



Chemistry Olympiad - Final Stage

- Section 1 consists of 20 multiple choice questions. For each question there are four possible answers A, B, C and D. Choose the one you consider correct and circle it.

Each correct answer will score 2.5 marks. A mark will not be deducted for a wrong answer. Any rough working should be done in this booklet. You may use a calculator.

- Section 2 consists of 5 work-out problems. The answers must be written clearly in the space provided after every question.

White sheets provided are for draft, which is not to be graded.

- Duration is 1 hour. Pick your own strategy to win.

Write your full name below and do not open the booklet until instructed to do so. Good luck!

FULL NAME:

Do NOT write in this table

SECTION- (I)	SECTION- (II)	Q.I	Q.II	Q.III	Q.IV	Q.V	Total (I+II)
$20 \times 2.5 = 50$		10	11	10	10	09	100

February 26th, 2021

AKFA University Chemistry Olympiad, Final Stage

SECTION I

For each of the questions in this section, one or more of the three numbered statements 1 to 3 may be correct. Decide whether each of the statements is or is not correct (you may find it helpful to put a tick against the statements that you consider to be correct).

The responses A to D should be selected on the basis of

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

No other combination of statements is used as a correct response.

1. Which of the following molecules and ions have a regular trigonal planar shape?

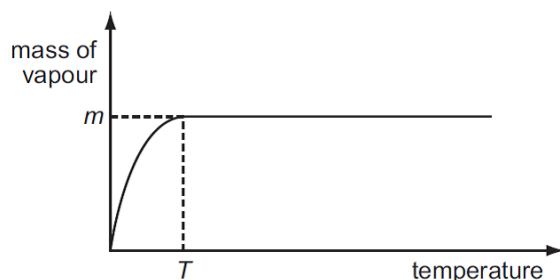
i. AlCl_3

ii. CH_3^+

iii. PH_3

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

2. A quantity of solid Y was placed in a previously evacuated vessel and the apparatus was then held at a series of different temperatures. At each temperature, the mass of Y in the vapour state was calculated from pressure measurements. The results are shown below.



What can be deduced from the diagram?

i. The mass of Y used in the experiment was m.

ii. The pressure of the vapour was constant for all temperatures above temperature T.

iii. Liquid appeared at temperature T.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

3. Which of the enthalpy changes of the following reactions can only be obtained by application of Hess' Law?

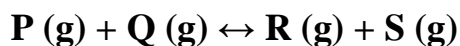
i. The hydration of anhydrous copper sulphate to form crystals of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$.

ii. The formation of methane from its elements.

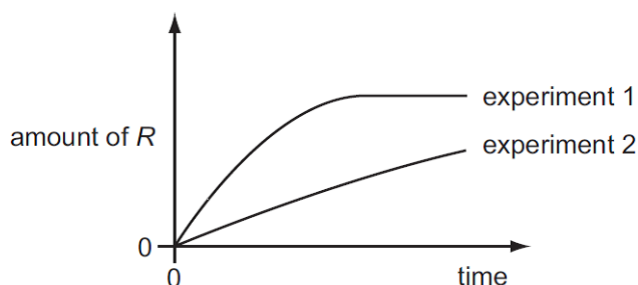
iii. The combustion of glucose, $\text{C}_6\text{H}_{12}\text{O}_6$.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

4. The stoichiometry of a catalysed reaction is shown by the equation below.



Two experiments were carried out in which the production of R was measured against time. The results are shown in the diagram below.



Which changes in the conditions from experiment 1 to experiment 2 might explain the results shown?

- i. Less of P was used.
- ii. A different catalyst was used.
- iii. Product S was continuously removed from the reaction vessel.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

5. Use of the Data Booklet is relevant to this question. Which properties would be expected from radium, ${}_{88}\text{Ra}$, or its compounds?

- i. Radium carbonate decomposes only at a very high temperature.
- ii. Radium hydroxide is very insoluble.
- iii. Radium does not react with cold water.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

6. The number of moles of chlorine that react with 1 mol of X is twice the number of moles of chlorine that react with 1 mol of Y. Which of these pairs could be X and Y?

