0.045 mol. Only 0.023 mol of HCl will react; ($NaHCO_3$) is limiting. ∴ $V(CO_2)$ = 0.023 × 24.79 = 0.57017 L = 570.17 mL
6.	B	As above Q5. Only 0.023 mol reacted; ∴ 0.45 – 0.023 = 0.022 mol of HCl was in excess.
7.	C	The oxides of I and II are basic and will react with acids. The oxides of V and VI are acidic and will react with bases. The oxide of IV is amphiprotic and will react with both acids and bases. The oxides of III react with acids.
8.	B	Davy suggested that acids contain hydrogen. Lavoisier suggested that acids contain oxygen. Arrhenius suggested that acids ionise to form H^+ ions. Brønsted & Lowry suggested that acids are proton donors.
9.	C	The equation for the reaction is $Ba(OH)_2(aq) + 2HCl(aq) \rightarrow BaCl_2(aq) + 2H_2O(l)$ n(HCl) = 0.0500 × 0.350 = 0.0175 mol n($Ba(OH)_2$) = 0.050 × 0.025 = 0.00125 mol n(HCl) reacting = 2 × 0.00125 = 0.00250 mol n(HCl) remaining = 0.0175 – 0.0025 = 0.0150 mol

10. **B** The only strong base in the list is calcium hydroxide. All hydroxides are strong bases. Ammonia is a weak base.

11. **D** I. CuO neutralises an acid, but as it is insoluble it is not an alkali (i.e. no OH^- are produced)✓.
II. Acid + base ✓,
III. Acid + carbonate is a neutralisation reaction, but in addition to the salt, $CO_2(g)$ is also produced ✓.
IV. MgO in solution produces OH^-, hence the neutralisation reaction ✓

12. **D** To neutralise the excess stomach acid, a base is required. Sodium hydroxide is very caustic base and cannot be buffered; hence $Mg(OH)_2$ is used. (B) and (C) are not bases.

13. **B** As ant bites are acidic, a base is required to neutralise the acid, baking powder is the only base in the list. Baking powder contains $NaHCO_3$.

14. **D** Neuralisation is an exothermic reaction, hence heat is released; which indicates that the reactants have higher energy than the products.

15. **C** The acidic oxides are CO_2, SO_2 and SO_3, and the basic oxides are Na_2O, MgO and K_2O. H_2O and CO are neutral oxides, while Al_2O_3 and ZnO are amphoteric.

16. **D** From pH 4.5 to 6, the indicators will be yellow, yellow and colourless. Between pH 3 and 4.5, methyl orange will be orange, which will add to the yellow and colourless of the other two. From 6 to 7.5, bromothymol blue will be green, which will add to the yellow and colourless of the other two indicators.

17. **B** P, T are metals and form basic oxides, R, U are non-metals and form acidic oxides, Oxides of Q and S are amphoteric.

18. **B** Arrhenius suggested that acids ionise to form H^+ ions. Davy suggested that acids contain hydrogen. Lavoisier suggested that acids contain oxygen.

19. **C** If methyl red is yellow, the pH is greater than 6.2 and if phenolphthalein is colourless, the pH is less than 8.3.

20. **A** CO_2 and N_2O_4 react with water to form acidic solutions, whereas solutions formed when CaO and Na_2O react with water are basic.

21. **B** Methyl orange will show yellow for the potato juice, hence distinguishing between the acids. The other indicators are not within the required range.

22. **A** Weak acid (acetic acid) and a strong base (barium hydroxide) would produce a basic salt.

23. **C** When the pH of a solution changes by 1 unit, $[H^+]$ has changed by a factor of 10. Also, when the pH increases the concentration of hydrogen ions falls. Thus, when the pH changes from 9 to 13, $[H^+]$ has fallen by 10 000.

24. **C** Sodium acetate is the salt of a weak acid and a strong base and will have a pH > 7. KCl and $NaNO_3$ are both salts of strong acids and strong bases. Their solutions will have pH = 7. NH_4Cl is a salt of a strong acid and a weak base.

25. **B** Acid II has the smallest concentration and the lowest pH. The stronger acid will be the most ionised in aqueous solution. More H^+ is produced from a smaller amount of acid II.

26. **D** In aqueous solution, $Ba(OH)_2$ will be completely dissociated and $[OH^-]$ will be $5 \times 10^{-3} \times 2 = 1 \times 10^{-2}$ M.
$-\log_{10}[OH^-] = 2 \therefore pH = 14 - 2 = 12$

27. **C** Sodium acetate is the salt of a weak acid and a strong base and will have a pH > 7. KCl and $NaNO_3$ are both salts of strong acids and strong bass. Their solutions will have pH = 7. NH_4Cl is a salt of a strong acid and a weak base.

28. **D** $[Ba(OH)_2] = 5.0 \times 10^{-5}$. $[OH^-] = (5.0 \times 10^{-5}) \times 2 = 1 \times 10^{-4}$ M – $\log_{10}[OH^-] = 4 \therefore pH = 14 - 4 = 10$

29. **C** $[H^+] = 10^{-3}$; $\therefore [OH^-] = 10^{-14}/10^{-3} = 1 \times 10^{-11}$ as $[H^+][OH^-] = 10^{-14}$

30. **A** Sulfuric acid reacts with Mg to produce the salt $MgSO_4$. As the acid is used up the pH will rise. Also, magnesium has an affinity for hydroxide ion. As the sulfate goes into solution, hydroxide anions associate with the magnesium, increasing the pH.

31. **B** Acetic acid is a weak monoprotic acid. Citric acid is a weak triprotic acid. The $[H^+]$ in the citric acid solution will be slightly greater than that in the acetic acid solution. Hydrochloric acid is a strong acid.

32. **C** The acetic acid has been diluted. Hence $[H^+]$ will decrease and thus pH rises. Acetic acid is a weak acid and the % hydrolysis, or degree of ionisation, increases with increasing dilution. Increasing the volume causes the position of equilibrium to move to the right.

33 **D** Acid II and IV are completely ionised, hence are strong acids.

34 **B** As above; weak acids will only partially ionise, hence I and III are weak acids. The diluted acids will have less molecules and ions in the solution, hence III and IV are diluted.

35. **D** $pH = -\log_{10}([H^+]) = -\log_{10}(0.018) = -(-1.74) = 1.74$

36. **D** When reacted with excess acid 1 mole of each of these compounds will produce 1 mole of CO_2. The largest mole of compound and hence mole of CO_2 will result from the compound with the smallest molar mass since n(compound) = 1.0 ÷ molar mass.

37. **C** Increasing pH corresponds to decreasing $[H^+]$. When the pH changes by 1 unit the $[H^+]$ changes by a factor of 10.

38. **B** As the temperature decreases the pH rises and hence $[H^+]$ falls. H^+ ions are present because HA has partially ionised. When $[H^+]$ falls, less HA has ionised.

39. **B** The solution with the highest pH will have the lowest $[H^+]$. More dilute solutions have lower $[H^+]$. HCl is a strong acid and will be completely ionised in solution, whereas acetic acid is only partially ionised.

40. **C** The combining ratio of $Ba(OH)_2$: HCl is 1:2.
$n(Ba(OH)_2) = 0.02 \times .02 = 0.00004$ mol;
$n(HCl) = 0.04 \times 0.05 = 0.002$ mol. ∴ $Ba(OH)_2$ is limiting.
HCl reacted = $0.0004 \times 2 = 0.0008$ mol.
Excess HCl = $0.002 - 0.0008 = 0.0012$ mol.
∴ $[H^+] = 0.0012/(0.05 + 0.02) = 0.01714$ M.
$pH = -\log_{10}(0.01714) = 1.77; \approx 1.8$

41. **A** HSO_4^- is a proton donor (SO_4^{2-}) and acceptor H_2SO_4, hence is amphiprotic.

42. **C** The solution must be diluted by a factor of 100 ($[H^+]$ changes from 10^{-3} to 10^{-5} mol L^{-1}). In (C), the solution is diluted from 10 mL to 1000 mL by adding 990 mL of water.

43. **A** In this case, the reaction of a strong acid (HCl) with a weak base (NH_3) will produce an acidic salt, (NH_4Cl). Hence the equivalence point of this reaction will be less than pH 7. This will be detected in the pink to pale yellow colour change.

44. **B** Citric acid is triprotic, hence for neutralisation, 3 moles of OH^- would be required for 1 mole of citric acid.

45. **C** pH of $4 = 10^{-4}$ ∴ $(0.1 \text{ L} \times 0.01 \text{ M})/10^{-4} = 10$ L. As there is already 100 mL of acid, they need to add 9900 mL of water.

46. **B** The neutralisation reaction is 1:1 ratio, hence the acid is in excess. n(NaOH] = 0.004, n[HCl] = 0.006, ∴ 0.002 mol of HCl is unreacted. To find the [H^+] = 0.002 mol/0.1 L = 0.02M. pH = $-\log_{10}(0.02)$ = 1.7

47. **B** The more positive the value of pK_a, the smaller the extent of dissociation, hence pK_a of 3.29 means it is weaker than acetic acid.

48. **B** The pH of a buffer solution changes very little when small amounts of a base (or an acid) are added. The added base reacts with a weak acid present in the buffer. As more of the base is added, the concentration of this weak acid falls and eventually the pH of the buffer starts to rise.

49. **A** A buffer solution is formed when an acid is mixed with its conjugate base in approximately equal concentrations. HNO_3 is a strong acid.

50. **A** Step 3 will dilute the base transferred from the pipette, i.e. there is less base to react. This will mean that a smaller volume of acid will have to be used and thus the calculated concentration of acid will be too high.

51. **B** The equivalence point of the second titration is between pH 7 and about pH 3. The appropriate indicator must completely change colour in this pH range.

52. **C** The equivalence point of a titration is when the number of moles of acid and the number of moles of base are in the same ratio as in the relevant chemical equation.

53. **B** Washing the pipette with water will mean that less base will be taken. Hence less acid would be needed. Subsequent titrations would not be affected since the pipette would now be wet with base. Answers (A) and (C) would mean that more acid would have been used. (D) is the correct analysis procedure and should produce consistent results.

54. **A** The dilution procedures in (B) and (C) would not be expected to give reliable results since they are of limited accuracy. (D) would be reliable only if the flask had been clean **and** completely dry. (A) is the most reliable and precise method.

55. **C** $n(N_2O_5)$ = 2.16 ÷ 108.02 = 0.0200 mol
$n(HNO_3)$ = 2 × 0.0200 = 0.0400 mol
n(NaOH) = 0.0400 mol (1:1 reaction);
volume NaOH = 0.0400 ÷ 0.25 = 0.160 L.

56. **A** In conjugate acid–base pairs, the acid has one more H^+ than the base. H_3O^+ and OH^- differ by $2H^+$, as do H_3O^+ and O^{2-}.

57. **D** A buffer is formed when a weak acid is mixed with its conjugate base. The pair $H_2PO_4^-/HPO_4^{2-}$ is a weak acid and its conjugate base.

58. **C** The solid is weighed in a beaker, dissolved and transferred to a volumetric flask using a filter funnel. An accurately measured volume is essential to produce a standard solution.

59. **A** $Na_2CO_3 + 2CH_3COOH \rightarrow 2NaCH_3COO + H_2O + CO_2$
$n(CH_3COOH) = 0.1 \times 0.5 = 0.05$ mol
$n(Na_2CO_3) = \frac{1}{2}n(CH_3COOH) = 0.05/2$ mol
Mass $(Na_2CO_3) = 0.05/2 \times 10^6 = 2.649$ g = 2.65 g.

60 **B** HCl and CH_3COOH are both monoprotic acids. Since equal volumes of the acids with the same concentration are used they will require the same volume of the NaOH solution.

61 **C** In an acid–base conjugate pair, the acid and the base only differ by H^+.

62 **D** (D) represents a burette, which will deliver an accurate volume of a solution.

63 **D** The indicator should change colour when there is a very rapid change in pH, i.e. on the vertical part of the curve (pH 7 to 12).

64 **C** A conjugate base would only differ by H^+.

65 **A** For a buffer solution to be effective the, almost equal amounts of weak acid and its conjugate base and vice versa. HCl is a strong acid, and hence is ineffective as a buffer.

66 **A** A burette is the only piece of apparatus in thc list, which would deliver an accurate volumetric quantity.

Free-response questions

6.1 Properties of acids and bases

Question 1

Acids:

- In water, H^+ dissociates and can conduct electricity due to the presence of ions (electrolytes).
- Have a sour taste.
- Are corrosive.
- Have a pH less than 7, hence change blue litmus red.
- Reacts with reactive metals to produce $H_2(g)$ and decompose carbonates to produce $CO_2(g)$.
- Neutralise a base by producing a salt and water.

Bases:

- Are bitter and have a soapy feel.
- Neutralise acids to produce salt and water.
- Are caustic.
- If soluble in water, produce alkali solutions, which conduct electricity.
- Have a pH greater than 7 and change red litmus blue.

[4 marks]

Question 2

Compound name	*Formula*	*Compound name*	*Formula*
Potassium hydroxide	KOH	Ammonia	NH_3
Nitrous acid	HNO_2	Carbonic acid	H_2CO_3
Sulfurous acid	H_2SO_3	Phosphoric acid	H_3PO_4
Sulfuric acid	H_2SO_4	Barium hydroxide	$Ba(OH)_2$
Hydrochloric acid	HCl	Sodium hydrogen carbonate	$NaHCO_3$

[10 marks]

Question 3

$HCl(aq) + NaHCO_3(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$

Net: $H^+(aq) + HCO_3^-(aq) \rightarrow H_2O(l) + CO_2(g)$

[2 marks]

Question 4

$CaCO_3(aq) + SO_2(g) \rightarrow CO_2(g) + CaSO_4(aq)$

Products are: carbon dioxide and calcium sulfate.

[3 marks]

Question 5

$2HCl(aq) + Al(OH)_3(s) \rightarrow AlCl_3(aq) + 3H_2O(l)$

$2HCl(aq) + Mg(OH)_2(s) \rightarrow MgCl_2(aq) + 2H_2O(l)$

[2 marks]

Question 6

The elements of groups I and II are metals. The oxides of these metals are basic (e.g. Na_2O, BaO). In descending these groups, the oxides become more basic. On the right-hand side of the periodic table the oxides of non-metals in groups IV to VII, are acidic (e.g. CO_2, NO_2, SO_3, Cl_2O_7). The acidity of these oxides increases towards the top of these groups. Elements towards the centre of the periodic table often form amphiprotic (amphoteric) oxides (e.g. Al_2O_3, ZnO). The noble gases (inert gases) have very low reactivity and do not generally form compounds. However, a number of compounds of xenon with highly electronegative elements, such as fluorine and oxygen have been isolated. There are two oxides, XeO_3 and XeO_4. XeO_3 reacts with water to give an acidic solution.

