CHEMISTRY

UNITS 1&2

2021

WA Student Number: In figures

In words _____

_____

Circle your teachers name: ***Barnes*** ***Dhue*** ***Fagan*** ***Holyoake***

Lloyd ***Thompson*** ***Venter***

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time: three hours

Materials required/recommended for this paper

To be provided by the supervisor:
This Question/Answer Booklet
Multiple-choice Answer Sheet
Chemistry Data Book

To be provided by the candidate:
Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, eraser, correction tape/fluid, ruler, highlighters

Special items: up to three calculators, which do not have the capacity to create or store programmes or text, are permitted in this ATAR course examination

Important note to candidates

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of examination
Section One Multiple-choice	25	25	50	/ 25	/ 25
Section Two Short answer	7	7	60	/ 67	/ 35
Section Three Extended answer	5	5	70	/ 76	/ 40
					/ 100

Instructions to candidates

1. Write your answers in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.

2. Answer the questions according to the following instructions.

   Section One: Answer all questions on the separate Multiple-choice answer sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. Do not use erasable or gel pens. If you make a mistake, place a cross through that square, then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

   Sections Two and Three: Write your answers in this Question/Answer Booklet.

3. When calculating numerical answers, show your working or reasoning clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning. Express numerical answers to the appropriate number of significant figures and include appropriate units where applicable.

4. You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.

5. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

6. The Chemistry Data Book is not to be handed in with your Question/Answer booklet.

Section One: Multiple-choice **25% (25 marks)**

This section has **25** questions. Answer **all** questions on the separate Multiple-choice answer sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. Do not use erasable or gel pens. If you make a mistake, place a cross through that square, then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Suggested working time: 50 minutes.

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1. Which of the following statements regarding an atom of neon-20 is correct?

   (a) The atomic number is 20.
   (b) The mass number is 20.
   (c) The number of neutrons is 20.
   (d) The number of electrons is 20.

2. Consider the equations below showing the behaviour of sulfurous acid when dissolved in water.

   I. $H_2SO_3(aq) \rightleftharpoons H^+(aq) + HSO_3^-(aq)$
   II. $HSO_3^-(aq) \rightleftharpoons H^+(aq) + SO_3^{2-}(aq)$

   Based on these equations which of the following conclusions can be made about sulfurous acid?

   (a) It is a strong diprotic acid.
   (b) It is a strong acid.
   (c) It is a weak diprotic acid.
   (d) It has a pH above 7.

3. Which of the formulae in the table below correctly match the names given?

	Name	Formula
(i)	dinitrogen tetroxide	N_2O_4
(ii)	strontium nitrite	$SrNO_2$
(iii)	lithium hydrogenphosphate	Li_2HPO_4
(iv)	iron(III) cyanide	$Fe_2(CN)_3$
(v)	sodium oxalate	Na_2O

   (a) (i) and (iv) only.
   (b) (ii) and (iii) only.
   (c) (i) and (iii) only.
   (d) (ii) and (v) only.

4. The aqueous solubility of a particular solute is being investigated. As the temperature of the water decreases, the solubility of the solute would likely **increase** if the solute

(a) was a gas.
(b) was a solid.
(c) was polar.
(d) was non-polar.

5. A student wrote three sentences describing the structure of graphite.

I It consists of layers or sheets of **carbon** atoms which form flat hexagonal rings.
II Each **carbon** atom is connected to three other **carbon** atoms by covalent bonds.
III There are no covalent bonds existing between each layer of **carbon** atoms

Which of these statements are correct?

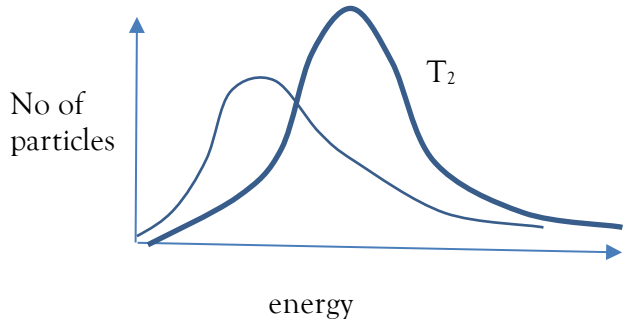
(a) I only
(b) I and II only
(c) I and III only
(d) I, II and III

6. Which pair of statements explains the increase in the rate of a reaction when the temperature is increased or a catalyst is added?

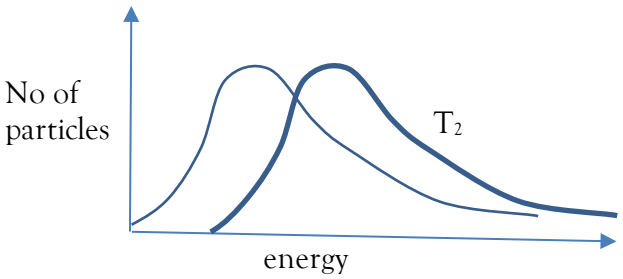
	Increasing temperature	**Adding a catalyst**
(a)	activation energy decreases	activation energy increases
(b)	change in enthalpy(ΔH) decreases	average kinetic energy of the particles increases
(c)	average kinetic energy of the particles increases	activation energy decreases
(d)	number of particles increases	change in enthalpy(ΔH) decreases

7. The sample of gas, in a closed system, is heated to a higher temperature, T_2. Four chemistry students were asked to draw the curve that represents the distribution of energy at this new temperature. They are shown below, which one is correct?