	X	Y
1	Mg (s)	Na (s)
2	H ₂	KBr (aq)
3	Cold NaOH (aq)	Hot NaOH (aq)

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

7. Which statements are true about the Haber process for the manufacture of ammonia?

- i. At higher temperatures, the yield goes down but the rate of production of ammonia is faster.
- ii. At higher pressures, the yield goes down but the rate of production of ammonia is faster.
- iii. In the presence of a catalyst, the yield goes down but the rate of production of ammonia is faster.

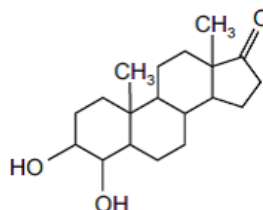
A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

8. Which compounds can be obtained from ethene in a single reaction?

- i. CH_3CH_3
- ii. $(-\text{CH}_2-\text{CH}_2)_n-$
- iii. $\text{HOCH}_2\text{CH}_2\text{OH}$

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

9. The steroid shown is an intermediate compound obtained during the synthesis of Formestane which is used in the treatment of breast cancer.

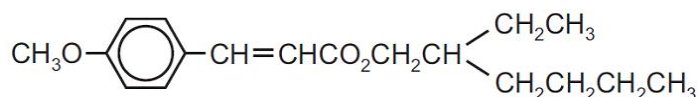


Which statements about this compound are correct?

- i. It reacts with hydrogen cyanide in a nucleophilic addition reaction.
- ii. It can be oxidised by warm acidified potassium dichromate (VI) to a carboxylic acid.
- iii. It will react with Fehling's solution.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

10. A sun protection cream contains the following ester as its active ingredient.



What are the products of its partial or total hydrolysis by aqueous sodium hydroxide?

- i. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2\text{CH}_3)\text{CH}_2\text{OH}$
- ii. $\text{CH}_3\text{O}-\text{C}_6\text{H}_4-\text{CH}=\text{CHCO}_2^-\text{Na}^+$
- iii. $\text{CH}_3\text{O}-\text{C}_6\text{H}_4-\text{CO}_2^-\text{Na}^+$

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

11. The relative molecular mass of a molecule of chlorine is 72. Which properties of the atoms in this molecule are the same?

i. radius

ii. nucleon number

iii. relative isotopic mass

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

12. What will always be a characteristic of a compound containing a single carbon atom with four different groups bonded to it?

i. It will have an optical isomer.

ii. It will have a chiral centre.

iii. It will have a structural isomer.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

13. Boron is a non-metallic element which is placed above aluminium in Group III of the Periodic Table. It forms a compound with nitrogen known as boron nitride which has a graphite structure. Which of the following conclusions can be drawn from this information?

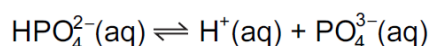
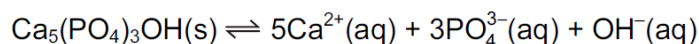
i. The empirical formula of boron nitride is BN.

ii. The boron and nitride atoms are likely to be arranged alternately in a hexagonal pattern.

iii. Boron nitride has a layer structure with van der Waals' forces between the layers.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

14. Hydroxyapatite, $\text{Ca}_5(\text{PO}_4)_3\text{OH}$, is the main constituent of tooth enamel. In the presence of saliva, the following equilibria exist.



Which of the following statements help to explain why tooth enamel is dissolved more readily when saliva is acidic?

i. The hydroxide ions are neutralised by the acid.

ii. The phosphate ion $\text{PO}_4^{3-}(\text{aq})$ accepts $\text{H}^{+}(\text{aq})$

iii. Calcium ions react with acids.

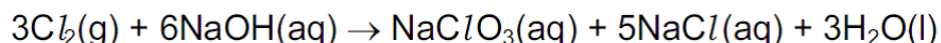
A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

15. What properties enable magnesium oxide to be used as a refractory lining in a furnace?

- i. It has a high melting point.
- ii. It has a low thermal conductivity.
- iii. It does not react with basic slags.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

16. Chlorine reacts with hot concentrated aqueous sodium hydroxide according to the equation below.



Which conclusions can be drawn from this information?

- i. The oxidation state of the chlorine in one of the products is +5.
- ii. The chlorine undergoes disproportionation.
- iii. The sodium hydroxide acts as a reducing agent.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

17. Which equations represent stages in the Contact process for manufacturing sulphuric acid?

- i. $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$
- ii. $\text{H}_2\text{O} + \text{SO}_2 \rightarrow \text{H}_2\text{SO}_3$
- iii. $\text{H}_2\text{SO}_3 + \text{O}_2 \rightarrow \text{H}_2\text{SO}_4$

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

18. For the reaction $(\text{CH}_3)_3\text{SiCl} + \text{C}_2\text{H}_5\text{O}^- \rightarrow (\text{CH}_3)_3\text{SiOC}_2\text{H}_5 + \text{Cl}^-$ which statements are likely to be true?