[4 marks]

Question 7

$CaO(aq) + H_2SO_4(aq) \rightarrow CaSO_4(aq) + H_2O(l)$

$2H^+ + O^{2-} \rightarrow H_2O(l)$

[2 marks]

Question 8

(a) The basic outline of the experiment is as follows:

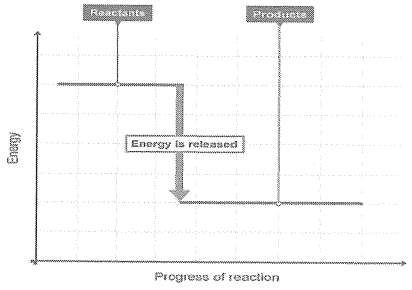
- The temperature of 50 mL of an acid, with a known concentration, is measured in a dry calorimeter.
- 50 mL of a base, with a known concentration, is added to the acid.
- When the temperature has stablised, $\Delta T(T_f - T_i)$ is recorded and calculated.
- The mass of the acid and base ≈ 100 g .
- Calculate the enthalpy of neutralisation using the equation

ΔH = mass, g $\times$ 4.18 J/g/K $\times$ ΔT

If a strong acid and a strong base are used, the ΔH should be close to –57 kJ mol^{-1}.

[2 marks]

(b)



[1 mark]

[Total = 3 marks]

Question 9

The solutions listed range from very low pH (brick cleaner, a strong acid) to very high pH (oven cleaner, a strong base). The other materials are either weak acids or weak bases or neutral. Red cabbage is the most versatile indicator being able to distinguish between the strong and weak acids and most of the bases. The other indicators are less useful. They are all able to distinguish between acids and bases but only some are able to distinguish strong acids from weak acids or to distinguish a weak base from a strong one.

[3 marks]

Question 10

Arrhenius defined an acid as a substance that produces hydrogen ions when dissolved in water. He defined a base as a substance that dissolves in water and produces hydroxide ions. Acid–base reactions are neutralisation reactions.

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

His theory could also explain the difference between strong and weak acids but was unable to explain other observations. For example, some salts are acidic, others are basic and others again are neutral.

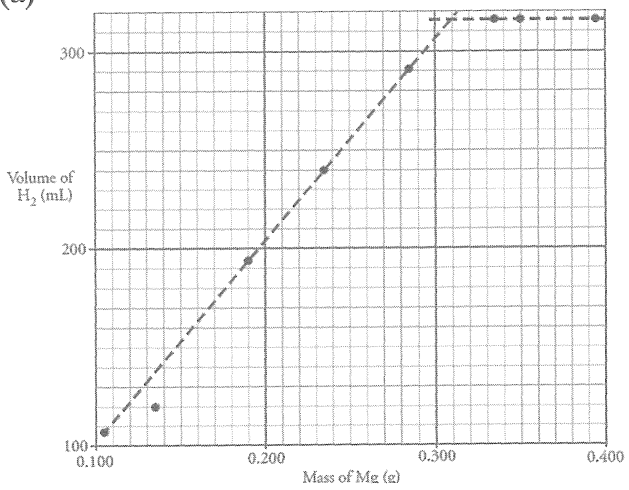
Some compounds whose properties suggest that they are either acidic or basic, but which do not qualify according to the Arrhenius definition. An example is ammonia (NH_3) Its aqueous solution turns litmus blue, it reacts with acids, and displays all the other properties of a base.

The Brønsted–Lowry definition is that an acid is a proton donor and a base is a proton acceptor. An acid–base reaction occurs when a proton is transferred from an acid to a base. An example is the acetate anion, CH_3COO^-, that can combine with a proton to form acetic acid. The Brønsted–Lowry definition is a more general definition and includes the Arrhenius definition. It does not contradict it.

[4 marks]

Question 11

(a)



[3 marks]

(b) The largest volume of gas produced would be 316 mL. The smallest mass of Mg to produce this volume would be 0.31 g [1 mark]

(c) $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

$n(HCl) = 0.100 \times 0.255 = 0.0255$ mol

$n(H_2) = 0.0255 \div 2 = 0.01275$ mol

Volume $H_2 = 0.01275 \times 24.79 = 0.316$ L or 316 mL

If the mass of Mg is less than 0.31 g (0.01275 mol) then the acid is in excess and the volume of H_2 produced will be less than 316 mL. When the mass of Mg is greater than 0.31 g, the acid is the limiting reagent and the volume of H_2 will be 316 mL.

[2 marks]

(d) $n(Mg) = 0.135 \div 24.3 = 0.005556$ mol

Volume H_2 expected $= 0.005556 \times 24.79 = 0.137$ L or 137 mL. [2 marks]

[Total = 8 marks]

Question 12

(a) $CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$

Reactants: ethanoic acid and sodium hydroxide [3 marks]

(b) The reactants are: $CH_3COONa(aq) + H_2O(l)$ – if we look at the net equation: $CH_3COO^- + Na^+(aq)$ and $H^+ + OH^-$

The Na^+ is hydrolysed in the water and combines with OH^- to produces a basic solution, of NaOH. [3 marks]

(c) Acetic acid is a weak acid with $K_a = 1.86 \times 10^{-5}$ and in this case, $c_{\text{weak acid}} >>> K_a$; that is, the equation to use is

$$[H^+] = \sqrt{K_a \cdot c_{\text{weak acid}}} = \sqrt{(1.86 \times 10^{-5}) \times 0.7} = 0.0013638 \text{ M}$$

$pH = -\log[H^+] = -\log(0.0013638) = 2.865$ [1 mark]

[Total = 7 marks]

Question 13

(a) Sulfuric acid, H_2SO_4, nitric acid, HNO_3, and hydrochloric acid, HCl, are all strong acids produced in large quantities. Sodium hydroxide, NaOH, is a strong base.

[2 marks]

(b) The reaction of a strong acid with a strong base release a large amount of energy. The reaction of a strong base with a weak acid or the reaction of a strong acid with a weak base produces less energy. This is one reason why chemical spills should be neutralised by adding either a weak base or a weak acid. Secondly if an acid spill is neutralised by a weak base any excess base will be only weakly basic. Similarly spills of a base should be treated with a weak acid. Solids such as sodium hydrogen carbonate, $NaHCO_3$, or disodium hydrogen phosphate, Na_2HPO_4, can be used to clean up spills of either acids or bases. Both compounds are amphiprotic and will react with either a base or an acid.

$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$
$NaHCO_3(s) + NaOH(aq) \rightarrow Na_2CO_3(aq) + H_2O(l)$
$Na_2HPO_4(s) + HCl(aq) \rightarrow NaCl(aq) + NaH_2PO_4(aq)$
$Na_2HPO_4(s) + NaOH(aq) \rightarrow Na_3PO_4(aq) + H_2O(l)$

An excess of either solid could be swept away once the neutralisation is complete.

[4 marks]
[Total = 6 marks]

Question 14

The earliest definition of an acid referred to their properties, such as sour taste and reaction with bases. In the late 18th century Lavoisier thought that all oxides would dissolve in water to give acidic solutions and suggested that 'all acids contained oxygen'.

sulfur dioxide + water → sulfurous acid

However, some oxides were neutral or dissolved to give basic solutions. Also some acids, such as HCl and HCN, did not contain oxygen. Davy then suggested that 'all acids contained hydrogen'. This was later changed to 'all acids contain replaceable hydrogen'. Acids react with some metals, such as zinc, to produce hydrogen.

zinc + acid → zinc salt + hydrogen

Arrhenius noticed that electrolysis of acids gave hydrogen at the cathode (negative electrode). He suggested that 'when dissolved in water, all acids ionise to form hydrogen ions'.

$H_2SO_4(aq) + H_2O(l) \rightarrow HSO_4^-(aq) + H_3O^+(aq)$

Also, according to Arrhenius strong acids were completely ionised in water whereas weak acids were only partially ionised. Arrhenius suggested that when a base dissolved in water, hydroxide ions were formed. Acid–base reactions involved hydrogen ions reacting with hydroxide ions to form neutral water.

Arrhenius could not explain why carbonates and some metal oxides are basic. Often, they do not dissolve in water but they do neutralise acids.

$CuO(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l)$

The Brønsted–Lowry theory defines acids as proton (H^+) donors and bases as proton acceptors. Acids give up a proton and become a conjugate base.

$$\underset{\text{acid}}{H_2SO_4(aq)} + \underset{\text{base}}{H_2O(l)} \rightarrow \underset{\text{conjugate base}}{HSO_4^-(aq)} + \underset{\text{conjugate acid}}{H_3O^+(aq)}$$

This theory also more clearly defined the role of the solvent and explained why salts can be neutral, acidic or basic.

[5 marks]

Question 15

An acid–base indicator has a different colour/s depending on the pH of the solution to which it is added. Indicators are weak acids of a certain colour whose conjugate base has a different colour. The red molecule *HInd* is the weak acid and proton donor. The green Ind^- is the conjugate base and proton acceptor. In water the following reaction occurs:

$$\underset{\text{red}}{HInd(aq)} + H_2O(l) \rightleftharpoons H_3O^+(aq) + \underset{\text{green}}{Ind^-(aq)}$$

Addition of acid ($H_3O^+(aq)$) will shift the equilibrium to the left and the solution will turn red. Addition of base (OH^-) will remove H_3O^+ ions, forming water. The equilibrium will shift to the right, and the solution will turn green as the concentration of Ind^- ions increases. [4 marks]

Question 16

(a) Red cabbage is a material that contains a natural indicator. The coloured parts are cut into very small pieces and placed in a beaker with some water. The water is boiled until the liquid is coloured. After cooling, the solid material is removed and the liquid retained. [2 marks]

(b) A known acidic solution and a known basic solution are placed in separate test tubes. A few drops of the natural indicator solution is added to each test tube. The colour of each test tube is noted. [2 marks]

[Total = 4 marks]

Question 17

(a) HCl is a strong acid and is completely ionised in solution.
$pH(HCl) = -\log_{10}(0.35) = 0.46$ [1 mark]

(b) **(i)** The equation for the reaction is

$$Ba(OH)_2(aq) + 2HCl(aq) \rightarrow BaCl_2(aq) + 2H_2O(l)$$ [1 mark]

(ii) $n(HCl) = 0.0500 \times 0.350 = 0.0175$ mol
$n(Ba(OH)_2) = 0.050 \times 0.025 = 0.00125$ mol
$n(HCl)$ reacting $= 2 \times 0.00125 = 0.00250$ mol
$n(HCl)$ remaining $= 0.0175 - 0.0025 = 0.0150$ mol
$c(HCl) = 0.0150 \div (0.050 + 0.050) = 0.15$ mol L^{-1}
pH = 0.82 [3 marks]

[Total = 5 marks]

Question 18

(a) Arrhenius suggested that acids ionise in water to produce $H^+(aq)$ ions and bases produce $OH^-(aq)$ ions. The reaction in the glass tube is between the gases NH_3 and HCl and does not occur in aqueous solution. [1 mark]

(b) The reaction of NH_3 with HCl involves the transfer of a proton from HCl to NH_3, which is the Brønsted–Lowry definition of an acid–base reaction.

$$NH_3(g) + HCl(g) \rightarrow NH_4^+ + Cl^-$$ [2 marks]

[Total = 3 marks]

Question 19

$$Al + 3HCl \rightarrow AlCl_3 + \frac{3}{2}H_2$$

$$\text{Moles gas} = \frac{0.150}{24.79} = 6.05 \times 10^{-3} \text{ mol } H_2 \text{ gas}$$

$$H_2{:}Al = \frac{3}{2} : 1 \therefore \frac{2}{3} \times 6.05 \times 10^{-3} \text{ mol Al}$$

$$\text{Mass Al} = n \times M = \frac{2}{3} \times 6.05 \times 10^{-3} \times 26.98 = 0.109 \text{ g (3 sig. figs)}$$

[4 marks]

6.2 Using Brønsted–Lowry theory

Question 20

pH = –log(7.1 × 10^{-5}) = 4.15 and pOH = 14.00 – 4.15 = 9.85

[2 marks]

Question 21

(a) $2H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$ [1 mark]

(b) $6H^+(aq) + 3O^{2-}(aq) \rightarrow 3H_2O(l)$ [1 mark]

[Total = 2 marks]

Question 22

Species that can either act as an acid by donating a proton, or act as a base by accepting a proton are amphiprotic (amphoteric).

When acting as an acid HPO_4^{2-} donates H^+ as follows.

$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons PO_4^{3-}(aq) + H_3O^+(aq)$

When acting as a base, HPO_4^{2-} accepts H^+ as follows:

$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + OH^-(aq)$ [3 marks]

Question 23

Pair 1: HSO_4^-/SO_4^{2-}; Pair 2: HPO_4^{2-}/PO_4^{3-}

[2 marks]

Question 24

(a) As a B–L base: $HSO_4^-(aq) + H_2O(l) \rightarrow H_2SO_4(aq) + OH^-(aq)$ [1 mark]

(b) As a B–L acid: $HSO_4^-(aq) + H_2O(l) \rightarrow SO_4^{2-} + H_3O^+(aq)$ [1 mark]

[Total = 2 marks]

Question 25

pOH = –log(0.0026) = –2.59; pOH = –(–2.59) = 2.59

pH = 14 – 2.59 = 11.41

[1 mark]

Question 26

(a) $[H^+] = 10^{-8.14} = 7.2 \times 10^{-9}$ M [1 mark]

(b) The soil is basic is pH > 7 [1 mark]

[Total = 2 marks]

Question 27

To test it is amphiprotic; it should act as an acid and a base, ∴ add acid and observe for sign of neutralisation, such as heat. Measure pH, then add another base and again measure the pH; pH should increase.

[2 marks]

Question 28

(a) $[H^+] = 10^{-2.4} = 4.0 \times 10^{-3}$ mol L^{-1} [1 mark]

(b) Hydrogen sulfide is the weakest acid as it has the highest pH and therefore lowest concentration of hydrogen ions; this indicated less ionisation of the H_2S molecule.