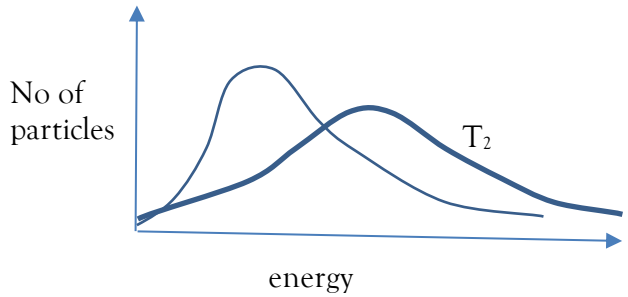
a)



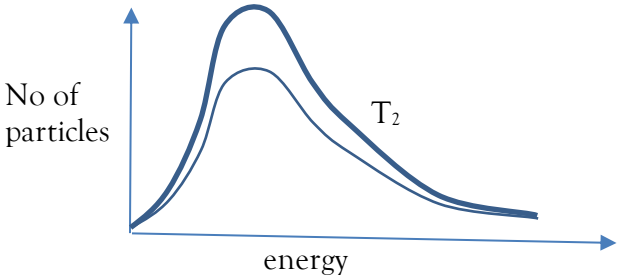
b)



c)



d)



8. Which of the following statements is/are correct for particles in the transition state of a chemical reaction?

(i) They can quickly form reactants.
(ii) They can quickly form products.
(iii) They have maximum enthalpy.

(a) (ii) only.
(b) (i) and (ii) only.
(c) (ii) and (iii) only.
(d) All of (i), (ii) and (iii).

Questions 9, 10 and 11 relate to the information provided in the partially completed table below.

	Symbol	Number of protons	Number of neutrons	Number of electrons
V	^{22}Na		11	
W		15	15	15
X	$^{22}Na^{+}$	11		
Y	$^{31}P^{3-}$			18
Z		13		10

9. Which two species are isotopes?

(a) V and X.
(b) W and Y.
(c) X and Z.
(d) V and Z.

10. Which two species have the same electron configuration?

(a) V and X.
(b) W and Y.
(c) X and Z.
(d) V and Z.

11. The radius of

(a) V is less than that of W.
(b) X is less than that of Z.
(c) Y is less than that of W.
(d) X is less than that of V.

12. Consider the chemical reaction below.

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

Which of the following changes would **not** increase the rate of reaction?

(a) Increasing the concentration of $SO_2(g)$ in the system.
(b) Increasing the volume of the system.
(c) Increasing the temperature of the system.
(d) Adding an appropriate catalyst to the system.

13. The semi-structural formula of 4,4-dimethylpent-2-ene is

(a) $(CH_3)_3CCH_2CHCH_2$
(b) $CH_3C(CH_3)_2CH(CH_3)CH_3$
(c) $CH_3CHCHC(CH_3)_2CH_3$
(d) $CH_3CH_2CH(CH_3)CH(CH_3)CH_3$

14. Which one of the following substances will have the highest boiling point?

(a) methane (CH_4)
(b) ethane (CH_3CH_3)
(c) dichloroethane (CH_3CHCl_2)
(d) dichloromethane (CH_2Cl_2)

Questions 15 and 16 relate to the information below.

Four (4) beakers labelled W, X, Y and Z, were known to contain the following 0.5 mol L^{-1} solutions; $Na_2S(aq)$, $K_2CO_3(aq)$, $ZnCl_2(aq)$ and $Pb(NO_3)_2(aq)$.

In order to find the identity of the solutions, samples were taken from each of the beakers and mixed. The table below shows which samples were mixed, as well as the corresponding observations.

	W	X	Y
X	white solid formed		No visible reaction
Y	white solid formed	no visible reaction	
Z	white solid formed	white solid formed	grey solid formed

15. The formula of the grey solid produced when samples from beakers Y and Z were mixed is

(a) $Pb(NO_3)_2$.
(b) $PbCl_2$.
(c) $PbCO_3$.
(d) PbS.

16. The results in the table demonstrate that $ZnCl_2(aq)$ was in beaker

(a) W.
(b) X.
(c) Y.
(d) Z.

17. A sample of juice was being analysed by high-performance liquid chromatography (HPLC) to confirm whether citric acid was present. Subsequently, the results of the analysis were compared to a calibration curve to determine the concentration of citric acid in the juice.

In order for the data to be reliable, the HPLC conditions used for the citric acid analysis must be the same as those used to produce the citric acid calibration curve. These are referred to as 'controlled variables'.

Which of the following is **not** a variable that needs to be controlled in this investigation?

(a) The stationary phase.
(b) The mobile phase.
(c) The pressure applied.
(d) The amount of sample loaded.

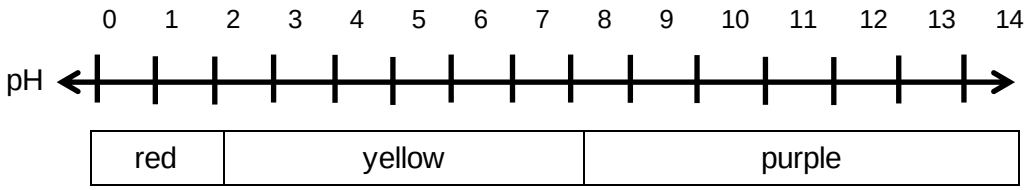
18. Which one of the following does **not** have an electron configuration of 2,8,8?

(a) Ar
(b) Al^{3+}
(c) Cl^{-}
(d) Ca^{2+}

19. Activation energy is the

(a) minimum amount of energy released in a chemical reaction.
(b) maximum amount of energy released in a chemical reaction.
(c) minimum amount of energy required for a chemical reaction to occur.
(d) maximum amount of energy required for a chemical reaction to occur.

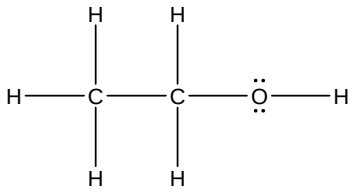
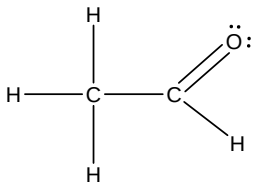
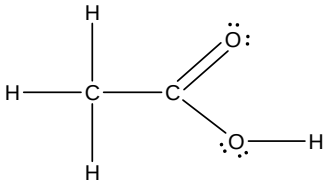
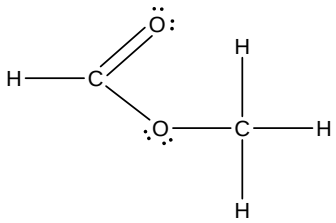
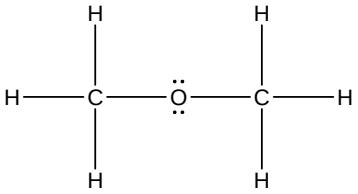
20. Metacresol purple is a pH indicator exhibiting three (3) different colours, as shown in the diagram below.