- i. It involves nucleophilic attack by $\text{C}_2\text{H}_5\text{O}^-$.
- ii. Cl^- is displaced by $\text{C}_2\text{H}_5\text{O}^-$.
- iii. The oxygen-carbon bond is not broken.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

19. Modern cars are fitted with catalytic converters. These remove carbon monoxide, unburnt hydrocarbons and oxides of nitrogen from exhaust gases. Which of these pollutant gases are removed by oxidation?

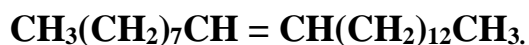
i. carbon monoxide

ii. hydrocarbons

iii. nitrogen oxides

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

20. The sex-attractant of the house-fly is muscalure, with the following formula.



Which statements about muscalure are correct?

i. It will decolourise aqueous bromine.

ii. It will be oxidised by cold aqueous alkaline KMnO_4 to give a diol.

iii. It will be optically active.

A	B	C	D
All are correct	Only i & ii are correct	Only ii & iii are correct	Only i is correct

SECTION II:

I. (a) Methanoic acid, HCO_2H , is a weak acid, with $K_a = 1.77 \times 10^{-4} \text{mol dm}^{-3}$.

(i) Write an expression for the K_a of methanoic acid.

.....[1]

(ii) Use your expression to calculate the $[\text{H}^+]$ in a $0.0500 \text{ mol dm}^{-3}$ solution of methanoic acid.

.....
.....[1]

(iii) Calculate the percentage of HCOOH molecules that are ionised in this solution. [1]

(iv) Calculate the pH of this solution.

.....
.....[1]

(b) Calculate the pH of a $0.0500 \text{ mol dm}^{-3}$ solution of the strong acid HCl .

.....[1]

(c) Both HCO_2H and HCl react with powdered magnesium metal, giving off hydrogen gas. For a fixed amount of magnesium, the rate equation for the reaction is as follows.

$$\text{rate} = k [\text{H}^+(\text{aq})]$$

(i) Write an equation for the reaction between HCO_2H and Mg .

.....[1]

When 20.0 cm^3 of a $0.0500 \text{ mol dm}^{-3}$ solution of either acid is reacted with an excess of powdered magnesium, the same volume of hydrogen is given off, but the methanoic acid solution reacts much more slowly than the hydrochloric acid.

(ii) Calculate the volume of hydrogen given off.

.....[1]

(iii) Explain why the hydrogen is evolved more slowly from the methanoic acid solution.

.....
[1]

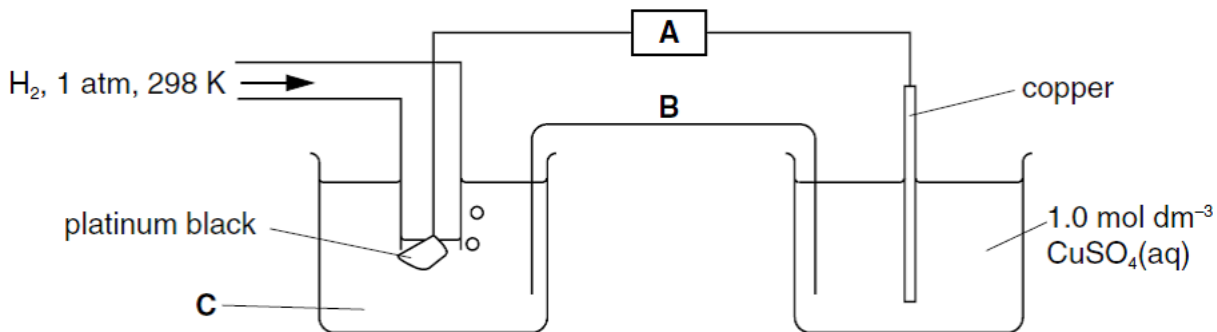
(iv) Explain why, eventually, the methanoic acid solution produces just as much hydrogen as the hydrochloric acid solution.

.....