[3 marks]
[Total = 4 marks]

Question 29

(a) According to B–L, H_2S donates a proton: $H_2S \rightarrow H^+ + HS^-$ [2 marks]

(b) $H_2S + H_2O \rightarrow H_3O^+ + HS^-$; Acid/base pair: H_2S/ HS^- and H_3O^+ / H_2O [3 marks]
[Total = 5 marks]

Question 30

(a) $[H^+] = 10^{-1.5} = 3.2 \times 10^{-2}$ M [1 mark]

(b) new $[H^+] = [H^+]3.2 \times 10^{-2} = 10/1000 = 3.2 \times 10^{-4}$, pH = 3.5 [1 mark]
[Total = 2 marks]

Question 31

(a) Sodium carbonate is the stronger base because a higher pH indicates a greater concentration of hydroxide ions. [2 marks]

(b) pH = 9 this $[H^+] = 10^{-9}$, $[OH^-] = 10^{-14}/10^{-9} = 10^{-5}$ M [1 mark]

(c) CO_3^{2-} [1 mark]
[Total = 4 marks]

Question 32

$c = nv$; $0.520 \times 30 = 0.100 \times v = 156$ mL

[1 mark]

Question 33

(a) $[H^+] = 10^{-13}$ ∴ $[OH^-] = 10^{-14}/10^{-13} = 10^{-1}$ M [1 mark]

(b) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$ [1 mark]

(c) moles of H^+ = moles of OH^- = 0.10 mol/L × 0.200L = 0.020 mol;
V = 0.02/0.40 = 50 mL [1 mark]
[Total = 3 marks]

Question 34

Amphiprotic nature, i.e. acts as an acid and a base:
As a B–L acid: $HCO_3^-(aq) + H_2O(l) \rightarrow H_2CO_3(aq) + OH^-(aq)$
As a B–L acid: $H_2CO_4^-(aq) + H_2O(l) \rightarrow CO_3^{2-} + H_3O^+(aq)$ [2 marks]

Question 35

(a) $n(HCl) = 0.050 \times 0.010 = 5 \times 10^{-4}$ mol
final volume of solution = 4.95 + 0.05 = 5.00 L

$c(H^+)$ in diluted solution $= \frac{5 \times 10^{-4}}{5.00} = 0.0001$ and pH = 4.0 [1 mark]

(b) Methanoic acid and fumaric acid will lower the pH of foods with the following results:

- At a lower pH oxidation of the food is prevented or at least slowed.
- The growth of many bacteria is inhibited as the pH decreases.
- The flavour of many foods is improved. [2 marks]

(c) Since the three acids all have the same concentration the variation in pH of the three solutions must be related to the strengths of the acids. HCl is a strong acid and is completely ionised in solution and has the lowest pH. Methanoic acid and fumaric acid are both weak acids and only partially ionised in solution. Methanoic acid is a weaker acid than fumaric acid, is less ionised and thus has a higher pH.
[2 marks]
[Total = 5 marks]

Question 36

Solutions of sodium hydrogen sulfate, $NaHSO_4$, and sodium dihydrogen phosphate, NaH_2PO_4, are acidic because the ions HSO_4^- and $H_2PO_4^-$ are partially ionised in solution.

$HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$ and $H_2PO_4^-(aq) \rightleftharpoons H^+(aq) + HPO_4^{2-}(aq)$

From the pH values HSO_4^- is a stronger acid than $H_2PO_4^-$ since more H^+ is produced.

The solution of disodium hydrogen phosphate is basic because the ion HPO_4^{2-} is a weak base and reacts with water to produce OH^- ions.

$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + OH^-(aq)$

[3 marks]

Question 37

(a) $Cl_2(aq) + H_2O(l) \rightleftharpoons HOCl(aq) + HCl(aq)$

$OCl^-(aq) + H_2O(l) \rightleftharpoons HOCl(aq) + OH^-(aq)$ [2 marks]

(b) From the equations in part **(a)** addition of Cl_2 will lower the pH of the pool since HOCl and HCl are acids. While addition of NaOCl to a swimming pool will raise the pH of the water since OH^- is produced. [2 marks]
[Total = 4 marks]

Question 38

$n(HCl) = (0.120 \times 0.07500) = 9.00 \times 10^{-3}$ mol
$n(NaOH) = (0.200 \times 0.025) = 5.00 \times 10^{-3}$ mol
$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$
mol ratio NaOH:HCl = 1:1
HCl is in excess by $(9.00 \times 10^{-3} - 5.00 \times 10^{-3}) = 4.00 \times 10^{-3}$mol
Final volume of solution = 75.00 + 25.00 = 100.0 mL
$[H_3O^+] = (4.00 \times 10^{-3}$ mol$) \div 0.100$ L $= 0.0400$ mol L^{-1}
$pH = -\log_{10}[H_3O^+] = -\log_{10} 0.0400 = 1.3979$
= 1.40 (correct to 3 significant figures.)

[3 marks]

Question 39

This experiment is a suitable model for the formation of acid rain. There are a number of features in common with the industrial process. When sulfur present in fossil fuels is burnt sulfur dioxide is formed:

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

The sulfur dioxide then reacts with water (the rain) to produce an acidic solution (the acid rain):

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$$

The effect of the acid rain is shown by the change in colour of the litmus paper.
Some of the limitations of the model are

- it is much smaller in scale.
- it does not simulate the real effects of acid rain, e.g. environmental damage.
- it does allow for the release of sulfur dioxide from natural sources.

[5 marks]

Question 40

Model the behaviour of acids and bases.

Acids		*Bases*	
Strong and concentrated, HA	*Strong and dilute, HA*	*Strong and concentrated, NaOH*	*Strong and dilute, NaOH*
$H^+ H^+ A^- \quad H^+ A^- \quad H^+ H^+$ $A^- A^- \quad H^+ A^- \quad A^- \quad H^+$ $H^+ A^- \quad H^+ H^+ A^- \quad H^+$ $A^- \quad H^+ H^+ \quad H^+ A^- \quad H^+ A$	$H^+ \quad A^- \quad H^+ A^- \quad H^+ \quad H^+$ A^- $A^- \quad H^+ \quad A^- \quad A^- \quad A^-$ H^+	$Na^+ \quad Na^+ \quad OH^- \quad Na^+ \quad OH^-$ $Na^+ \quad OH^- \quad OH^- \quad Na^+ \quad OH^-$ $OH^- \quad Na^+ \quad Na^+ \quad Na^+ \quad OH^-$ $Na^+ \quad Na^+$	$Na^+ \quad OH^-$ $Na^+ \quad Na^+$ OH^- Na^+
Weak and concentrated, HA	*Weak and dilute, HA*	*Weak and concentrated, Na_2CO_3*	*Weak and dilute Na_2CO_3*
$H^+ HA \quad A^- \quad HA \quad A^- \quad H^+$ $HA \quad A^- \quad HA \quad A^- \quad H^+$ $HA \quad H^+ \quad H^+ \quad A \quad A^-$ $HA \quad HA$	$HA \quad A^- \quad HA \quad H^+ \quad A^-$ $HA \quad H^+$ $HA \quad H^+ \quad A^-$ $A^- \quad H^+ \quad HA$	$Na^+ \quad CO_3^- \quad OH^- \quad Na_2CO_3 \quad Na^+$ $NaCO_3 \quad CO_3^- \quad Na^+ \quad Na_2CO_3$ $Na_2CO_3 \quad Na^+ \quad CO_3^- \quad CO_3^-$ $Na_2CO_3 \quad Na^+ \quad CO_3^- \quad Na^+$ $CO_3^- \quad Na_2CO_3 \quad Na_2CO_3$ OH^-	Na^+ $OH^- \quad Na_2CO_3$ Na_2CO_3 Na^+ $CO_3^- \quad Na \quad NaCO_3$ Na^+

[10 marks]

6.3 Quantitative analysis

Question 41

(a) $2NaHCO_3(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$ [1 mark]

(b) The burette may have been washed with water and not with the sulfuric acid. This would have diluted the acid leading to a larger titre. Subsequent titrations would not be affected since now the diluted acid had been removed. Too much alkali may have been delivered from the pipette, hence more acid would be required. [1 mark]

(c) Average titre = $(21.45 + 21.54 + 21.51) \div 3 = 21.50$ mL
$n(I_2SO_4)$ used = $0.02150 \times 0.254 = 0.005461$ mol
From the equation $n(NaHCO_3) = 2 \times n(H_2SO_4) = 0.01092$ mol
$c(NaHCO_3) = 0.01092 \div 0.0200 = 0.546$ mol L^{-1} [3 marks]
[Total = 5 marks]

Question 42

(a) The following steps should be used to prepare a standard solution of potassium hydrogen phthalate, $KHC_8H_4O_4$.

- Dry a sample of $KHC_8H_4O_4$ at 120 to 130°C in an oven for 60 minutes.
- An appropriate mass of the solid is weighed into a clean dry beaker.
- A small amount of distilled water is added to dissolve all of the $KHC_8H_4O_4$.
- The solution is transferred to a 250 mL volumetric flask.
- The beaker is washed several times to transfer the remaining solution to the volumetric flask.
- Distilled water is added to the flask until the bottom of the meniscus just reaches the graduated line on the neck of the flask.
- A stopper is placed in the flask which is then shaken to thoroughly mix the contents. [3 marks]

(b) To be a primary standard a substance should:

- be a readily available inexpensive solid with a high degree of purity (>99.9%).
- have a known composition (formula) which does not change when the solid is exposed to the air (i.e. it should not react with any of the components of air).
- have a high molecular weight to minimise weighing errors. [2 marks]

(c) $n(KHC_8H_4O_4)$ required = 0.25 × 0.15 = 0.0375 mol

mass $(KHC_8H_4O_4)$ = 0.0375 × 204.2 = 7.658 or 7.66 g [2 marks]

[Total = 7 marks]

Question 43

(a) $MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l) + CO_2(g)$

[1 mark]

(b) Boiling the liquid will remove any CO_2 produced by the reaction. CO_2 is an acidic gas which would otherwise react with NaOH.

[1 mark]

(c) n(HCl) added initially = 0.0200 × 0.996 = 0.01992 mol

[1 mark]

(d) n(NaOH) needed to react with excess HCl = 0.02239 × 0.11 = 0.002463 mol

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

n(HCl) remaining = n(NaOH) = 0.002463 mol

[1 mark]

(e) n(HCl) reacted with tablet = 0.01992 – 0.002463 = 0.01746 mol

$n(MgCO_3)$ in tablet = 0.01746 ÷ 2 = 0.008729 mol

mass $MgCO_3$ = 0.008729 × 84.3 = 0.7358 or 0.746 g

[2 marks]

(f) % $MgCO_3$ in tablet = (0.736 ÷ 0.747) × 100 = 98.5%

This value is less than that claimed by the manufacturer.

[2 marks]

[Total = 8 marks]

Question 44

(a) $Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$
$n(Na_2CO_3) = 2.73/106 = 0.0258$ mol; $c(Na_2CO_3) = 0.0258/0.250L = 0.103M$
$0.103 \times 25.0/1 = c \times 20.52/2 = 0.251M$ [1 mark]

(b) diagram of a burette above conical flask, hydrochloric acid in burette, sodium carbonate and indicator in the conical flask. (use pencil and ruler) [4 marks]

(c) Use a pipette. Rinse with about 5 mL of the solution to be measured, discard rinsing. Use a pipette bulb to fill. When filled hold vertically and ensure there are no bubbles, bottom of the meniscus is on the mark and no drops are outside the tip. After emptying, hold the tip to the surface for 5 seconds as the tip has been calibrated to contain remnant solution. [2 marks]

[Total = 7 marks]

Question 45

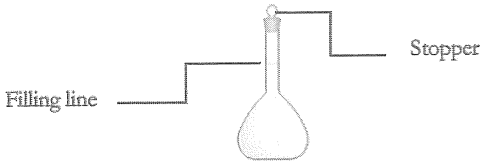
(a) sodium carbonate; sodium hydroxide is hygroscopic (it absorbs water from the air) [2 marks]

(b) Ensure all solution enters the flask, by using a funnel, and the funnel and the beaker are to be rinsed well with distilled water from a wash bottle and all the washings are to be added to the volumetric flask. [2 marks]

(c) distilled water, as water is added to it anyway. [1 mark]

(d) The carbonate is to be dissolved before adding to the flask, then insert stopper and invert and swirl several times. [1 mark]

(e)



[1 mark]
[Total = 7 marks]

Question 46

Set up a concentration table:

Concentration, mol L^{-1}	CH_3COOH	H^+	CH_3COO^-
Initial	0.090	0	0.11
Change	$-x$	$+x$	$+x$
Equilibrium	$0.090 - x$	x	$0.11 + x$

In buffers, x will be very small, as the conjugate base is already present, hence dissociation is suppressed. ∴ at equilibrium $(0.090 - x) \approx 0.090$
and also $(0.11 + x) \approx 0.11$
$K_a = [H_3O^+][CH_3COO^-]/[CH_3COOH] = x(0.11 + x)/(0.090 - x) = x(0.11)/0.090 = 1.8 \times 10^{-5}$
Solve for x: $0.11x = (0.090)(1.8 \times 10^{-5})$
∴ $x = 1.8 \times 10^{-5}$ M $= [H^+]$;
$pH = -\log(1.8 \times 10^{-5}) = 4.82 = pH$ of the buffer

[2 marks]

Question 47

As benzoic acid is a weak acid, $[H_3O^+]$ must be calculated using a reaction table:

	C_6H_5COOH	⇌	H^+	$C_6H_5COO^-$
Initial	0.050		0	0
Change	$-x$		$+x$	$+x$
Final	$0.050 - x$		x	x

The equilibrium constant K_a is given by:

$$K_a = \frac{[H^+][C_6H_5COO^-]}{[C_6H_5COOH]} = \frac{x^2}{0.050 - x}$$

As $pK_a = -\log_{10}K_a$, $K_a = 10^{-4.20}$ and is very small, $0.050 - x \approx 0.050$ and hence:
$x^2 = 0.050 \times 10^{-4.2}$ or $x = 1.78 \times 10^{-3}$ M $= [H^+]$
Hence, the pH is given by: $pH = -\log_{10}[H^+] = -\log_{10}(1.78 \times 10^{-3}) = 2.75$

[2 marks]

Question 48

(a) As formic acid is a weak acid, $[H_3O^+]$ must be calculated using a reaction table:

	HCO_2H	H_2O	⇌	H_3O^+	HCO_2^-
Initial	0.20	Large		0	0
Change	$-x$	Negligible		$+x$	$+x$
Final	$0.20 - x$	Large		x	x

The equilibrium constant K_a is given by:

$$K_a = \frac{[H_3O^+][HCO_2^-]}{[HCO_2H]} = \frac{x^2}{0.020 - x}$$

As $pK_a = -\log_{10}K_a$, $K_a = 10^{-3.77}$ and is very small, $0.20 - x \approx 0.20$ and hence:
$x^2 = 0.20 \times 10^{-3.77}$ or $x = 5.8 \times 10^{-3}$ M $= [H_3O^+]$
Hence, the pH is given by:
$pH = -\log_{10}[H_3O^+] = -\log_{10}(5.8 \times 10^{-3}) = 2.23$ [2 marks]

(b) $HCOOH(aq) + NaOH(s) \rightarrow HCOO^-(aq) + Na^+(aq) + H_2O(l)$ [1 mark]

[Total = 3 marks]

Question 49

$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$; ∴ $[OH^-] = 0.002$M;
$P(OH) = -\log(0.002) = 2.7$, $pH = 14 - 2.7 = 11.3$

[1 mark]

Question 50

One example of a buffer in a natural system is the buffer in human blood, which has a narrow functioning pH range. The ideal pH for blood is 7.4. The pH is maintained by H_2CO_3/HCO_3^- pair by the following equation:

$$H_2CO_3(aq) \rightleftharpoons HCO_3^-(aq) + H_3O^+$$

This buffer reaction reduces the effect of pH changes in the blood which may be introduced from acidic or basic food and drink consumed, by increasing the concentration H_3O^+ or OH^- to maintain the optimum pH of 7.4 for proper cell functioning. Similarly, the carbon dioxide waste in the blood is involved in a similar reaction, where: $CO_2(g) \rightleftharpoons CO_2(aq)$, thus forming carbonic acid and then the buffer equation as above, to maintain blood pH.