Which of the solutions below would be **least** likely to turn yellow, when several drops of metacresol purple are added to it?

(a) $H_2O(l)$
(b) $NH_3(aq)$
(c) NaCl (aq)
(d) NaOH(aq)

21. Which of the organic substances below would exhibit dipole-dipole forces but **not** hydrogen bonding between molecules in a pure sample?

(i)	
(ii)	
(iii)	
(iv)	
(v)	

(a) (i) and (v) only.
(b) (ii) and (iv) only.
(c) (ii), (iii) and (v) only.
(d) (ii), (iv) and (v) only.

22. Which one of the following rows correctly classifies each substance?

	Hydrogen peroxide (H_2O_2)	**Ethanoic acid (CH_3COOH)**	**Ammonium carbonate ($(NH_4)_2CO_3$)**
(a)	Non–electrolyte	Strong electrolyte	Weak electrolyte
(b)	Non–electrolyte	Weak electrolyte	Strong electrolyte
(c)	Weak electrolyte	Strong electrolyte	Weak electrolyte
(d)	Weak electrolyte	Non–electrolyte	Strong electrolyte

Questions 23 and 24 refer to the following three (3) organic reactions.

(i) $CH_3CHCHCH_3 + H_2O \rightarrow$ **X**

(ii) $CH_3CH_3 +$ **Y** $\rightarrow CH_2ClCH_3 + HCl$

(iii) $CH_3CH_2CH_2Br + NaOH \rightarrow CH_3CH_2CH_2OH +$ **Z**

23. Which of the following options correctly identifies substances X, Y and Z?

	X	**Y**	**Z**
(a)	$CH_3CH_2CHOHCH_3$	Cl_2	NaBr
(b)	$CH_3CHOHCH_2CH_3$	HCl	NaBr
(c)	$CH_3CHOHCH_2CH_3$	Cl_2	HBr
(d)	$CH_3CH_2CH_2CH_2OH$	HCl	Br_2

24. Which of these would be classified as a substitution reaction?

(a) (i) only.
(b) (ii) only.
(c) (i) and (iii) only.
(d) (ii) and (iii) only.

25. Which one of the following processes is exothermic?

(a) melting gold
(b) evaporating water
(c) freezing carbon dioxide
(d) boiling water

End of Section One

Section Two: Short answer **35% (67 marks)**

This section has **seven (7)** questions. Answer **all** questions. Write your answers in the spaces provided.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 60 minutes.

Question 26 **(10 marks)**

For each of the following

i. Write a **balanced ionic equation** (including state symbols).
ii. Describe the expected observations for the reaction.

(a) A small amount of aluminium carbonate powder is slowly added to an excess of nitric acid solution. (6 marks)

Description	Marks
Formula of reactants correct	1
Formula of products correct	1
Equation balanced	1
All correct states of matter correct	1
Observation(reactants): White powder added to a colourless solution resulting in…	1
Observation(products): a colourless solution and a colourless odourless gas produced	1
Total	**6**

Sample Answer:

Ionic equation:

$$A\ell_2(CO_3)_3(s) + 6\ H^+(aq) \rightarrow 2\ A\ell^{3+}(aq) + 3\ H_2O(\ell) + 3\ CO_2(g)$$

(b) Adding a small amount of iodine water to an excess of liquid oct–2–ene. (4 marks)

Equation:

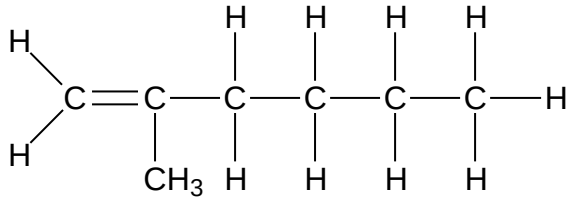
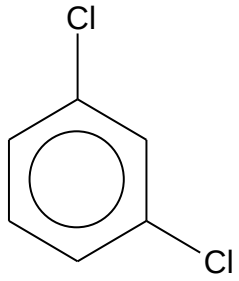
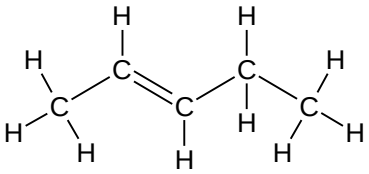
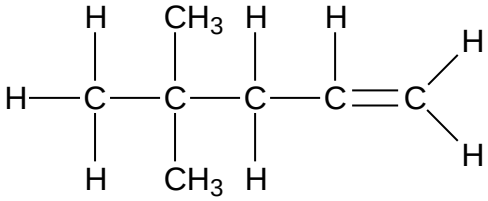
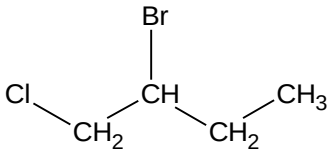
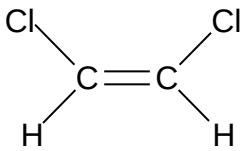
Description	Marks
Formula of reactants correct	1
Formula of products correct	1
Equation balanced	1
Observation: Brown solution added to a colourless liquid, the brown quickly decolourises, mixture becomes colourless. (two immiscible, colourless liquids observed)	1
Total	4

