



New Zealand Chemistry Olympiad Trust
Training Group Selection Examination

Monday 31 October 2016

TIME ALLOWED: 120 minutes

Answer **ALL** questions on this examination booklet.

Calculators may be used.

A periodic table with atomic masses is also provided.

NOTE - This paper is in two sections. Complete both sections.

Section A Multichoice: Total marks 50/100

There are 25 questions. **EACH answer is worth 2 marks**

Answer ALL questions — circle the letter of the correct answer.

Section B Long Answers: Total marks 50/100

The mark value for each question is shown.

All answers must be written in the space provided.

In questions involving numerical calculations show all reasoning and work.

STUDENT'S NAME: _____

STUDENT'S EMAIL: _____

SCHOOL: _____

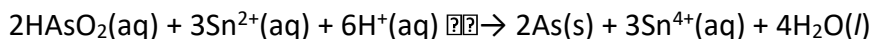
	Section A	Section B						Total
	Multichoice	Long Answers						
	/2 × 25= 50	/9	/6	/10	/9	/8	/8	/100
Mark								

SECTION A - Multichoice

For each question circle the letter of the correct answer.

Question 1

What is the oxidant (oxidising agent) in the reaction for which the equation is shown below?



- A. HAsO_2
- B. Sn^{2+}
- C. H^+
- D. Sn^{4+}
- E. H_2O

Question 2

In which compound does manganese have an oxidation number of +3?

- A. KMnO_4
- B. $\text{K}_2[\text{Mn}(\text{CN})_6]$
- C. $\text{K}_5[\text{Mn}(\text{CN})_6]$
- D. MnSO_4
- E. $\text{CsMn}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$

Question 3

0.0005 moles of metal chloride were dissolved in water. 60.0 mL of 0.025 mol L⁻¹ silver nitrate solution were required to complete precipitation of silver chloride from the solution of the metal chloride. Choose the formula of the metal chloride that is consistent with these results.

- A. MCl
- B. M_2Cl
- C. MCl_2
- D. MCl_3
- E. M_2Cl_3

Question 4

A sample has a mass of 54 mg and contains 3.01×10^{20} molecules of SF_n .
What is the value of n?

- A. 1
- B. 2
- C. 4
- D. 6
- E. 8

Question 5

What is the Na^+ ion concentration in the solution formed by mixing 20 mL of 0.10 mol L⁻¹ Na_2SO_4 solution with 50 mL of 0.30 mol L⁻¹ Na_3PO_4 solution?

- A. 0.09 mol L⁻¹
- B. 0.15 mol L⁻¹
- C. 0.24 mol L⁻¹
- D. 0.48 mol L⁻¹
- E. 0.70 mol L⁻¹

Question 6

Which species has the same shape as the NO_3^- ion?

- A. SO_3 B. SO_3^{2-} C. NH_3 D. ClF_3 E. ClO_3^-

Question 7

Consider the following reaction and the associated value for $\Delta_r H^\circ$:



Which statement about this information is **incorrect**?

- A. $\Delta_r H^\circ$ will be $-92.3 \text{ kJ mol}^{-1}$ if the HCl is produced as a liquid.
 B. The four HCl bonds are stronger than the four bonds in 2H_2 and 2Cl_2 .
 C. If the equation is reversed, $\Delta_r H^\circ$ equals $+92.3 \text{ kJ mol}^{-1}$.
 D. 23.1 kJ of heat will be evolved when 1 mol of $\text{HCl}(\text{g})$ is produced.
 E. The reactants are in their standard states.

Question 8

In which reaction will an increase in the volume of the container favour the formation of products?

- A. $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightarrow 2\text{HI}(\text{g})$
 B. $4\text{NH}_3(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\text{l})$
 C. $\text{C}(\text{s}) + \text{H}_2\text{O}(\text{g}) \rightarrow \text{CO}(\text{g}) + \text{H}_2(\text{g})$
 D. $3\text{O}_2(\text{g}) \rightarrow 2\text{O}_3(\text{g})$
 E. $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$

Question 9

Which pair of changes describes the effect of a catalyst on a chemical reaction?