[3 marks]

Question 51

Indigenous Australians did not knowingly analyse acids and bases, but rather used neutralisation techniques for treatment of ailments, food preparation, limited farming (as they are predominantly hunters and gatherers) and other aspects in their everyday lives. Including: utilising saps from plants to neutralise animal stings, including wasps, ants and marine stingers.

There are ethical guidelines to prevent industry from exploiting the popularity of bush food, which include seeking bush food knowledge from indigenous Australian. Research with organisation such as CSIRO and Aboriginal elders is ongoing, and it includes testing the pH levels of bush food to encourage healthy consumption of bush food, such as testing for vitamin C in bush fruit.

Industry: Testing of effluent – both gases and liquids – to ensure meeting EPA guidelines. Such as neutralisation by calcium oxide (lime) of sulfuric acid from the effluents discharged from the electroplating process. Following analyses of the acid concentration, sufficient calcium oxide is added to achieve neutralisation.

[4 marks]

Question 52

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

$n(HCl) = 0.1034 \times 0.025 = 2.585 \times 10^{-3}$ mol

mol ratio NaOH:HCl = 1 : 1, hence $n(NaOH) = 2.585 \times 10^{-3}$ mol

$c(NaOH) = n/v = 2.585 \times 10^{-3}/0.02575$

$= 0.1004$ M (correct to 4 significant figures) [2 marks]

(b) (i) Average titre = (16.60 + 16.50 + 16.55)/3 – 16.55 mL

$n(NaOH) = 0.1004 \times 0.01655 = 1.66162 \times 10^{-3}$ mol

mol aspirin: NaOH=1:1, hence $n(aspirin) = 1.66162 \times 10^{-3}$ mol

$m(aspirin) = 1.66162 \times 10^{-3} \times 180.154 = 0.2993$ g

$= 299.3$ mg (correct to 4 significant figures) [3 marks]

(ii) Aspirin contains two functional groups, an acidic group, –COOH, and an ester group, $–OCOCH_3$, and is a polar molecule. Although the first of these groups can form hydrogen bonds with water molecules the ester group and the rest of the molecule, $–C_6H_4–$, do not bond well to water molecules. Hence aspirin does not have a high solubility in water. The addition of ethanol would increase its solubility over that in water only. [1 mark]

[Total = 6 marks]

Question 53

(a) The mistake made by the student was to blow through the pipette. The pipette is manufactured to deliver an exact volume when left to drain without shaking or blowing to remove the last drop. The student should hold the pipette vertically over the conical flask and allow it to drain as completely as possible without assistance.

[2 mark]

(b) In step 2, rinsing the pipette would wet it on the inside and therefore dilute the sodium carbonate solution. In step 3 the bottom (or centre) of the meniscus of the sodium carbonate solution, not the sides, should have been on the gradation mark of the pipette. A smaller volume of solution than the stated pipette volume would be transferred to the conical flask. In both cases less hydrochloric acid is needed to react with the sodium carbonate solution resulting in a smaller titre. When this figure is used to calculate the concentration of hydrochloric acid the result will be greater than the actual concentration.

[3 marks]

[Total = 5 marks]

Question 54

(a) $n(\text{NaOH}) = (50.00 \times 1.00) \div 1000 = 0.0500$ mol

[1 mark]

(b) $n(\text{NaOH})$ remaining = $n(\text{HCl}) = (27.60 \times 1.00) \div 1000 = 0.0276$ mol

$n(\text{NaOH})$ reacting with $CO_2 = 0.0500 - 0.02760 = 0.0224$ mol

$n(CO_2)$ reacting = $n(\text{NaOH}) \div 2 = 0.0224 \div 2 = 0.0112$ mol

Mass $CO_2 = 0.0112 \times 44.01 = 0.493$ g

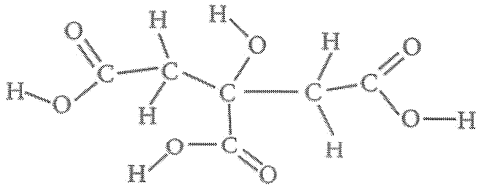
% purity of dry ice = $(0.493 \div 0.616) \times 100 = 80.0\%$

[4 marks]

[Total = 5 marks]

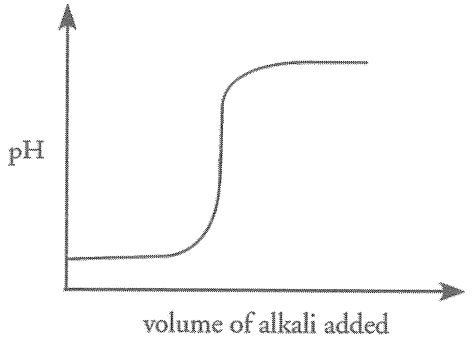
Question 55

(a)



[1 mark]

(b) A pH electrode is calibrated using solutions of known pH. The electrode is placed in a titration flask containing the citric acid solution. The pH electrode is connected to a pH meter interfaced to a computer, which displays pH changes and allows the equivalence point of the titration to be determined. A graph similar to the one below is often obtained.



[2 marks]

(c) The equation for the reaction of citric acid with sodium hydroxide is

$C_6H_8O_7(aq) + 3NaOH(aq) \rightarrow C_6H_5O_7Na_3(aq) + 3H_2O(l)$

n(citric acid) = (25.00 × 0.100) ÷ 1000 = 0.00250 mol
n(NaOH) = 3 × 0.00250 = 0.00750 mol
c(NaOH) = (0.00750 ÷ 41.50) × 1000 = 0.181 mol L^{-1} [4 marks]
[Total = 7 marks]

Question 56

(a) The acetate ion undergoes a hydrolysis reaction with water to produce hydroxide ion. Hence the solution will have a pH greater than 7.

$CH_3COO^-(aq) + H_2O(l) \rightleftharpoons CH_3COOH + OH^-(aq)$ [2 marks]

(b) The addition of sodium acetate to acetic produces a buffer solution. The pH of the resulting solution will be determined by the following equilibrium

$$CH_3COO^-(aq) + H_3O^+(aq) \rightleftharpoons CH_3COOH + H_2O(l)$$

When a small amount of NaOH is added to this solution it will react with some of the $H_3O^+(aq)$ and thus reducing their concentration. This will cause the equilibrium above to move to the left, producing $H_3O^+(aq)$ and partially opposing the change. The change in $[H_3O^+]$ is thus minimised as is the change in pH. [3 marks]
[Total = 5 marks]

Question 57

(a) Water should be used to rinse the conical flask as this will not change the number of moles of Na_2CO_3 placed in it. [2 marks]

(b) $HCl + NaOH \rightarrow H_2O + NaCl$

$n(NaOH) = cV$
$= 0.250 \times 0.0295$
$= 7.375 \times 10^{-3}$
$\therefore n(HCl) - 7.375 \times 10^{-3}$ after reaction with seashell
Original HCl $= cV$
$= 0.200 \times 0.0500 = 0.0100$ moles
$\therefore$ HCl used $= 0.0100 - 7.375 \times 10^{-3}$
$= 2.625 \times 10^{-3}$ moles used

$2HCl + CO_3^{2-} \rightarrow H_2O + CO_2 + 2Cl^-$

$HCl : CO_3^{2-} = 2 : 1$

$$\therefore nCO_3^{2-} = \frac{2.625 \times 10^{-3}}{2}$$
$$= 1.3125 \times 10^{-3}$$
$$m - 1.3125 \times 10^{-3} \times 60.01$$
$$= 0.07876 \text{ g}$$
$$= \frac{0.07876 \text{ g}}{0.145 \text{ g}} \times 100\%$$
$$= 54.3\%$$

[4 marks]
[Total = 6 marks]

Question 58

(a) $c = \frac{n}{V} \Rightarrow n = cV$

$n_{\text{acetic}} = 0.5020 \times 0.02500$

$= 0.01255$ mol

Molar ratio 1 : 1

$\therefore c_{\text{NaOH}} = \frac{0.01255}{0.01930} = 0.6503 \text{ mol L}^{-1}$ [3 marks]

(b) Because the acetate ion is a weak base, it has accepted a proton from the water resulting in production of hydroxide ions. Therefore, the solution has a pH > 7.

$CH_3COO^-(aq) + H_2O(l) \rightarrow CH_3COOH(aq) + OH^-(aq)$ [2 marks]

[Total = 5 marks]

Answers – Module 7: Organic Chemistry

Multiple-choice questions

Question	Answer	Comments
1.	B	C=C groups are numbered from the first C atom of the group with that C atom having the lowest possible number.
2.	D	The longest chain has six C and all single bonds, hence hexane, 1-ethyl and 1-methyl on the third carbon, which are placed alphabetically in the name.
3.	C	Double bond in pentene can be in two positions: 1-pentene and 2-pentene. In addition, three methylbutenes: 2-methyl-1-butene, 2-methyl-2-butene and 2-methyl-3-butene. The methyl position does not change. Not possible to achieve a dimethyl propene.
4.	C	(A), (B) and (D) are alkanes [formula C_nH_{2n+2}] and C is an alkene [formula C_nH_{2n}].
5.	A	With the addition of each carbon, two hydrogens are added; hence the molecular mass increase by 14; for all alkanes, alkenes and alkynes.
6.	A	Irrespective of the shape of the structural formula presented, the basis of naming is counting the longest chain, ∴ hexane, and then allocate the lowest numbers possible for the function group/s. In this question, 2 × methyl function groups, 1 on C_3 and 1 on C_4.
7.	B	Same as Q6, but in this case, two double bonds, the chain with the two double bonds is the longest; allocate the lowest numbering system to the double bond first, then the two methyl groups.
8.	D	Isomers have the same structural formulae, but with different arrangement, branching or functional group. Butanoic acid: $C_4H_8O_2$ and 2,3-butanediol: $C_4H_{10}O_2$.
9.	D	In D, the double bond can on first C and Cl on third C.
10	A	Alkyne's formula is C_nH_{2n-2}, formula $C_8H_{(2*8-2)}$.
11.	D	Three carbon single bonded chain, hence propane, amines have NO_2 at the end of chain, with a suffix added to the alkane, with *–e* dropped. Amine is C_1 and methyl on C_2.
12.	B	A, C and D are not isomers but identical.

13. **D** 1° alcohols: OH attached to one alkyl– usually at the end of the chain; 2° alcohol: C containing OH is attached to one other alkyl group, 3° alcohol: C containing OH is attached to two other alkyl groups.

14. **D** I: carboxylic have two O atoms, and II has an extra H atom – $C_5H_{11}O$.

15. **D** Longest chain is a heptane with two methyl groups on C_3 and C_4.

16. **C** I and II are carboxylic acids, I has Cl atom in C_4 and II has Br atom on C_2.

17. **A** The longest chain with the double bond (functional group) has six C, between C_1 and C_2, hence 1-hexene. I atom on C_3 and two methyl groups on C_4.

18. **B** Four C atoms and single bonds, butane. Allocate the numbers alphabetically, hence chloro- has the lower number to –fluoro.

19. **A** Same system as Q18 but use a prefix of di– before the naming of two halogens.

20. **A** W and X have the molecular formulae with Cl and F in different positions.

21. **D** This is the common name for the monomer from which PVC polymer is produced.

22. **D** Carboxylic acids have two O atoms –COOH at the end of the chain, in addition to 10 H atoms.

23. **D** The allocations of the numbers with the multiple halogens such as in this compound has to ensure the lowest numbers are used, hence –fluoro has three atoms so is on C_1 and is given a prefix of tri–.

24. **A** As Q23.

25. **B** Alkanes are saturated and hence H atoms are removed and substituted to add the Cl_2.

26. **C** Alcohols are polar and hence have the highest BP. (D) is also polar, but the two F atoms produce a net negative dipole, hence methanol's BP is higher.

27. **A** The formula for alkanes is: C_nH_{2n+2}, hence (A).

28. **D** As Q27.

29. **D** Increased surface area and increased number of C increase the BP. Hence, II and III will have a higher BP. I could also be higher as it has a greater surface area.

30. **B** For water to boil, the temperature needs to be raised by 80°C. Energy required to boil water = $0.250 \times 4.18 \times 80 = 83.6$ kJ. 0.1 mol is supplied, multiply by molar heat of combustion for each hydrocarbon:
methane = 88.9 kJ mol^{-1} and butane = 287.4 kJ mol^{-1}

31. **C** Test 1 differentiates between saturated and unsaturated (A & C). Test 2 is a neutralisation reaction with a base to produce $H_2(g)$, hence C as it has to be an acid.

32. **B** Polar compounds and short chained alcohols, such as ethanol.

33. **B** Alkanes are tetrahedral with 109.5°.

34. **D** Alkynes are linear, hence 180°.

35. **D** LPG is liquified C_3 and some C_4 and is stored under pressure. Hence design specifications and transportation of tanks are very strict for safety reasons.

36. **D** Homologous series share the same chemical properties, only their physical properties change based on the length of the chain.

37. **B** Volatility is where liquid hydrocarbons change to gas at the surface.

38. **B** Accidents do occur and hence there has to be a safety plan in place which is to be followed in case of any mishap, to protect human life and the environment.

39. **D** If an alcohol does not form, the double bond is between C_2 and C_3, hence bromo will fill the two unsaturated C atoms.

40. **A** If the double bond is between C_1 and C_2, the H and Cl atoms could be added to either C, hence producing isomers.

41. **D** Two Cl atoms will substitute two H atoms, hence forming: 1,1-, 1,2-, 1,3-, 1,4-, 2,2- and 2,3-.

42. **C** Balanced equation: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$. If 2 moles of propane reacts, 6 moles of CO_2 is produced. Propane is saturated hence will not react with bromine.

43 **B** If an alcohol does not form, the double bond is between C_3 and C_4, hence bromo will fill the two unsaturated C atoms.

44. **B** If the double bond is between C_1 and C_2, the Br atoms could be in either of the two carbons, and H atom on the other.

45. **C** Concentrated H_2SO_4 is a dehydrating agent with alcohol, to produce an alkene which is unsaturated, hence reacts with Br.

46. **B** Methane is saturated, hence two H atoms are removed to be substituted by HCl.

47. **D** The hydrogenation will not change the structure of the molecule, but only change it to being saturated, (D) is a pentene.