Sample Answer

$$\text{Overall: } I_2(aq) + C_8H_{16}(\ell) \rightarrow C_8H_{16}I_2(\ell)$$

Question 27 **(7 marks)**

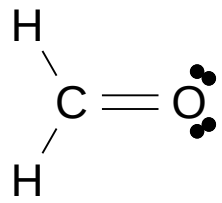
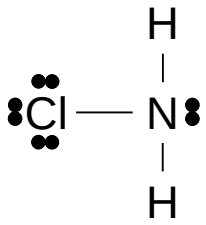
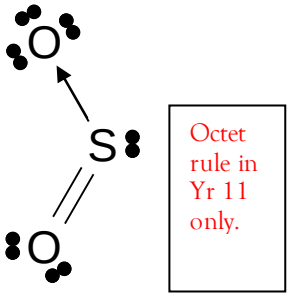
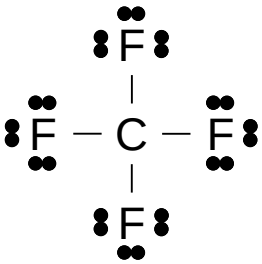
Complete the table below

Name of organic molecule	Structural formula
2 – methylhex–1–ene	
1,3 – dichlorobenzene	
Trans-pent-2-ene	
4,4–dimethylpent–1–ene	
5–bromo–2–methylhept–1–ene	$CH_2C(CH_3)CH_2CH_2CHBrCH_2CH_3$
2-bromo-1-chlorobutane	
cis–1,2–dichloroethene	

Note: 1 mark deducted (once only) for a space between substituent groups and functional group

Question 28 **(12 marks)**

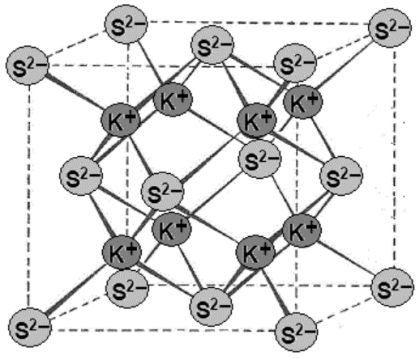
(a) Complete the table below. (12 marks)

Name of molecule	Lewis Structure	Shape	List of all intermolecular forces present between molecules
Methanal H_2CO		Trigonal planar	Dispersion Dipole–Dipole
Chloramine $H_2NC\ell$		Trigonal Pyramid (Pyramidal)	Dispersion Dipole–Dipole Hydrogen bonding
Sulfur dioxide SO_2		Bent or V-shaped	Dispersion Dipole–Dipole
Carbon tetrafluoride CF_4		Tetrahedral	Dispersion

Description	Marks
1 mark per box (Lewis Structures)	4
1 mark per box (Shape). If structure is wrong but shape based on wrong structure is correct (1 mark)	4
1 mark per box (intermolecular forces). Must have all forces listed for a mark.	4
Total	**12**

Question 29 **(15 marks)**

Below is a simplified representation of the lattice structure of solid potassium sulfide.



(a) Describe, in terms of all the forces formed and forces broken, the process of solid potassium sulfide dissolving in water.

(4 marks)

Description	Marks
Ionic bonds between ions in the lattice are broken OR Solute-solvent interactions strong enough to overcome ionic bonds	1
Ion–dipole(and dispersion forces) are formed between ions and water molecules.	1
Dissociation of ionic substance described / shown	1
Formation of ions hydrated/surrounded by polar water molecules described / shown	1
Total	**4**

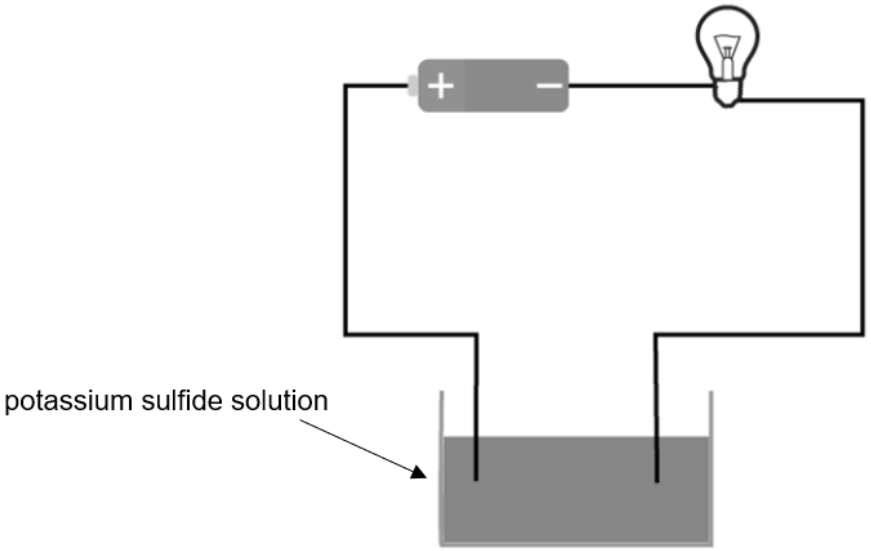
MARKER FEEDBACK: Very few students answered this question fully. Many students were able to describe ionic lattice and ion-dipole interactions, but did not demonstrate clear understanding of dissociation or hydration. This would have been best demonstrated with a clearly labelled diagram.

(b) Explain, in terms of breaking of existing bonds and forming of new bonds, why this process of dissolving solid potassium sulfide in water causes the temperature of the water to decrease. (4 marks)

Description	Marks
More energy is required to break the strong ionic bonds(lattice energy)	1
Than is released when ion–dipole forces are formed between ions and water molecules (hydration energy)	1
The net result is that energy is absorbed in this process, that is the process is endothermic	1
Endothermic reactions absorb heat energy and convert to chemical energy thus cause the temperature to decrease	1
Total	**4**

MARKER FEEDBACK: Common errors: misunderstanding of exo/endothermic definitions and energy implications; very few students linked strength of ionic bonds to bond breaking and forming energy requirements; no discussion of conversion from kinetic (heat) energy to chemical energy held in bonds.

(c) Explain why the solution of potassium sulfide can conduct electricity when the following apparatus is used to test its conductivity. (3 marks)



Description	Marks
The ions are free to move and function as charge carriers	1
Meaning the potassium ions can flow → and the sulfide ions can flow ←	1
The result of this flow of ions is that the solution can conduct electricity	1
Total	**3**

MARKER FEEDBACK: Common errors: Lots of talk about delocalised electrons! Many students did not demonstrate understanding that mobile ions carry charge in solution; Very few students linked flow of mobile polar ions to polarity of electrodes.