	Activation energy	Enthalpy change of reaction
A	Decreased	Decreased
B	Decreased	No change
C	Decreased	Increased
D	No change	Decreased
E	Increased	No change

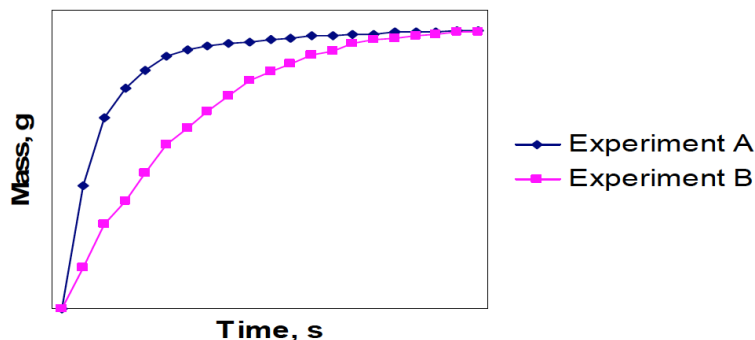
Question 10

The average bond enthalpy (bond energy) of a C—F bond is 485 kJ mol^{-1} .
 For which of the following processes is $\Delta_r H$ approximately $+1940 \text{ kJ mol}^{-1}$?

- A. $\text{CF}_4(\text{l}) \rightarrow \text{C}(\text{s}) + 2\text{F}_2(\text{g})$
 B. $\text{CF}_4(\text{g}) \rightarrow \text{C}(\text{s}) + 2\text{F}_2(\text{g})$
 C. $\text{CF}_4(\text{g}) \rightarrow \text{C}(\text{g}) + 2\text{F}_2(\text{g})$
 D. $\text{CF}_4(\text{g}) \rightarrow \text{C}(\text{s}) + 4\text{F}(\text{g})$
 E. $\text{CF}_4(\text{g}) \rightarrow \text{C}(\text{g}) + 4\text{F}(\text{g})$

Question 11

The graph below shows student data from two trials in which he studied the rate of a particular reaction, changing just one of the reaction conditions in the second trial.



Which one of the following statements **MUST** be **INCORRECT**?

- A. Exactly the same amounts of reactants were used in the two experiments
- B. The reaction temperature was higher in Experiment A than in Experiment B
- C. The mass of one of the products was being measured in the two experiments
- D. The final rate of reaction was greater in experiment A than in Experiment B
- E. The initial rate of reaction was greater in Experiment A than in Experiment B

Question 12

A lemon-flavoured drink contains citric acid as the only acidic component. 10.00 mL of the drink is diluted with 15.00 mL of distilled water and titrated with NaOH solution using phenolphthalein as indicator. Under these conditions citric acid behaves as a diprotic (or dibasic) acid, H_2A .

25.00 mL of 0.100 mol L^{-1} sodium hydroxide solution is used to reach the endpoint of the titration. Which is the concentration of the citric acid in the drink?

- A. 0.100 mol L^{-1}
- B. 0.125 mol L^{-1}
- C. 0.200 mol L^{-1}
- D. 0.250 mol L^{-1}
- E. 0.500 mol L^{-1}

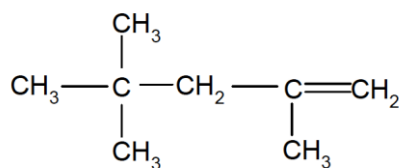
Question 13

Lattices of ionic compounds are more stable if the ions are small and highly-charged and combined in a simple 1:1 ratio. On the basis of this information, choose the pair of ions that are likely to form crystals with the highest melting (or decomposition) temperature.

- A. Li, O
- B. Ag, O
- C. Li, F
- D. Mg, F
- E. Mg, O

Question 14.

The following compound is used as an additive in gasoline to improve its octane value.



Which of the following is a correct IUPAC name for this compound?

- A. 2,2,4-trimethylpent-1-ene
- B. 2,2,4-trimethylpent-2-ene
- C. 2,2,4-trimethylpent-5-ene
- D. 2,4,4-trimethylpent-1-ene
- E. 2,4,4-trimethylpent-2-ene

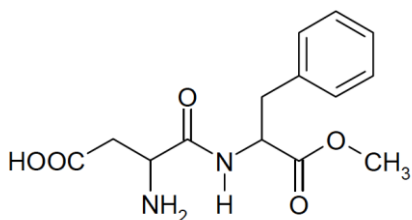
Question 15

Which molecular formula could NOT represent a compound containing a hydroxyl (-OH) group?