48. C Only an acid will decompose a carbonate and change blue litmus red.

49. A Unlike the hydration of alkenes which produce an alcohol, alkynes are hydrated to form alcohols that spontaneously tautomerise (reaction which involves simple proton transfer) to ketones.

50. C An addition reaction can only occur in unsaturated compounds, in this case by addition of HCl.

51. A An alkene will decolourise water W, X is an alkene and are insoluble. Y is unreactive but is soluble (methanol) and Z unreactive but is a long chain hence partly soluble (hydrophilic end).

52. B With the addition of I_2, an I atom will be added to C_2 and C_3 as this is the position of the double bond.

53. C When brown brominated water is added to hexane, there will be no reaction, as hexane has a lower density, it will be the upper layer. Hexene will react with bromine water, with the lighter layer of the hydrocarbon on top, hence the two layers.

54. B Ethanol has more bonds to break and reform than methanol and hence the net energy will be greater for ethanol.

55. C Dehydration of ethanol will produce ethene and water.

56. B When 1 mole of each of the fuels is burnt the energy released is
$\Delta H_c(C_2H_5OH) = 29.6 \times 46.1 = 1365$ kJ mol^{-1};
$\Delta H_c(C_8H_{18}) = 47.8 \times 114.2 = 5459$ kJ mol^{-1};
$\Delta H_c(C_4H_{10}) = 49.5 \times 58.1 = 2876$ kJ mol^{-1};
$\Delta H_c(C_3H_8) = 50.3 \times 44.1 = 2218$ kJ mol^{-1}.

57. A As this is an exothermic reaction, low temperature drives the reaction to the LHS, hence is incorrect.

58. C Concentrated H_2SO_4 is a dehydration agent; removing a water molecule from alcohol to produce an alkene, but in dilute form it is reversed.

59. D $n(C_4H_{10}O) = 1.50 \div 74.1 = 0.02024$ mol
Heat energy given to water = $1530 \times 0.02024 = 30.97$ kJ
Temperature rise of water = = 24.7°C
Final temperature of water = 20.7 + 24.7 = 45.4°C

60. C Molar mass of 1-propanol = 60 g mol^{-1}
$\Delta H_c(C_3H_7OH) = 2021 \div 60 = 33.68$ kJ g^{-1}

61. B 1 mol of glucose produces 2 mol of ethanol and 2 mol of carbon dioxide.

62. **A**

Heat energy given to water $= \frac{4.18 \times 250 \times 16.0}{1000} = 16.72$ kJ

$n(CH_3OH) = \frac{125.58 - 124.38}{32} = 0.0375$ mol

$\Delta H_c = 16.72 \div 0.0375 = 446$ kJ mol^{-1}

63. **C** 1 mol propanol reacts to form 4 mol = 72.1 g water
2021 kJ are evolved when 72.1 g water forms
1530 kJ are evolved when (1530 × 72.064)/2021 g water forms
= 55 g

64. **C** The mol ratio butan-1-ol: carbon dioxide in the equation is 1:4, thus 2 mol butan-1-ol produce 8 mol carbon dioxide.

65. **B** n(ethanol) = 1000 ÷ 46.06 = 21.71 mol
Energy released by 1.0 kg ethanol = 21.71 × 1360 = 29528 kJ.
Distance travelled = 29528 ÷ 2270 = 13.0 km

66. **B** The amounts of energy per gram of compound are CO = 8.32 kJ; CH_4 = 55.6 kJ; C_2H_2 = 50.0 kJ and C_2H_6 = 52.0 kJ.

67. **D** Ethanol is miscible in both polar and non-polar substances, as it is a short molecule with a hydrophilic and a hydrophobic end, hence forms dipole-dipole bonds with octane.

68. **D** Molecules of heptan-1-ol have seven carbon atoms, i.e. the formula is $C_7H_{15}OH$. Molar mass of heptan-1-ol = 116.2 g mol^{-1}. Heat released by 1.0 g is 4638 ÷ 116.2 = 39.9 kJ.
Mass of water heated = 39.9 ÷ (4.18 × 25) = 0.382 kg

69. **D** The equation for the fermentation of glucose is
$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$
$n(CO_2)$ formed = 2 × (10.3 ÷ 180) = 0.1144 mol
Volume (CO_2) = 0.1144 × 24.79 = 2.84 L

70. **B** Hydrogen bonding occurs with the lone pair of e^- on the O atom, and the H (which δ^+) in the water molecule.

71. **D** The black is soot (C). $H_2O(g)$ and $CO_2(g)$ are also produced as the product of combustion.

72. **C** Only a 1° alcohol will produce a carboxylic by the strong oxidising agent, KMnO4, and the product is an acid, which will change blue litmus red.

73. **C** This is esterification reaction, where a water molecule is produced as the result of the formation of the ester from an alcohol and a carboxylic acid.

74. **B** Ethyl pentanoate is an ester formed when ethanol and pentanoic acid react. It has the formula $C_4H_9CO_2CH_2CH_3$.

75. **D** Hydrolysis of an ester would produce an alcohol and a carboxylic acid. The carboxylic loses the OH and the alcohol 1 H to form a water molecule.

76. **A** The anionic surfactant has a negative head, the cationic a position one, the non-ionic is neither and the amphoteric has both.

77. **A** Anionic surfactants carry a negatively charged hydrophilic end.

78. **C** As Q75.

79. **D** Cracking of petroleum fractions produces ethylene and/or propene. Reaction of ethylene with $H_2SO_4(aq)$ gives ethanol but reaction of propene with $H_2SO_4(aq)$ gives a mixture of propan-2-ol and propan-1-ol. Reaction of an alcohol with propanoic acid will produce the corresponding alkyl propanoate.

80. **D** As the reactants and the products are volatile hydrocarbons, a heating mantle would eliminate the use of an open flame from a Bunsen burner.

81. **C** Polypropene has the general formula $(C_3H_6)_n$ or $(CH_2)_{3n}$. Number of C atoms is $3n$. Molar mass = $3n \times 14$ = 105 000 g mol^{-1} and thus $3n$ = 105 000/14 = 7500.

82. **B** Since methyl methacrylate contains a C=C it will undergo addition polymerisation. $-CH_3$ and $-COOCH_3$ groups will be bonded to every second C atom. These will be separated by a $-CH_2$ group.

83. **A** In step 2, HCl has been removed from $C_2H_4Cl_2$, to produce an alkene; then polymerisation.

84. **B** Petroleum contains large hydrocarbon molecules. These are cracked to produce smaller molecules (e.g. petrol) and C_2H_4.

85. **D** Since acrylic acid contains a C=C group it is most likely to undergo addition polymerisation. In A and C, the polymer could be made from HOCH$_2$CH$_2$COOH by a condensation reaction.

86. **B** Since vinyl acetate contains a C=C it will undergo addition polymerisation. –H and $-OCOCH_3$ groups will be bonded to every second C atom. These will be separated by a $-CH_2-$ group.

87. **D** An unsaturated hydrocarbon such as chloroethene is an ideal monomer to form PVC.

88. **B** Lactic acid contains –OH and –COOH groups and will undergo condensation reactions to form the polymer. When 1000 monomers react in this way, 999 ester links will be formed, and 999 molecules of water will be eliminated. The molar mass of lactic acid is 90 g mol^{-1} and that of the polymer will be (90 × 1000) – (999 × 18) ≈ 72 000 g mol^{-1}.

89. A For a condensation reaction to occur, two functional groups react to form a new group with the elimination of a small molecule, usually water.

90. C Cellulose will react with water to form glucose.
$(C_6H_{10}O_5)_n + nH_2O \rightarrow nC_6H_{12}O_6$
Water is eliminated from ethanol to form ethylene in a dehydration reaction.

91. D This condensation polymer results from the reaction of –OH and –COOH groups. To form each ester link, one functional group loses OH and the other loses H (to form water, the other product.

92. B Biopolymers are produced by living organisms and are usually easily decomposed by bacteria in the environment. Polymers made from petrochemicals are more difficult to biodegrade.

93. D Styrene is an unsaturated compound and can act as a monomer for addition polymerisation. C_2H_4 is reacted with benzene to form ethylbenzene, which in turn is reacted with S to form styrene and H_2S.

94. A Condensation and dehydration require the elements of water to be removed. Esterification is the reaction of an acid with an alcohol. This resin was produced by addition polymerisation.

9.5 C In an addition reaction, a C=C is broken and replaced by two single bonds. (D) is an esterification reaction.

96. D From the label, the cup is made from a naturally occurring polymer found in plants. (A), (B) and (C) are man-made polymers, respectively polyethylene, polystyrene and polyvinyl chloride. (D) is cellulose, a naturally occurring polymer.

97. D The –OH and –COOH groups in the monomers will react to form ester groups (–O–CO–) in the polymer. (A) does not contain ester groups. (B) is not a polymer. (C) contains an ester group but also a peroxy group.

98. D In this nylon, there are six $–CH_2–$ groups between each NH group and four $–CH_2–$ groups between each C=O group. Condensation polymerisation of the monomers in (D) will produce this result.

99. C Screwdriver handles need to be rigid for a firm grip, polystyrene is a tough polymer with high impact strength.

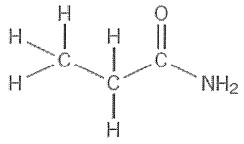
100. D The double bond is between C_1 and C_2, hence allowing the third C to become a methyl group.

101. B As Q100.

Free-response questions

7.1 Nomenclature

Question 1



[1 mark]

Question 2

(a) The two compounds are trimethylpentane and methylheptane. Isomers have the same molecular formula but different structures. [2 marks]

(b) Benzene is not an alkane. Alkanes have the general formula C_nH_{2n+2}. Benzene belongs to a group of compounds that have the general formula C_nH_{2n-6}.

[2 marks]

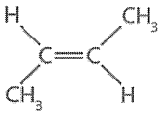
(c) $C_7H_{16}(g) + 11O_2(g) \rightarrow 7CO_2(g) + 8H_2O(l)$ [2 marks]

[Total = 6 marks]

Question 3

(a) B is an alkene. [1 mark]

(b)

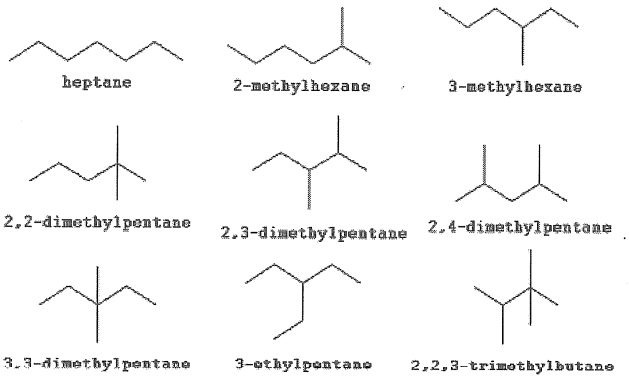


[1 mark]

[Total = 2 marks]

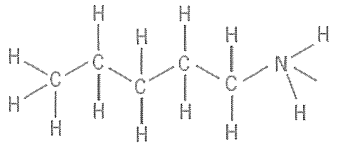
Question 4

Heptane has 9 isomers: heptane, 2-methylhexane, 3-methylhexane, 2,2-dimethylpentane, 2,3-dimethylpentane, 2,4-dimethylpentane, 3,3-dimethylpentane, 3-ethylpentane, 2,2,3-trimethylbutane.



[2 marks]

Question 5
An isomer: 1-pentanamine.



[2 marks]

7.2 Hydrocarbons

Question 6
Ethanoic acid has a higher boiling point than methyl ethanoate due to hydrogen bonding between molecules. Ethanoic acid is acidic; methyl ethanoate is not acidic.

[2 marks]

Question 7
Ethanoic acid has the higher boiling point due to the hydrogen bonds between molecules.

[2 marks]

Question 8
C_2H_5OH has the highest BP, due to the hydrogen bonding between the O atom and the neighbouring H.

[2 marks]

Question 9
Butane has a higher BP, as the number of C increase, the BP increases.

[2 marks]

Question 10
Alkanes: the boiling point of alkanes is determined by molecular weight. The BP has almost a linear relationship with the molecular weight of the molecule, i.e. as the molecular weight increases, so does the boiling point. Branched alkanes have lower BP to their straight chain isomers.

Alkenes: follow the same trend as alkanes, but as alkenes have a slightly greater surface area, their BP is slightly higher as well.

[2 marks]

Question 11

Ethanol, CH_3CH_2OH	*Ethene, $CH_2=CH_2$*
Liquid at room temperature due its polar nature, but volatile.	A colourless gas with a faint sweetish smell, BP <0°C.
Density is less than 1.	Slightly less dense than air.
BP ≈ 78°C.	pH – neutral.
pH – neutral.	

[3 marks]

Question 12

Oil and gas pollution occurs when any or all of these take place:

- drilled rock cuttings (contaminated with toxic drilling fluid) is discharged into the seas or lands,
- produced water (contaminated with crude oil or gas) is discharged into the seas, lands, or injected in underground formation,
- seismic operations that disturb human and marine lives,
- hydrocarbon discharge or spillage in the sea or land during hydrocarbon production and transportation, which can be either accidental or planned discharges,
- burning of hydrocarbon oil (in cars, trucks, trains, and planes), and flaring of hydrocarbon gas. Accidental discharges can be because of vessels collision with rock or ice, explosion, a blowout of an offshore well, or pipeline leakages. The largest volume of wastes during exploration is drilling muds and cuttings while the largest volume of production waste is produced water.

Despite of these issues, oil and gas production needs to and will continue until research of alternatives from natural resources has advanced beyond its current status; such as for the following uses:

- Biodegradable polymers from plant sources are being used by many countries, but in third-world countries, polymers sources from crude oil are cheaper to produce and are a necessary commodity for survival – such as for carrying and storing water, as a building material etc. In addition, using the land and water to plant crops for polymer production is unrealistic when these are required for food production.
- Hydrocarbons sourced from crude oil which is used for transportation and shipping is the cheapest source; and again, as with biopolymers, biofuels currently are extremely expensive and inaccessible to many citizens in third-world countries. If production of such fuels was to cease, significant worldwide famine would be a possibility.
- Electricity production – Despite the availability of alternative power generation sources, such as solar, wind, hydro-, etc; most countries are still heavily reliant on fossil fuel for electricity with very slow transition to the alternatives. Again, the use of alternatives is not within the reach of third world countries due to the high expense of establishing the infrastructure.

Hence for the reasons stated, the cessation of oil and gas exploration, production and use cannot stop suddenly, but only gradually with the introduction of alternatives, otherwise the socioeconomic effects would be catastrophic.

[6 marks]

Question 13

Ascending order: 1) 2,2-dimethylbutane, 2) 2-methylpentane, 3) hexane

These three hydrocarbons are isomers, i.e. they have the same compound formula, but are bonded differently. Hexane has the highest BP, as it is a straight chain, hence the highest surface area.