(d) Explain why dissolving the same amount (in mole) of hydrogen sulfide gas (H_2S) in water produces a solution that has a lower conductivity than that of K_2S. (4 marks)

Description	Marks
H_2S is a weak electrolyte/weak acid	1
Meaning it only partially ionises (ionises to a small extent)	1
The solution of H_2S will thus have a lower concentration of ions than that of K_2S which fully dissociated (is a strong electrolyte)	1
With a lower concentration of ions there are less charge carriers present to conduct electricity through the solution thus H_2S has a lower conductivity.	1
Total	**4**

MARKER FEEDBACK: Most students got 0 marks for this question. Students needed to discuss the difference between strong and weak electrolytes and implications for conductivity (Experiment 29). Common errors: discussion of covalent bonding; number of electrons in H and K atoms; intermolecular forces; electronegativity and polar bonds; linking conductivity to molar mass.

Very few marks awarded overall for Q29a-d.

Question 30 **(5 marks)**

Phosphorus pentachloride reacts with water to produce a mixture of phosphoric and hydrochloric acids, as shown in the chemical equation below.

$$PCl_5(s) + 4\,H_2O(l) \rightarrow H_3PO_4(aq) + 5\,HCl(aq)$$

(a) Describe why both the products of this reaction are classified as 'acids' according to the Arrhenius theory. (1 mark)

Description	Marks
Both (ionise to) produce $H^+(aq)$ ions in solution.	1
Total	**1**
NOTE: must include "in solution". Dissociation (split apart) is not ionisation (transfer of electrons).	

(b) Define a 'weak' acid, and identify which of the products is classified as weak. (2 marks)

Description	Marks
A weak acid is one that partially ionises in solution.	1
H_3PO_4	1
Total	**2**

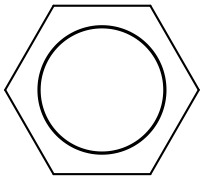
(c) Define a 'monoprotic' acid, and identify which of the products is classified as monoprotic. (2 marks)

Description	Marks
A monoprotic acid has one ionisable / acidic hydrogen per molecule.	1
HCl	1
Total	**2**
NOTE: must include "per molecule"	

Question 31 **(9 marks)**

Thin layer chromatography (TLC) can be used to detect the presence of preservatives in different cosmetics. A glass plate coated in polar silica gel is used as the stationary phase. The mobile phase is a benzene-propanone (8:2) mixture.

(a) Complete the following table regarding the components of the mobile phase. (3 marks)

Description			Marks
Structural diagram			1
'Polar' or 'non-polar' substance	non-polar	polar	2
		Total	**3**

Using the conditions described above, several preservatives were analysed by TLC. Once separated, the preservatives were visualised by UV detection. The retention factor values were calculated using the formula;

$$\text{Retention factor } (R_f) = \frac{\text{distance travelled by component}}{\text{distance travelled by solvent}}$$

The results of this analysis are provided in the table below.

Preservative	R_f
Dichlorophene	0.50
Fluorosan	0.56
Hexachlorophene	0.14
Salicylanilide	0.65
Tribromsalan	0.60
Chlorhexidine acetate	0.40
Phenylphenol	0.68

(b) Which of these preservatives is the most polar? Justify your answer. (4 marks)

Description	Marks
Hexachlorophene.	1
The stationary phase is polar **and** the mobile phase has a low polarity. Must have BOTH	1
Therefore the most polar component will be most strongly attracted / will interact most strongly / will adsorb most strongly to the stationary phase.	1
Thus the most polar component will move **most slowly** and have the lowest retention factor. Must refer to rate of travel to be awarded this	1
Total	**4**

MARKER FEEDBACK: a lot confused retention factor with retention time. Most students did not clearly give the polarity of both phases – this is essential as it is a balance between them so you need to discuss both.

Three cosmetic products; shampoo, deodorant and hand soap; were then analysed by TLC under identical conditions. A diagram of the resultant TLC plate is provided below.

(c) Which cosmetic product is most likely to contain tribromsalan? (1 mark)

Description	Marks
Deodorant.	1
Total	**1**

(d) Give one (1) reason that it cannot be known for certain that tribromsalan is in this cosmetic product. (1 mark)

Description	Marks
Any of the following: • Another chemical may have the same retention factor in identical conditions • The information provided does not rule out possible sources of error which may decrease the accuracy of the data	1
Total	**1**

Question 32 **(9 marks)**

Hydrogen peroxide is a colourless solution which decomposes into water and oxygen gas under standard laboratory conditions.
The enthalpy change for this reaction is given as; $\Delta H = -196$ kJ mol^{-1} of hydrogen peroxide.

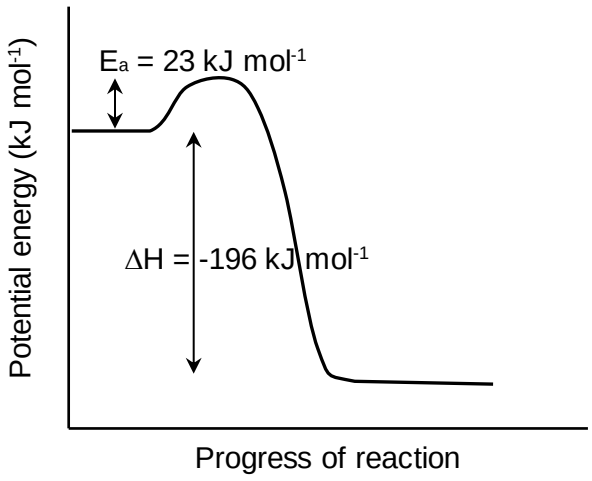
(a) Write a balanced thermochemical equation representing this reaction. (3 marks)

Description	Marks
Equation $2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g) + 392$ kJ	
Correct species	1
Correct balancing	1
Correct enthalpy change. if they used ΔH had to be 392 kJ or specify kJ/mol of hydrogen peroxide. Simply rewriting $\Delta H = -196$ kJ mol^{-1} not paid	1
Total	**3**