[2]

[Total 10]

II. (a) The following diagram shows the apparatus needed to measure the standard electrode potential of copper. In the spaces below, identify or describe what the three letters A–C represent.



A.....
 B.....
 C.....[3]

(b) A student wishes to measure the standard electrode potential of the $\text{Fe}^{3+}/\text{Fe}^{2+}$ electrode. In the space below, draw and label the set-up for the right-hand beaker that would replace the one shown in the diagram above. [1]

(c) Predict how the E of the $\text{Fe}^{3+}/\text{Fe}^{2+}$ electrode would vary as

(i) the $[\text{Fe}^{3+}]$ is increased,

.....

(ii) the $[\text{Fe}^{2+}]$ is increased.

.....[1]

(d) An aqueous solution of iron(III) chloride is used to dissolve the excess of copper metal from printed-circuit boards. Use the half-equations and E^\ominus values in the *Data Booklet* to

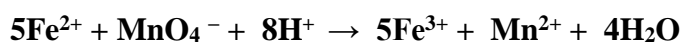
(i) Write an equation for this reaction,

.....[1]

(ii) Calculate the E^\ominus cell for the reaction.

.....[1]

(e) The solution resulting from dissolving the copper from a small printed-circuit board was acidified and titrated with $0.0200 \text{ mol dm}^{-3}$ KMnO_4 . A volume of 75.0 cm^3 was required for the end point. The equation for the titration reaction is as follows.



Calculate:

(i) The number of moles of Fe^{2+} in the solution,

[2]

(ii) The mass of copper that had dissolved from the printed-circuit board.

[2]

[Total 11]

III. (a) Apart from its electronic structure, state two properties of iron or its compounds that are characteristic of a transition element.

.....
.....[2]

(b) Acidified solutions of iron (II) salts can be titrated using a dilute solution of potassium manganate (VII)

(i) Use the *Data Booklet* to calculate the standard cell potential and to write a balanced ionic equation for the reaction that takes place during the titration.

.....
.....[2]

(ii) Explain why no indicator is required. What colour change would you see at the end point?

.....
.....
.....[2]

(c) Use the reaction between Fe^{3+} ions and water molecules to explain the meanings of the terms *ligand* and *complex formation*.

.....
.....
..... [2]

(d) An important biological molecule containing iron is haemoglobin.

(i) What is the role of haemoglobin in the body?

.....

(ii) Use your answer to (i) to explain why carbon monoxide is poisonous.

.....[2]

[Total 10]

IV. A student obtained the following results when analysing an organic compound, **H**.

test		observation
test 1	relative molecular mass	72
test 2	% composition by mass	C, 66.7%; H, 11.1%; O, 22.2%
test 3	reactions with Br ₂ (aq)	Br ₂ decolourised
test 4	reaction with Na(s)	H ₂ (g) evolved
test 5	reaction with warm Cr ₂ O ₇ ²⁻ /H ⁺	green colour observed

The student allowed test 5 to go to completion and then investigated the **product** of test 5 with the following result.

test 6	reaction with 2,4-dinitrophenylhydrazine	no reaction
--------	--	-------------

(a) Calculate the molecular formula of compound **H**.

[2]

(b) What can be deduced about the nature of **H** by the following tests?

(i) test 3

(ii) test 4 [2]

(c) (i) What functional group would have given a positive result in test 6?

.....

(ii) What functional group is shown to be present in **H** by tests 5 and 6?

..... [2]

(d) On testing a sample of **H**, the student found that it was not chiral. **H** did, however, show *cis-trans* isomerism. How does *cis-trans* isomerism arise in an organic molecule?

.....

..... [2]

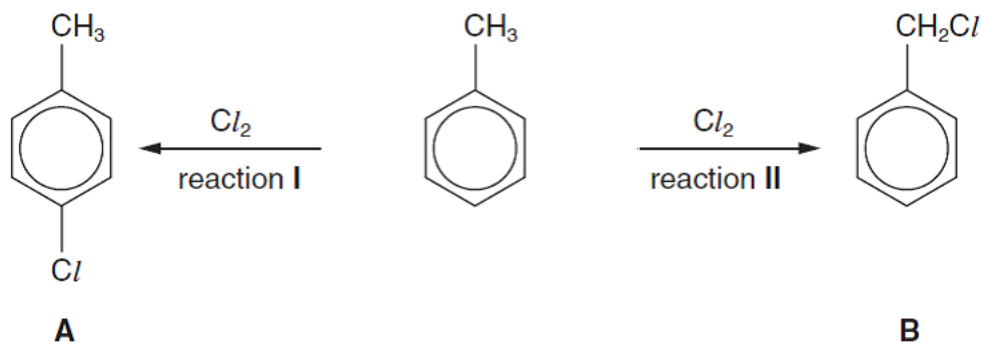
(e) Use all of the information above to draw labelled, displayed formulae of the stereoisomers of compound **H**.