2- methylpentane is a shorter structure due to the methyl branch, hence has a BP lower that hexane, but higher than 2,2-dimethylbutane, which has more branches and is shorter structure compare to the other2 hydrocarbons.

[4 marks]

Question 14

The physical properties of substances are due to the influence of intermolecular forces which occurs between the molecules. These physical properties include: melting point, boiling point, vapor pressure, evaporation, viscosity, surface tension, and solubility.

Hydrogen bond is the strongest of these attractive forces and they occur between the hydrogen attached to an electronegative atom of one molecule and an electronegative atom of a different molecule, such as oxygen.

Ethanol, for example, is greatly affected by hydrogen bonding which causes its liquid state at room temperature and its solubility in water – due to hydrogen bonding between the O atom in the OH and the H atom in water.

Dipole–dipole forces occur when dipoles are created by differences in electronegativities of the atoms of adjacent molecules. The attractive forces are like the H-bonding, but the magnitude of the dipoles is significantly smaller. The magnitude of these forces influences the state and boiling point of the substances.

Low molecular mass hydrocarbons, such as methane, lack strong dipoles, but can experience dispersion forces between the molecules. Their dipoles are weak and transient and solely depend on contact between molecules. As each methane molecule has a small surface area, the advent of this intermolecular force occurring is low, which leads to low boiling point. As the hydrocarbon increases in length, the surface area increases, and in turn the boiling point increases.

[3 marks]

Question 15

(a) An addition polymerisation reaction. [1 mark]

(b) The models are useful because they allow the student to simulate the bond breaking and bond forming that occurs during a reaction, and also to observe the structures in three dimensions giving an appreciation of molecular shapes and bond directions.

[2 marks]

[Total = 3 marks]

Question 16

Despite having different molar masses, all three molecules have similar boiling points due to their different structures and resulting intermolecular forces.

- Butyl acetate has the largest molar mass and therefore greatest dispersion forces, but it is only slightly polar and has no hydrogen bonding.
- Butan-1-ol has lower molar mass than butyl acetate and therefore smaller dispersion forces but it is polar and contains a hydrogen bound to an oxygen. Therefore, it exhibits hydrogen bonding, resulting in strong intermolecular forces.
- Acetic acid has the lowest molar mass and so the weakest dispersion force, but it is polar and contains a hydrogen bound to an oxygen allowing the formation of hydrogen bonds between molecules. The presence of a second oxygen in acetic acid increases the hydrogen bonding compared with butan-1-ol.

Therefore, all three molecules have similar total strength of intermolecular forces and therefore similar boiling points.

[5 marks]

7.3 Products of reactions involving hydrocarbons

Question 17

(a) An addition reaction (and a hydration reaction). [1 mark]

(b) Any two of the following reactions (2 marks for each correct example)

- Addition of hydrogen to give ethane $C_2H_4 + H_2 \rightarrow C_2H_6$.
- Addition of HCl to give chloroethane $C_2H_4 + HCl \rightarrow C_2H_5Cl$.
- Addition of bromine to give dibromoethane $C_2H_4 + Br_2 \rightarrow C_2H_4Br_2$.
- Addition polymerisation $nC_2H_4 \rightarrow (-CH_2-CH_2-)_n$.

[4 marks]

[Total = 5 marks]

Question 18

(a) Alkanes are compounds of carbon and hydrogen atoms held together only by single bonds (C–C and C–H bonds). Alkenes also contain carbon and hydrogen atoms but contain a carbon to carbon double bond as well as single bonds (C=C, C–C and C–H bonds). [2 marks]

(b) Bromine can be used to distinguish between an alkane and an alkene. If bromine water is added dropwise to an alkene the bromine colour will rapidly disappear. When bromine water is added to an alkane the colour only disappears after a considerable time and exposure to sunlight.

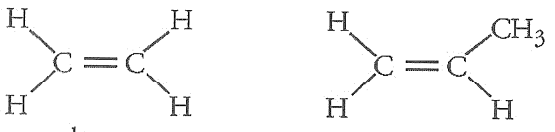
Bromine can damage the skin, it irritates the throat and eyes and bromine fumes are very toxic by inhalation. The hazards of using bromine can be addressed by carrying out the experiments in a fume cupboard, which will prevent the bromine vapours from being inhaled. Also, bromine water rather than liquid bromine should be used.

[3 marks]

[Total = 5 marks]

Question 19

(a)



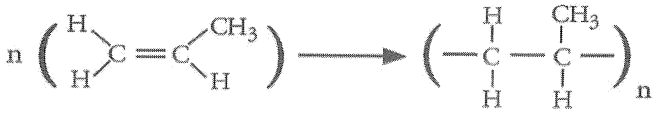
[2 marks]

(b) $C_4H_{10}(g) \rightarrow C_2H_4(g) + C_2H_6(g)$

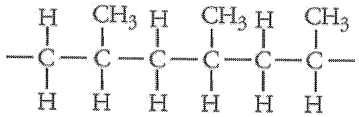
$C_4H_{10}(g) \rightarrow C_3H_6(g) + CH_4(g)$

[2 marks]

(c)

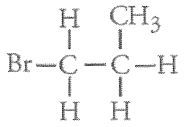


The structure of the polymer (showing three monomer units).

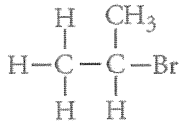


[2 marks]

(d) When HBr undergoes an addition reaction with propene, the Br atom can either add to the end C atom of the molecule or to the middle one.



1-bromopropane



2-bromopropane

[2 marks]
[Total = 8 marks]

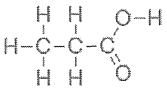
Question 20

(a) A: Hexene; B: 1,2-dichlorohexane; C: 2-chlorohexane. [3 marks]

(b) 2-hexene $H_3CCH{=}CHCH_2CH_2CH_3$; 3-hexene $H_3CCH_2CH{=}CHCH_2CH_3$ [2 marks]
[Total = 5 marks]

Question 21

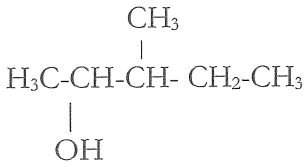
The hydrocarbon is propranoic acid, as it reacts readily with NaOH by a neutralisation reaction and forms an ester with ethanol. It is soluble as it dissociates in water and also due to the polar end of the hydrocarbon.



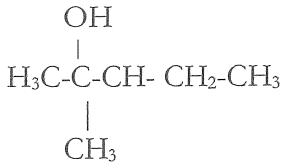
[4 marks]

Question 22

(a) [2 marks]



3-methyl-2-pentanol



2-methyl-2-pentanol

(b) Adding a strong oxidising agent would distinguish between the two alcohols. 2-methyl-2-pentanol is a tertiary alcohol, and does not react hence orange chromate solution will stay orange. However, 3-methyl-2-propanol is a secondary alcohol and with acidified dichromate will produce a ketone and the orange chromate solution will be reduced to a green colour. [2 marks]
[Total = 4 marks]

7.4 Alcohols

Question 23

(a) $2C_3H_7OH(l) + 9O_2(g) \rightarrow 6CO_2(g) + 8H_2O(l)$ [1 mark]

(b) $n(C_3H_7OH) = 85.0 \div 60.1 = 1.414$ mol
$n(CO_2) = n(C_2H_5OH) \times 3 = 4.243$ mol
Volume $CO_2 = 4.243 \times 24.79 = 105.2$ L, i.e. 105 L [2 marks]

Question 24

(a) Metals are better conductors of heat than glass. Less heat will be wasted heating the container. [1 mark]

(b) Mass methanol used = 35.674 – 34.396 = 1.278 g
n(methanol) = 1.278 ÷ 32 = 0.0399 mol [2 marks]

(c) Heat given to water = (4.18 × 300 × 11.8) ÷ 1000 = 14.8 kJ [1 mark]

(d) Heat of combustion = 14.80 ÷ 0.0399 = 371 kJ mol^{-1} [1 mark]

(e) Any two of:
- incomplete combustion of methanol
- heat lost to the air
- heat lost in heating the container
- heat lost from the container

[2 marks]
[Total = 7 marks]

Question 25

(a) $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$ [1 mark]

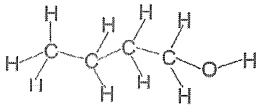
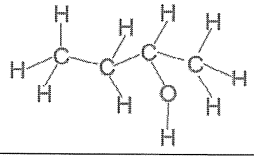
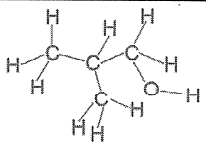
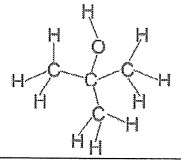
(b) $n(C_2H_5OH) = 1.0 \div 46 = 0.0217$ mol

Heat released for 1.0 g = 0.0217 × 1364 = 29.65, i.e. 30 kJ [1 mark]

(c) Energy needed to heat the water = $\frac{4.2 \times 950 \times (100 - 12)}{1000}$ = 351 kJ

Energy from the combustion = (351 × 100) ÷ 40 = 878 kJ;
$n(C_2H_5OH)$ = 878 ÷ 1364 = 0.6437 mol
Mass (C_2H_5OH) = 0.6437 × 46 = 29.61, i.e. 30 g [4 marks]
[Total = 6 marks]

Question 26

1-butanol	*2-butanol*	*2-methyl-1-propanol*	*2-methyl-2-propanol*
			

[4 marks]

Question 27

There are advantages and disadvantages in using ethanol as a fuel. Ethanol can be obtained by the fermentation of sugars from biomass and waste from food crops and thus is a renewable fuel. It has a lower greenhouse impact than the other fuels in the table. Ethanol burns more completely than petrol and produces less soot (carbon) and carbon monoxide. Engines using ethanol are cleaner. Ethanol produces less energy per gram than petrol. However, this is partially compensated by ethanol's higher octane rating. Engines will run on ethanol-petrol mixtures containing up to 15% ethanol without modification. However, if higher percentages of ethanol are used the engine must be modified. Large scale use of ethanol as a fuel or petrol extender will require more arable land that could otherwise be used for growing crops.

[5 marks]

Question 28

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

$2C_8H_{18}(g) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(g)$ [2 marks]

(b) **(i)** mass $C_8H_{18} = 0.698 \times 50.0 \times 1000 = 34\,900$ g or 34.9 kg [1 mark]

(ii) mass $C_2H_5OH = 0.785 \times 50.0 \times 1000 = 39\,250$ g or 39.3 kg [1 mark]

(c) n(octane) in 50 L = $34\,900 \div 114 = 306.1$ mol

energy from 50 L octane = $306.1 \times 5464 = 1.673 \times 10^6$ kJ = 1670 MJ

n(ethanol) in 50 L = $39\,250 \div 46 = 853.3$ mol

energy from 50 L ethanol = $853.3 \times 1364 = 1.164 \times 10^6$ kJ = 1160 MJ [4 marks]

(d) 5464 kJ is released when 1 mol octane reacts.

Reaction of 1 mol of octane produces 8 mol of CO_2.

5464 kJ is released when 8×44 g CO_2 is formed.

When 1000 kJ is released $(8 \times 44 \times 1000) \div 5464 = 64.4$ g CO_2 is formed.

For ethanol, 1000 kJ is released when $(2 \times 44 \times 1000) \div 1364 = 64.5$ g CO_2 is formed. [2 marks]

[Total = 10 marks]

Question 29

(a) $C_6H_{12}O_6(aq) \rightarrow 2CO_2(g) + 2C_2H_5OH(aq)$ [1 mark]

(b) mass of CO_2 released = 421.62 – 411.84 = 9.78 g

$n(CO_2) = 9.78 \div 44.01 = 0.222$ mol [1 mark]

(c) $n(C_2H_5OH) = n(CO_2) = 0.222$ mol

mass C_2H_5OH produced = $0.222 \times 46.1 = 10.2$ g [2 marks]

[Total = 4 marks]

Question 30

The amount of heat released when 1 mole of a substance undergoes complete combustion in O_2 to produce CO_2 and water.

[1 mark]

Question 31

(a) $3CH_3CH_2OH + Cr_2O_7^{2-} + 8H^+ \rightarrow 3CH_3CHO + 2Cr^{3+} + 7H_2O$; Product is ethanal.

$3CH_3CH_2OH + 2Cr_2O_7^{2-} \rightarrow 3CH_3CHOOH + 4Cr^{3+} + 11H_2O$, Product is ethanoic acid. [2 marks]

(b) Ethanol is oxidised by acidified sodium dichromate reaction, firstly to form ethanal, and with further oxidation, ethanoic acid is formed. To produce ethanal, excess ethanol is present to continue to produce ethanal, which is removed to prevent it from continuing to form ethanoic acid. [2 marks]

(c) Butan-2-ol is a secondary alcohol and hence only butanone is produced. The C atom containing the –OH group has no H atom, hence cannot continue reacting to produce further products. [2 marks]

[Total = 6 marks]

Question 32

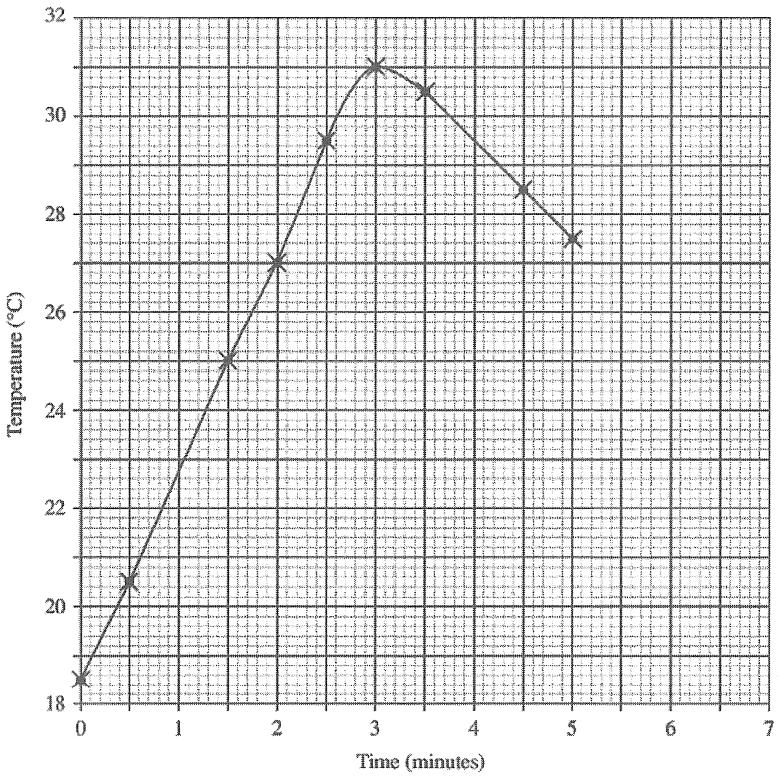
(a) The first three alcohols are soluble due to the –OH functional group. Hydrogen bonding occurs between the alcohols and water molecules, hence the solubility. Also, the –OH makes the alcohol polar and polar substances are soluble in other polar substances such as water. Butanol and pentanol are only slightly solubility due to the increase in the chain length, reducing the effect of the presence of the polar –OH functional group. [2 marks]