(b) Suggest one (1) method for measuring the rate of this reaction. (1 mark)

Description	Marks
Any of the following: • Measure the volume of oxygen produced • Measure the decrease in mass of hydrogen peroxide solution	1
Total	**1**

(c) On the axes below, sketch an energy profile diagram for the catalysed and uncatalysed reactions. Label the enthalpy change and the activation energy. (4 marks)

Description	Marks
	
Exothermic shape of curve	1
Enthalpy change correctly labelled including value with correct sign	1
Activation energy correctly labelled including value	1
Catalysed below uncatalysed	1
Total	**4**

(d) Suggest one (1) method, not related to the manganese(IV) oxide catalyst, that would further increase the rate of this reaction. (1 mark)

Description	Marks
Increase the temperature of the hydrogen peroxide solution accepted concentration but not the best answer.	1
Total	**1**

End of Section Two

Section Three: Extended answer **40% (76 marks)**

This section contains **five (5)** questions. You must answer **all** questions. Write your answers in the spaces provided below.

Where questions require an explanation and/or description, marks are awarded for the relevant chemical content and also for coherence and clarity of expression. Lists or dot points are unlikely to gain full marks.

Final answers to calculations should be expressed to the appropriate number of significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 70 minutes.

Question 33 **(15 marks)**

The Sabatier process was developed in 1897 by the French chemist Paul Sabatier. In this reaction, carbon dioxide and hydrogen gas are converted to methane and water vapour as shown in the chemical equation below.

$$CO_2(g) + 4\,H_2(g) \rightarrow CH_4(g) + 2\,H_2O(g)$$

The Sabatier process is conducted at a temperature of approximately 400 °C and a pressure of 30 atmospheres (i.e. 30 times atmospheric pressure).

(a) Explain, in terms of the collision theory, why using a high temperature increase the rate of the reaction. (4 marks)

Description	Marks
A high temperature increases the average kinetic energy of the reactant particles.	1
They will collide with a greater frequency	1
They will collide with a greater energy	1
Explains why results in an increased frequency of successful collisions.	1
Total	**4**

Much of Sabatier's ground breaking work focused on the mechanisms of catalysis. Whilst there are now several different metal catalysts routinely used in the Sabatier process, the original catalyst was nickel metal.

(b) Explain, in terms of the collision theory, how the inclusion of a metal catalyst affects the rate of this reaction. (3 marks)

Description	Marks
A catalyst provides an alternate reaction pathway with a lower activation energy. (It is not true that a catalyst changes a reactions Eact but it provides a different pathway for reactants to become products. This pathway has a lower Eact)	1
This increases the proportion of particles with Eact.	1
Increasing reaction rate	1
Total	**3**

In 1912, Sabatier won the Nobel Prize for Chemistry for the discoveries he had made regarding the use of **finely divided** catalysts. Today, ongoing research into the role of metal nanoparticle catalysts is providing exciting advancements in many areas of chemistry.

(c) Define a nanoparticle. (1 mark)

Description	Marks
Particles in the size range 1-100 nm.	1
Total	**1**

(d) Explain, in terms of collision theory, the advantage of using nickel in nanoparticle form compared to bulk nickel. (2 marks)

Description	Marks
A greater catalyst surface area is provided.	1
This allows an increased frequency of collisions between reactant particles and the catalyst.	1
Total	**2**

The Sabatier process is used by NASA on board the International Space Station, to produce water for the crew. The chemical equation for the Sabatier process is provided again below, for convenience.

$$CO_2(g) + 4\,H_2(g) \rightarrow CH_4(g) + 2\,H_2O(g)$$

The carbon dioxide exhaled by the astronauts is collected and reacted with hydrogen gas that forms as a by-product of a different on-board reaction. The water vapour is cooled and condensed into a liquid. This produces 2495 kg of water each year.

(e) Calculate the total mass of carbon dioxide that must be exhaled by the astronauts each year, in order to produce this mass of water. State your answer to the appropriate number of significant figures. (5 marks)

Description	Marks
$m(H_2O) = 2495 \times 10^3$ $= 2495000$ g	1
$n(H_2O) = 2495000 / 18.016$ $= 138488$ mol	1
$n(CO_2) = ½ \times n(H_2O)$ $= 69244$ mol	1
$m(CO_2) = 69244 \times 44.01$ $= 3047429$ g	1
$= 3.047 \times 10^6$ g **or** 3.047 t (4SF)	1
Total	**5**

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Question 34 **(17 marks)**

Floatation tanks (float tanks, sensory deprivation tanks) are lightless, soundproof tanks containing a salt solution which is dense enough to enable the user to float. Float tanks are said to provide benefits such as relaxation and pain relief, as well as improved sleep, circulation and immunity.

Float tanks contain around 1000 L of salt solution. This solution contains a very high concentration of Epsom salts, $MgSO_4.7H_2O(s)$, which is maintained at 35 °C. The resulting $MgSO_4(aq)$ solution is designed to be just under saturation point. If too little salt is added, the solution will not be dense enough to allow the user to float. If too much salt is added, crystals of solute form and may block water filtering equipment.

(a) Distinguish between a saturated and an unsaturated solution. (2 marks)

Description	Marks
Saturated – maximum amount of solute dissolved in a solvent (at a particular temperature).	1
Unsaturated – less than maximum amount of solution dissolved in a solvent (at a particular temperature).	1
Total	**2**

A particular float tank company prepared a tank containing 1000 L of salt solution. This solution had a density of 1.27 kg L^{-1} and was known to be composed of 30.0% $MgSO_4$ by mass.