[2]

[Total 10]

V. This question is concerned with organo chlorine compounds.

(a) State the conditions needed to produce the two compounds **A** and **B**.



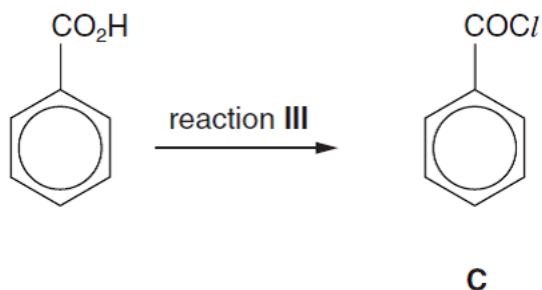
(i) conditions for reaction I

.....

(ii) conditions for reaction II

..... [2]

(b) State the reagent needed to carry out the following reaction.



reagent for reaction III: [1]

(c) The three chloro-compounds **A**, **B** and **C** vary in their ease of hydrolysis.

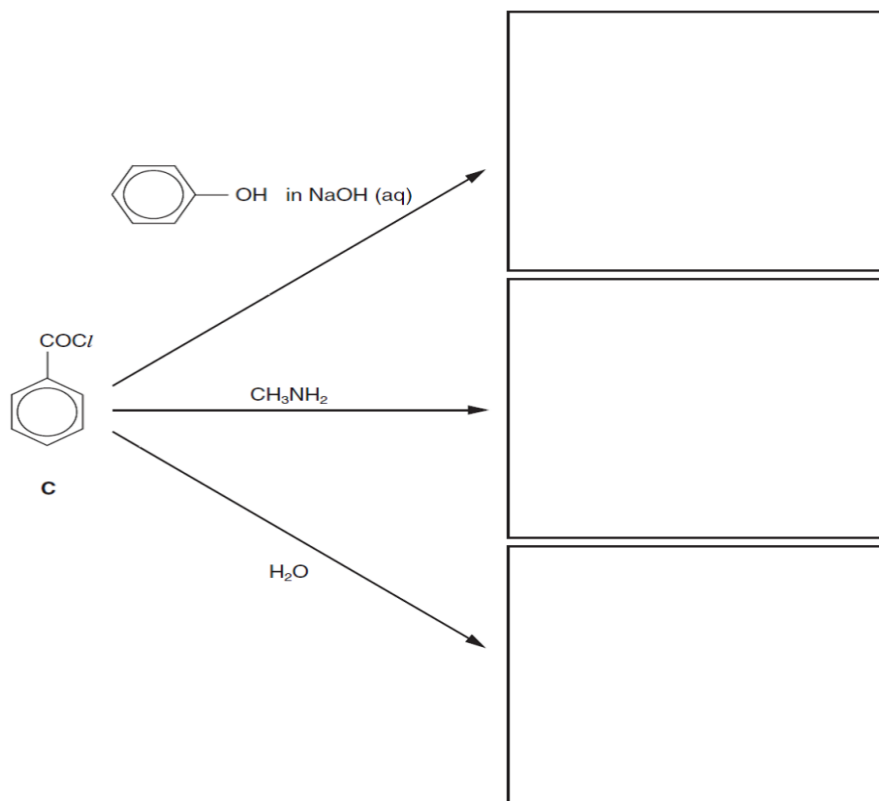
(i) Place a tick in the box corresponding to the correct relative rates of hydrolysis. [the symbol '>' means 'faster than']

	place one tick only in this column
A > B > C	
A > C > B	
B > A > C	
B > C > A	
C > B > A	
C > A > B	

(ii) Suggest an explanation for these differences in reactivity.

.....
.....
..... [3]

(d) Draw the structural formulae of the organic products of the following reactions of compound C. [3]



[Total 09]