(b) As the number of C atoms increases, the alcohols become less polar, i.e. more non-polar, and hence less soluble. [2 marks]

[Total = 4 marks]

Question 33

(a)



[3 marks]

(b) From graph, $\Delta T = 31.0 - 18.5 = 12.5°C$

Mass of ethanol burnt = 236.14 – 235.56 = 0.58 g

Moles ethanol =

Energy released = $n \times 827 = 0.0126 \times 827$

$= 10.420$ kJ

$= 10\,420$ J

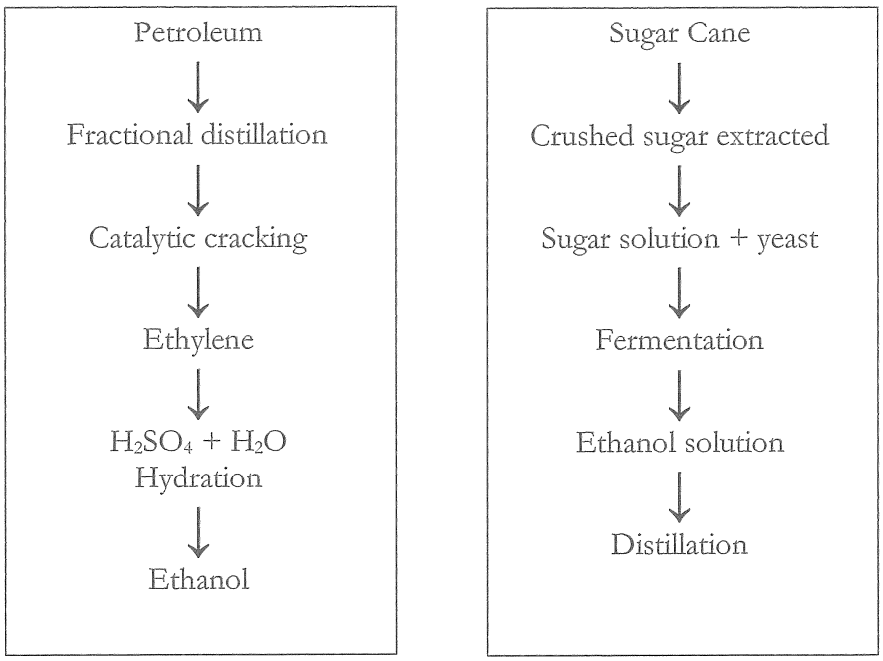
$\Delta H = mC\Delta T$

[3 marks]

[Total = 6 marks]

Question 34

(a)



[5 marks]

(b) Ethanol produced by the cracking of hydrocarbons is consuming a non-renewable fossil fuel resource so is not environmentally sustainable as the fossil fuels have been created over a long time and cannot be quickly replaced. The mining of fossil fuels is also detrimental to the environment.

Ethanol from sugar cane is a biofuel produced from sugar cane molasses after the sucrose has been separated. The sugar cane crop is replanted each year and is a renewable and sustainable resource, which does not cause destruction of the environment.

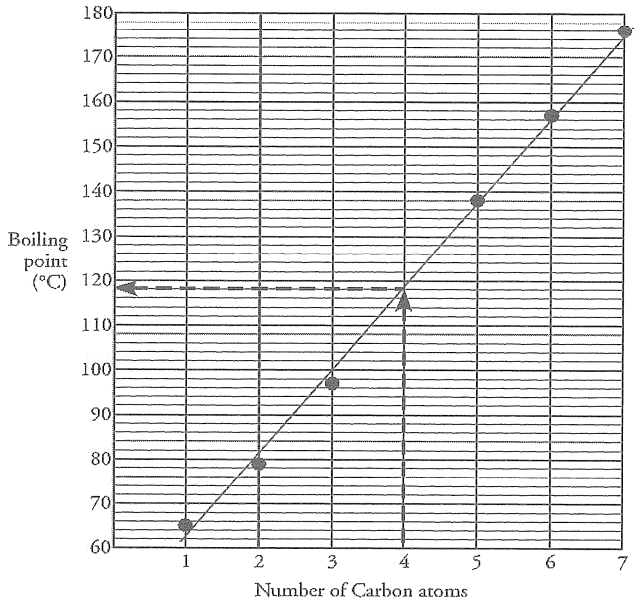
Both methods produce ethanol as a final product which when used as a fuel produces less CO_2 when compared to octane. CO_2 contributes to the enhanced greenhouse effect so less emissions will be more beneficial to the environment.

[3 marks]

[Total = 8 marks]

Question 35

(a)



[3 marks]

(b) BP of butan-1-ol = 118°C [1 mark]

(c) Dispersion forces. The molecules of all of these compounds contain an –OH group. Hence there is hydrogen bonding between the molecules for all the alkanols. However, as the chain length increases (by $-CH_2-$ each time) the number of electrons in the molecule increases and thus there is an increase in the strength of the dispersion forces. [1 mark]

[Total = 5 marks]

Question 36

n(ethanol) = 0.259 ÷ 46.07 = 5.62×10^{-3} mol

Heat released by ethanol = $1367 \times 5.62 \times 10^{-3}$ kJ = 7.69 kJ or 7690 J

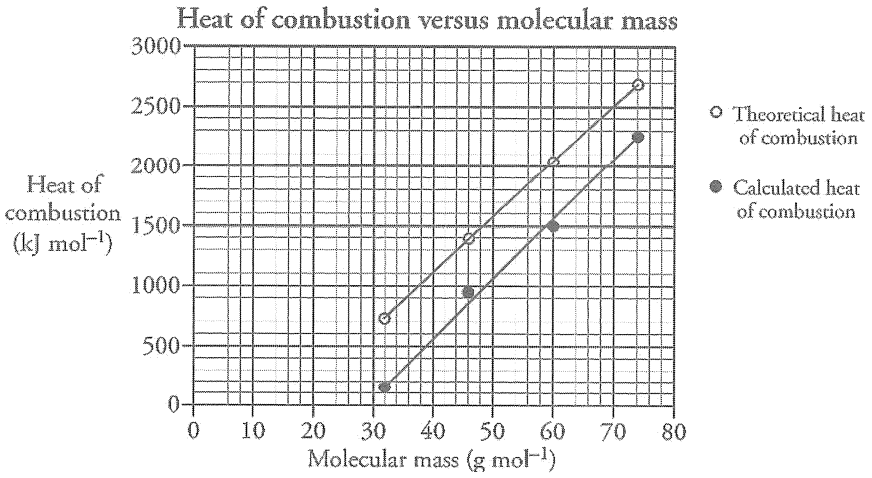
This amount of energy heats 120 g of the oily liquid by 50.0 – 20.0 = 30.0°C

Specific heat of the oily liquid = 7690 ÷ (120 × 30.0) = 2.14×10^3 J K^{-1} kg^{-1}.

[4 marks]

Question 37

(a)



[3 marks]

(b) The student's investigation is a valid way to show the link between molar mass and heat of combustion (ΔH). The experimental data obtained by the student shows a similar trend to the trend in the theoretical data (the lines are almost parallel). However quantitatively the student's data is inaccurate since there is a large amount of heat loss to the surroundings. There is a consistent difference between the experimental data and the theoretical data showing that there is a systematic error. The other variables have been controlled. [3 marks]

[Total = 6 marks]

Question 38

The major uses of ethanol are

(1) as a solvent
(2) as a supplement to transport fuels
(3) as a source to make ethylene
(4) as part of alcoholic drinks for human consumption

(1) Ethanol is a good solvent and will dissolve a large number of polar and non-polar substances. It is a polar molecule and the –OH group that can form hydrogen bonds to other substances. Ethanol is also miscible with water. The non-polar part of ethanol molecules ($-CH_2CH_3$) allows it to dissolve non-polar substances. This property of ethanol has a positive impact on society. Many substances, such as flavourings, colourings and medicines may not be very soluble in water but can be dissolved in ethanol instead. Solutions of these substances in ethanol can be diluted so that appropriate amounts are used. It may be easier for patients to take medicines as a liquid rather than as a solid.

(2) When ethanol is burnt energy is released.

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g);\ \Delta H = -ve$$

Hence ethanol can be used as an alternative fuel in car engines. It is used to supplement or to replace petrol. If ethanol can be produced from biomass then it is an alternative to fossil fuels.

(3) Ethanol can be dehydrated by heating it with concentrated phosphoric acid or concentrated sulfuric acid to form ethylene.

The ethylene produced can be used to make many different polymers, such as polyethylene. If the ethanol is produced from biomass or other renewable sources, then smaller amounts of fossil fuels will be needed to produce the polymers.

(4) Fermentation of glucose will produce ethanol.

This reaction is the basis of the fermentation industry and the production of alcoholic drinks for human consumption. It is also the reaction used to convert glucose from biomass into a transport fuel and hence replace fossil fuels.

[7 marks]

Question 39

Many polymers currently used in our society are not biodegradable and they accumulate in the environment. To address this concern biodegradable plastics are being investigated.

Polyhydroxybutanoate (PHB): PHB is produced by some strains of bacteria. It is a condensation polymer made from 3-hydroxybutanoic acid, $CH_3CH(OH)CH_2COOH$. It has similar properties to polymers made from petrochemicals but has the advantage that it is biodegradable. The cost of producing this biopolymer is higher than that of petrochemical polymers and only limited use has been made of PHB at the present time. The impact of this polymer on the environment is therefore limited but will increase when it is used more widely.

Polylactic acid (PLA): Starch waste from crops such as maize, potatoes, sorghum and corn can be converted into lactic acid by bacterial action. Condensation polymerisation of the lactic acid produces PLA. This polymer is strong and has other properties similar to those made from petrochemicals, such as polystyrene and polyethylene terephthalate. PLA has the advantage of being biodegradable. The cost of producing PLA is higher than that of petrochemical polymers. The impact of this polymer on the environment is therefore limited but will increase when it is used more widely.

[4 marks]

Question 40

(a) Advantages:

- Ethanol can be produced from renewable sources such as sugarcane as opposed to other fuels such as petrol which come from fossil fuels, the supply of which is finite.
- Ethanol undergoes complete combustion more easily than octane therefore producing less $C(s)$ which can clog engine parts, and less $CO(g)$ which is poisonous.

Disadvantages:

- Ethanol releases less energy per gram than octane meaning that a greater mass of fuel is required to travel the same distance.
- Producing ethanol from renewable sources requires vast amounts of arable land, reducing the availability of land for food crops. [4 marks]

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

[3 marks]
[Total = 7 marks]

7.5 Reactions of organic acids and bases

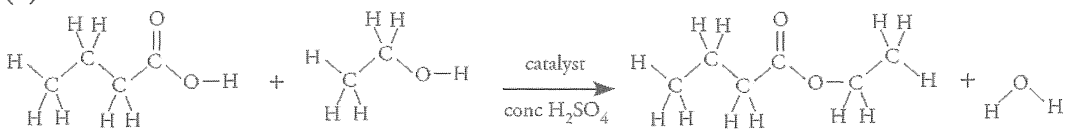
Question 41

Compound: 1-chloropropanoic acid; Salt: sodium 1-chloropropanoate

[1 mark]

Question 42

(a)



[2 marks]

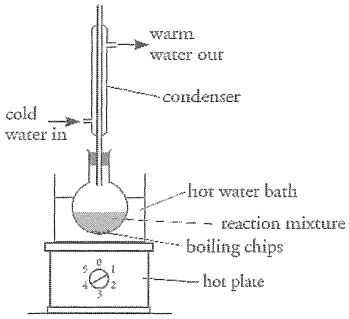
(b) *Either:* Concentrated sulfuric acid is used as a catalyst in the preparation of ethyl butanoate. It is highly corrosive to skin and must be used with great care. A supply of water such as a safety shower should be available. Also, an absorbent, such as sand, and a neutralising agent, for example solid sodium carbonate, should be present in the laboratory.
Or: As the chemicals used are flammable a fire extinguisher and blanket are required.

[2 marks]
[Total = 4 marks]

Question 43

Heating the reaction mixture under reflux conditions has several advantages.

- The reaction between an alcohol and a carboxylic acid is usually slow. Heating the mixture will increase the rate of reaction.
- The reactants and the ester are volatile and flammable. The reflux condition condenses the vapours and returns them to the reaction flask.
- Heating can be continued for a long time so that the mixture reaches equilibrium.



[4 marks]

Question 44

(a) Compound X is ethanol and compound Y is acetic (ethanoic) acid. [2 marks]

(b) Glucose can be converted into ethanol by fermentation with yeast. Yeast contains the enzyme zymase, which is a catalyst for the reaction.

Large vats are used to carry out the fermentation. Nutrients, such as ammonium phosphate, are added to provide phosphorus and nitrogen for the yeast. The process is carried out under anaerobic conditions, with pH ≈4 and at ≈35°C for optimal yield. At the end of the fermentation the concentration of ethanol in the aqueous solution is ≈10%.

Some of the ethanol is oxidised to acetic acid by heating it with acidified potassium dichromate solution.

Ethanol is placed in a flask and mixed with an equimolar amount of acetic acid. The esterification reaction is slow. To increase the rate of reaction a small amount of concentrated sulfuric acid is added, to act as a catalyst, and the mixture is heated under reflux conditions for several hours.

After the allotted time the sulfuric acid and any remaining acetic acid are neutralised by adding sodium hydrogen carbonate. The ethyl acetate is purified by distillation of the mixture. [6 marks]

(c) Distillation is used to increase the concentration of ethanol to ≈95%. The dilute aqueous solution of ethanol is heated until the 95% ethanol/water mixture boils at ~78°C. The vapour is then cooled and the condensed liquid is collected. A dehydrating agent is then used to remove most of the remaining water so that ethanol of >98% purity is obtained. [1 mark]

[Total = 9 marks]

Question 45

(a) This fat is a fatty acid, and by boiling the acid with NaOH, the salt of the acid is produced. This process is called saponification. [1 mark]

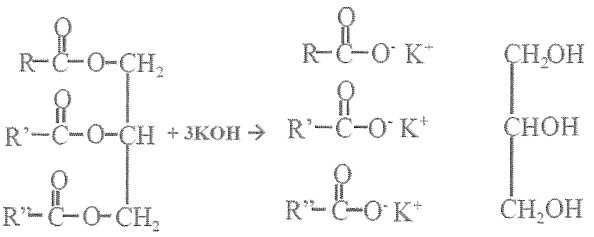
(b) Soap molecules contain two distinct ends, a hydrophilic end ($-COO^-$) which is water loving and a hydrophobic end ($-CH_2$), which is insoluble in water, but soluble in non-polar substances, such as grease. The action of soap is to clean, hence, the non-polar lifts off the grease from the surface which is suspended in the water to allow it to be rinsed off. [2 marks]

[Total = 3 marks]

Question 46

(a) Typical fats/oils used to make soap s are high molecular mass fats and oils such as triglyceride (esters) which can be saponified hydrolysed in basic solution (typically KOH or NaOH) to give soap (a carboxylate salt) and glycerol. Soaps from highly saturated, solid fats, are hard; whereas an unsaturated oil, such as olive oil, gives a liquid soap. [1 mark]

(b)



A triglyceride reacts with KOH to form a mixture of potassium carboxylates and glycerol.