(b) Calculate the concentration of the $MgSO_4(aq)$ solution in moles per litre. (5 marks)

Description	Marks
$m(solution) = 1.27 \times 1000$ $= 1270$ kg	1
$m(MgSO_4) = (30 / 100) \times 1270$ $= 381$ kg	1
$= 381000$ g (converts kg to g)	1
$n(MgSO_4) = 381000 / 120.37$ $= 3165.24$ mol	1
$c(MgSO_4) = 3165.24 / 1000$ $= 3.165$ mol L^{-1}	1
Total	**5**

(c) Calculate the mass of Epsom salts, $MgSO_4.7H_2O(s)$, that would have been dissolved to produce this solution. (2 marks)

Description	Marks
$n(MgSO_4.7H_2O)$ = 3165.24 mol	1
$m(MgSO_4.7H_2O)$ = 3165.24 x 246.482 = 780175 g (780 kg)	1
Total	**2**

The solubility of $MgSO_4.7H_2O(s)$ at 35 °C is known to be 113 g per 100 mL.

(d) Prove that this float solution is unsaturated. Show all workings. (3 marks)

Description	Marks
113 g per 100 mL = 1130 g per L = 1130000 g per 1000 L Thus the maximum amount of solute is 1130 kg per 1000 L.	2
Less than this (i.e. 780 kg) has been dissolved, therefore the solution is unsaturated.	1
Total	**3**
Alternate working: 780175 g per 1000 L = 780.175 g per L = 78.0175 g per 100 mL Thus the concentration in the tank is less than 113 g per 100 mL, therefore the solution is unsaturated. *There were some very unusual but in parts correct attempts made with these questions pt c and d. As such there was some occasional variation in the allocation of marks from the answer key*	

To ensure that health and safety standards are upheld, the salt solution used in float tanks is periodically treated with chemicals such as chlorine, bromine or UV light.

(e) Suggest a reason these treatments may be performed on the salt solution. (2 marks)

Description	Marks
Any one of the following: • Disinfect the water • Kill bacteria • Kill viruses • Kill fungi • • 1 mark was removed for an incorrect answer	2
Total	**2**

The float tank company decided to use bromine, $Br_2(l)$, to treat the salt solution described above. Industry guidelines state that the concentration of bromine must be maintained at 6 ppm.

(f) Calculate the mass of bromine that should be present in 1000 L of salt solution. (2 marks)

Description	Marks
For unequivocally demonstrating an understanding that ppm means mg per kg	1
From part (b) m(salt solution in tank) = 1270 kg	
Therefore 6 x 1270 = 7620 mg **or** 7.62 g Br_2	1
Total	**2**

The pH of the salt solution must also be monitored and should fall between 6.8 and 7.6.

(g) define the term pH? (1 mark)

Description	Marks
Negative log of the concentration of $H^+(aq)$ in a solution. Since a definition was asked for there was no variation allowed	1
Total	**1**

Question 35 **(12 marks)**

'Hardness' in water is caused by dissolved calcium compounds. When heated some of these decompose and solid calcium carbonate can form as follows:

$$Ca(HCO_3)_2(aq) \rightarrow CaCO_3(s) + 2\,H_2O(\ell) + 2\,CO_2(g)$$

This calcium carbonate can build up as 'fur' inside containers. It can be removed by reaction with hydrochloric acid.

(a) Calculate the mass of calcium carbonate that would be produced from 10 000.0 L of water containing calcium hydrogen carbonate at a concentration of 0.356 g L^{-1}.
(Assume 100% of the calcium hydrogen carbonate decomposes). (5 marks)

Description	Marks
$m(Ca(HCO_3)_2) = c \times V = 0.356\ g\ L^{-1} \times 10000L = 3\ 560\ g$	1
$M(Ca(HCO_3)_2) = 162.116\ g\ mol^{-1}$	1
$n(Ca(HCO_3)_2) = m / M = 3560\ g / 162.116\ g\ mol^{-1} = 21.96\ mol$	1
$n(CaCO_3) = n(Ca(HCO_3)_2) = 21.96\ mol$	1
$m(CaCO_3) = n \times M = 21.96\ mol \times 100.09 = 2197.93\ g$ $= 2.20 \times 10^3\ g$ 3SF	1
Total	**5**

(b) Calculate the minimum volume of 10.0 mol L^{-1} hydrochloric acid solution that would be required to remove all of this solid calcium carbonate from the container. (3 Marks)

Description	Marks
$n(HCl)$ required $= 2 \times n(CaCO_3)$	1
$= 2 \times 21.96\ mol = 43.92\ mol$	1
$V(HCl)$ required $= n / c = 43.92\ mol / 10.0\ mol\ L^{-1} = 4.39\ L$ 3SF +	1
Total	**3**

(c) In a second container it was found that 600.0 g of calcium carbonate had built up inside. 1.85 L of the 10.0 mol L^{-1} hydrochloric acid was added to remove the 'fur' from the containers, but this was too much acid. Calculate the moles of excess acid. (4 marks)

Description	Marks
$n(CaCO_3) = m / M = 600\ g / 100.09\ g\ mol^{-1} = 5.995\ mol$	1
$n(HC\ell)$ required = 2 x $n(CaCO_3)$ = 2 x 5.995 mol = 11.99 mol	1
$n(HC\ell)$ added = c x V = 10.0 mol L^{-1} x 1.85L = 18.5 mol	1
$n(HC\ell)_{excess} = n(HC\ell)_{added} - n(HC\ell)_{required} = 18.5 - 11.99 = 6.51$ mol	1
Total	4

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Question 36 **(17 marks)**

Sulfuric acid is used at the electrolyte in car batteries.

(a) Using the example of sulfuric acid explain what is meant by a strong acid. Use an equation in your answer. (3 marks)

Description	Marks
a strong acid totally ionises (accept dissociates) in solution / produce a high concentration of hydrogen ions when dissolved in solution/ sulfuric acid molecules ionise in solution	1
$H_2SO_4(aq) \rightarrow 2\ H^+(aq) + SO_4^{2-}(aq)$	1
(mentions Diprotic Nature) $H_2SO_4(aq) \rightarrow H^+(aq) + HSO_4^-(aq)$ $HSO_4^-(aq) \leftrightarrow H^+(aq) + SO_4^{2-}(aq)$ $H_2SO_4(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$	1
Total	**3**

(b) The concentration of sulfuric acid in a car battery is found to be 2.15 mol L^{-1}. A car battery contains 0.650 L of sulfuric acid.