[2 marks]
[Total 3 marks]

Question 47

Soap has a hydrophilic, negatively charged polar head and a long, hydrophobic non-polar tail. When a mixture of soap and water is added the non-polar tails of the soap will dissolve in the grease. When enough soap has surrounded the grease, the particle is lifted off the surface. The negatively charged heads of the soap prevent individual grease droplets recombining, effectively forming an emulsion of grease in water, allowing the grease to be removed from the surface. Answers could include: Other surfactants instead of soap.

[3 marks]

Question 48

(a) Suitable examples are ethyl acetate, propyl acetate, butyl acetate, ethyl propanoate, methyl propanoate. [1 mark]

(b) The three chemicals required for the preparation of an ester are an alcohol, a carboxylic acid and concentrated sulfuric acid. The potential hazards and how they can be controlled are given in the table.

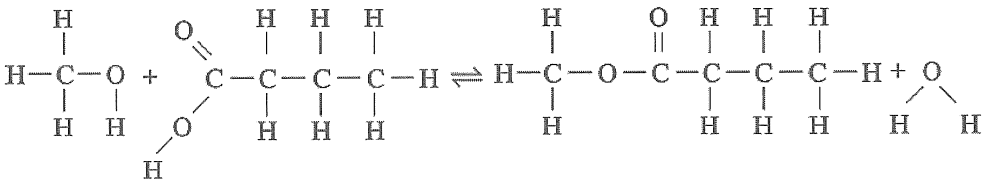
Substance	*Hazard*	*Control method*
Alcohol	Flammable and toxic	Keep away from naked flames. Heat using a hot plate.
Carboxylic acid	May cause skin burns. Often have a strong unpleasant odour and can cause throat irritation.	Wear protective clothing, e.g. a lab coat, gloves and safety glasses. Carry out experiment in a fume cupboard.
Conc. H_2SO_4	This material has noxious fumes and can cause severe skin burns.	Work in a fume cupboard, wear protective clothing, e.g. a lab coat, gloves and safety glasses. Use only small quantities.

[5 marks]
[Total = 6 marks]

Question 49

(a) One of the reactants is flammable. [1 mark]

(b)



[2 marks]

(c) Esterification is a slow reaction. Heating the reaction makes it go faster. However, the reactants and products of esterification have relatively low boiling points. The condenser (X) prevents the loss of these volatile substances by condensing them back into the reaction mixture and allows for the reaction to proceed at higher temperatures.

[2 marks]
[Total = 5 marks]

Question 50

(a)

$+ H_2O$ $+ HBr$ $\|$ O

[5 marks]

(b) A – 1-bromobutane, B – 1-butanol, C – butanal [3 marks]
[Total = 8 marks]

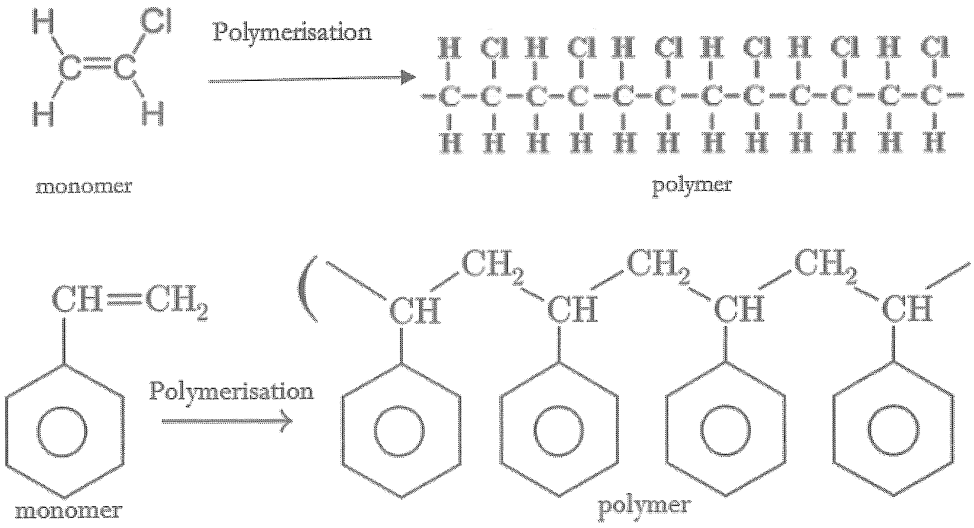
7.6 Polymers

Question 51

Monomers		*Polymers*		
Common Name	*Systematic name*	*Name*	*Properties*	*Use*
Ethylene	Ethene	LDPE – Low density polyethylene	Flexible and tough but low tensile strength, low heat deflection	• Soft drink bottles, toys • Shopping bags
Ethylene	Ethene	HDPE – High density polyethylene	Rigid and non-permeable, high tensile strength with low-stress crack resistance	• Garbage bins, cutting boards • Detergent bottles
Vinyl chloride	Chloroethene	PVC – polyvinylchloride	Clear, moderately tough, waterproof and with good flame resistance; but poor UV resistant	• Pipes, flooring • Raincoats, shower curtains
Styrene	Phenylethene	Polystyrene	Good moisture resistant, brittle	• Toys • Foam products, including for insulation • Body of appliances, car moulding • Clear cups
Tetrafluoroethylene	Tetrafluoroethene	PTFE – polytetrafluoroethylene	• Chemically inert due to the strength of carbon–fluorine bonds • Hydrophobic to water due to the high electronegativity of fluorine • High temperature resistance • One of the lowest coefficients of friction	• Coating for non-stick surfaces such as cookware • Piping for reactive or corrosive chemical • As a lubricant due to its non-adhesive properties

[4 marks]

Question 52



[4 marks]

Question 53

PVC – the Cl atom strengthens the chain, prevents movement hence the hardness of the polymer. The Cl atom also inhibits combustion, and hence it is fire resistant and used for firemen's clothing and similar. It is non-polar; hence it is waterproof so used for raincoats, shower curtains etc.

Polystyrene is a linear polymer hence it is thermoplastic. The presence of the benzene ring gives the chain more structure so it is hard and strong but brittle. Used for screwdriver handles, CD cases etc. When aerated, PS can be used as a strong foam for insulation and bulk food storage containers.

[2 marks]

Question 54

P1 – (a) Thermoplastic – used in toys, and bottles made of polyethylene, polystyrene and PVC. (b) Weak intermolecular forces link long chains, can be reshaped and moulded as becomes soft and flexible on heating and hard and re-shaped when cool
P2 – (a) Thermosetting plastic such as laminates for kitchen benches.
(b) Significant X-linking with covalent bonds between chains. The covalent bonds cannot be broken with heat.
P3 – (a) Elastomers like vulcanized rubber and synthetic rubber. (b) It can stretch but also it can revert to its original shape due to the overlapping of chains and some cross linking (which pull the chain back).
P4 – (a) HDPE thermoplastic which is hard and rigid. Used for toys, buckets, bins and playground equipment. (b) Polymer chains are packed tightly due to lack of significant branching. In turn, this leads to increased intermolecular forces, hence increase in strength and toughness (but also less flexibility).
P5 – (a) LDPE, thermoplastic, non-toxic, tough but also flexible. Used for plastic bags, food wrap and milk and juice containers. (b) Increased branching leads to weaker intermolecular forces between the chains, hence its flexibility and softness.

[5 marks]

Question 55

(a) Length of chain: strength increases with polymer length due to greater intermolecular forces.

(b) chain arrangement: if molecules are lined and closely packed (crystalline) lead to polymer strength and higher MP. Polymer chains arranged randomly (amorphous) are flexible and soft.

(c) Degree of branching: Increase in number and length of branching leads to improved mechanical properties, i.e. stiffer, harder and stronger polymer

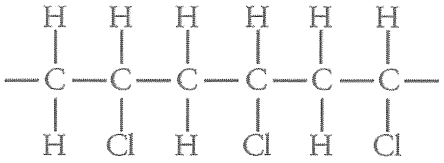
(d) Cross-linking between polymer chain: This can alter the properties of the polymer, such as resistance to solvents or increased heat resistance.

(e) Inclusion of additives: Additives are used to improve the property of the polymer for the application, such as a filter additive for improved UV protection or to improve the thermal stability or heat retardation of the polymer.

[5 marks]

Question 56

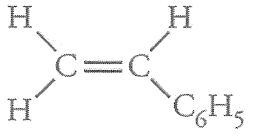
(a) **(i)**



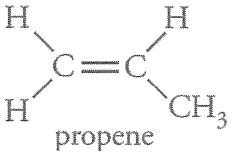
[2 marks]

(ii) Addition polymerisation. [1 mark]

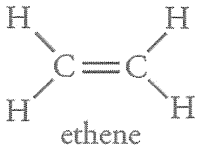
(b) The polymer is made from three monomers.



styrene



propene

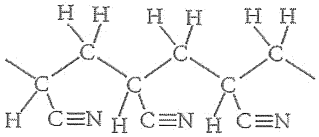


ethene

[3 marks]
[Total = 6 marks]

Question 57

(a)



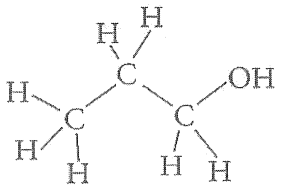
[1 mark]

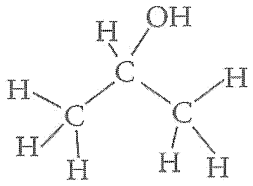
(b) Polyacrylonitrile must be able to be drawn into long filaments, which can be knitted together to make the material for rugs, blankets and clothes. It should have a high tensile strength, be lightweight and feel soft and warm. It should be possible to colour the polymer and the material must be washable. The polymer should be resistant to attack from chemicals and should not deteriorate in sunlight. [3 marks]

[Total = 4 marks]

Question 58

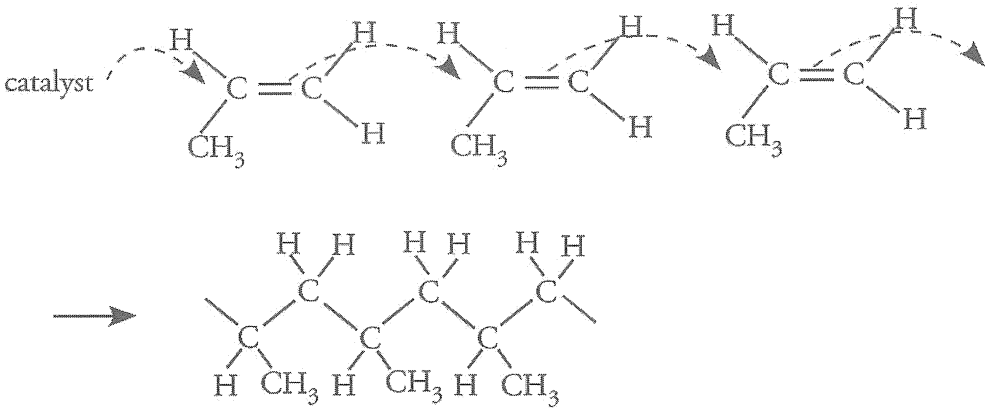
(a) Compound Q could be either 1–propanol or 2–propanol.





[2 marks]

(b) Propene is polymerised at low temperatures and pressures in the presence of a surface catalyst to form polypropene. In the presence of the catalyst the carbon to carbon double bond breaks and forms single covalent bonds to adjacent molecules, whose double bonds are also broken. Many thousands of propene molecules can be linked in this way. A polymer chain results.



[3 marks]

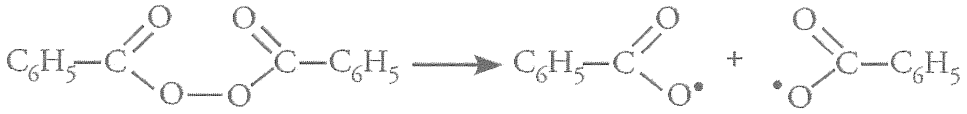
(c) The number of propene molecules that link together to form the polymer chain can vary from one chain to the next. Hence chains of different lengths are formed. These will have different molecular weights.

[1 mark]

[Total = 6 marks]

Question 59

(a) There are three steps in the addition polymerisation of a monomer, such as ethylene. They are initiation, propagation and termination. To start the process an initiator, such as benzoyl peroxide, is added to the alkene. Benzoyl peroxide contains an oxygen to oxygen single bond which is easily broken to form two radicals. These radicals each have an unpaired electron and are very reactive.



The unpaired electron from the radical combines with one of the electrons from the double bond of the alkene as follows.

$$C_6H_5COO\bullet + CH_2{=}CH_2 \rightarrow C_6H_5COO{-}CH_2{-}CH_2\bullet$$

In the propagation step, more molecules of the alkene can react to extend the chain length.

$$C_6H_5COO{-}CH_2{-}CH_2\bullet + CH_2{=}CH_2 \rightarrow C_6H_5COO{-}CH_2{-}CH_2{-}CH_2{-}CH_2\bullet$$

This process continues until two growing chains react and the process terminates.

$$C_6H_5COO{-}(CH_2)_xCH_2\bullet + \bullet CH_2(CH_2)_y{-}OOCC_6H_5 \rightarrow C_6H_5COO{-}(CH_2)_xCH_2{-}CH_2(CH_2)_y{-}OOCC_6H_5$$

[3 marks]

(b) In polystyrene, C_6H_5 groups are attached to the carbon atoms along the long chains. The polymer is very stiff because of the presence of these groups. The high stiffness of the polymer makes it suitable for making handles for tools (such as screwdrivers) and also for making the cases of car batteries.

Polyethylene consists of long chains of $-CH_2-$ groups with no side groups. There are two forms of polyethylene: high density polyethylene (HDPE) and low-density polyethylene (LDPE).

In HDPE there are very few branches to the chain and the long chains can pack close together. This results in a rigid polymer that is used to make durable items such as buckets, pipes and petrol tanks.

LDPE has many branches along the chain. The resulting polymer is flexible and is used to make squeeze bottles, cling wrap and plastic bags. [4 marks]

[Total = 7 marks]

This scan unfortunately does not have the module 8 answers.