(i) Calculate the mass of sulfuric acid in the car battery. (3 marks)

Description	Marks
$n(H_2SO_4) = c \times V = 2.15 \times 0.650 = 1.3975$	1
$m(H_2SO_4) = n \times M = 1.3975 \times 98.086$	1
$= 137$ g (correct sig figs and unit)	1
Total	**3**

(ii) Assuming the density (d=m/V) of the acid in the battery is 1.07 g mL^{-1} calculate the concentration of the sulfuric acid as a percentage by mass. (2 marks)

Description	Marks
$m(H_2SO_4)_{solution} = 650 \times 1.07 = 695.5$ g	1
$\%(H_2SO_4) = (137/695.5) \times 100 = 19.7\%$	1
Total	**2**

(c) The car battery was damaged and 0.300 L of the acid leaked onto the floor of the garage. 475 mL of a solution of 2.75 mol L^{-1} sodium hydroxide was used to neutralise the acid. Show by calculation that this was just enough to neutralise all the spilt acid. (4 marks)

Description	Marks
$n(H_2SO_4)_{spilled} = c \times V = 2.15 \times 0.300 = 0.645$ mol	1
$n(NaOH)_{used} = c \times V = 2.75 \times 0.475 = 1.31$ mol	1
1 mole of H_2SO_4 requires 2 moles of NaOH for neutralisation *or show by equation:* (STOIC RELATIONSHIP) $H_2SO_4 + 2\ NaOH \rightarrow + Na_2SO_4 + 2\ H_2O$	1
therefore, $n(NaOH)_{required} = 0.645 \times 2 = 1.29$ mol	1
Total	**4**

(d) Powdered aluminium oxide was then sprinkled over the area of the spillage to remove any excess chemicals. Aluminium oxide is an amphoteric substance, which means it can act as an acid or a base.

SEE NEXT PAGE

(i) Explain why aluminium oxide is the substance chosen to complete the clean-up process (2 marks)

Description	Marks
aluminium oxide will neutralise any excess acid (H_2SO_4)	1
and/or any excess base (NaOH)	1
Total	**2**

(ii) Use your knowledge of reaction rates to explain why the aluminium oxide was used in a powdered form. (3 marks)

Description	Marks
powdered aluminium will have a large surface area	1
this will increase the number of (successful) collisions between the particles in the acid/base / H^+/OH^- ions and the aluminium oxide	1
therefore the reaction rate will increase	1
Total	**3**

Question 37 **(15 marks)**

The first periodic table of the elements was designed by the Russian chemist Dmitri Mendeleev, and was published in 1869. The periodic table arranges the elements according to recurring trends.

The seven rows of the periodic table are called periods. Consider the elements in period 3, as shown below.

Na	Mg	Al	Si	P	S	Cl	Ar

(a) What feature do these period 3 elements have in common? (1 mark)

Description	Marks
These elements all have **valence electrons** which occupy the third energy level / shell.	1
Students should note that the valence electrons are in the third shell (not just state they have 3 shells)Total	**1**

As you move from left to right across period 3, both the first ionisation energy and electronegativity of the elements increase.

(b) Define 'first ionisation energy' and 'electronegativity', and explain the increasing trend observed in each. (5 marks)

Description	Marks
First ionisation energy is the energy required to remove one mole of electrons from one mole of atoms in the **gaseous state.**	1
Electronegativity is the attraction exerted on a **bonding pair** of electrons.	1
The **positive charge of the nucleus increases** as you move left to right across the period (in addition to a decreased atomic radius).	1
Therefore, **electrons are more attracted to the nucleus**, and	1
a greater amount of energy is required to **remove an electron**.	1
Atom is in gaseous state; they attract bonded electrons; the nucleus attracts the electrons not the other way around Total	**5**

Now consider the *chlorides* of the period 3 elements;

$NaCl$	$MgCl_2$	$AlCl_3$	$SiCl_4$	PCl_3	SCl_2	Cl_2

The first three of these chloride compounds are considered to exhibit ionic bonding, whilst the latter four are classified as covalent compounds.

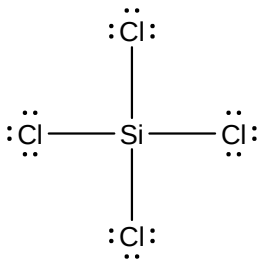
(c) Use the concepts of ionisation energy and electronegativity to explain why $NaCl$ is an ionic substance, whilst Cl_2 is a covalent substance. (4 marks)

Description	Marks
Sodium has a **low ionisation energy** and chlorine has a **high electronegativity**.	1
Therefore electrons are **transferred from sodium to chlorine**, forming cations and anions (i.e. ionic bonding).	1
Chlorine gas consists of two non-metal atoms with **high electronegativities.**	1
Therefore electrons are shared, forming an uncharged covalent molecule.	1
Total	**4**

(d) Explain why Cl_2 is the only one of these covalent compounds to contain non-polar bonds. (2 marks)

Description	Marks
The two chlorine atoms within Cl_2 have the **same electronegativity**.	1
Therefore the **electron pair is shared equally** by both atoms and no bond dipole is created.	1
Total	**2**

(e) Explain why $SiCl_4$ is classified as a non-polar molecule, despite containing polar bonds. Include the Lewis structure of $SiCl_4$ in your answer. (3 marks)

Description	Marks
Lewis structure:  (lone-pairs required)	1
The shape of the molecule is **symmetrical** / the molecule is a symmetrical tetrahedral shape. (not just tetrahedral)	1
Therefore the bond dipoles **cancel each other out** and there is no net dipole (resulting in a non-polar molecule).	1
Total	**3**

End of questions

Spare answer page

Question number: _____

Teacher	Questions	Mark		%
	1-25			/25

JV	26,27			
MD	28,30			
AB	31,32			
JT	29		67	
TOTAL Part B				% B /35
SH	34			
SH	35			
SF	36			
SF	37			
BL	38		76	
TOTAL Part C				% C /40
		Total %		