- A. H₂O
- B. CH₄O
- C. CH₂O
- D. H₂SO₄
- E. C₆H₆O

Question 16

Aspartame has the structure given below. This compound is used as a sweetener in diet drink.



Choose the number of carbon atoms in one molecule of aspartame.

- A. 12
- B. 13
- C. 14
- D. 15
- E. 16

Question 17

A substance melts at 681°C and conducts electricity when molten but not when solid. Choose the most likely type of attractive forces between the particles of this substance.

- A. Ionic bonding
- B. Metallic bonding
- C. Dipole-dipole interactions
- D. Covalent bonding
- E. Intermolecular forces

Question 18

The pH of an aqueous solution is 6.0 at 50 °C. Which is the hydroxide ion concentration in mol L⁻¹? ($K_w = 5.5 \times 10^{-14}$ at this temperature)

- A. 1.0×10^{-6}
- B. 2.3×10^{-7}
- C. 1.0×10^{-8}
- D. 5.5×10^{-8}
- E. 7.8×10^{-8}

Question 19

An equal volume of 0.5 mol L⁻¹ NaOH is added to each of the following solutions. In which case(s) does the pH of the solution decrease?

1. H₂O 2. 0.25 mol L⁻¹ Na₂CO₃ 3. 0.5 mol L⁻¹ HCl 4. 0.6 mol L⁻¹ KOH

- A. 1, 2 and 3 only
- B. 1 and 2 only
- C. 1 and 3 only
- D. 2 and 4 only
- E. 4 only

Question 20

Choose the conjugate acid of glycine (aminoethanoic acid).

- A. H₃O⁺
- B. H₂NCH₂COOH
- C. H₃N⁺-CH₂COOH
- D. H₂NCH₂CO₂⁻
- E. H₃N⁺-CH₂CO₂⁻

Question 21

The diagram shows the cross section of a burette that is partially filled with a solution. Which is the burette reading?

- A. 1.20 mL
- B. 1.26 mL
- C. 2.70 mL
- D. 2.74 mL
- E. 2.80 mL

Question 22

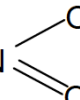
Which steps in the formation of NaF(s) are exothermic?

- I. $\text{Na(g)} \rightarrow \text{Na}^+(\text{g}) + \text{e}^-$
- II. $\text{F(g)} + \text{e}^- \rightarrow \text{F}^-(\text{g})$
- III. $\text{Na}^+(\text{g}) + \text{F}^-(\text{g}) \rightarrow \text{NaF(s)}$

- A. I only
- B. II only
- C. III only
- D. I and III only
- E. II and III only

Question 23

Which one of the following substances has one unpaired electron in its Lewis structure?

- A. NH_3 B. $\text{N} \equiv \text{N}$ C. $\text{N} = \text{O}$ D. $\text{H}-\text{C} \equiv \text{N}$ E. $\text{H}-\text{O}-\text{N}$ 

Questions 24

Which one of the following reactions is NOT a redox reaction?

- A. $\text{Br}_2 + \text{H}_2\text{O} \rightarrow \text{HBr} + \text{HBrO}$
- B. $\text{I}_2 + 2\text{Na}_2\text{S}_2\text{O}_3 \rightarrow 2\text{NaI} + \text{Na}_2\text{S}_4\text{O}_6$
- C. $\text{Na}_3\text{AsO}_3 + \text{H}_2\text{O}_2 \rightarrow \text{H}_2\text{O} + \text{Na}_3\text{AsO}_4$
- D. $\text{I}_2 + 6\text{NaOH} \rightarrow \text{NaIO}_3 + 5\text{NaI} + 3\text{H}_2\text{O}$
- E. $2\text{K}_2\text{CrO}_4 + \text{H}_2\text{SO}_4 \rightarrow \text{K}_2\text{Cr}_2\text{O}_7 + \text{K}_2\text{SO}_4 + \text{H}_2\text{O}$

Question 25

A colourless aqueous solution contains a single ionic compound. Use the following experimental information to deduce the identity of the compound.

When a small amount of dilute NaOH solution is added to the solution, a precipitate forms. This precipitate dissolves when excess NaOH is added.

Addition of AgNO_3 (silver nitrate) to another sample of the original solution gives a white precipitate.

- A. AlCl_3
- B. $\text{Ba}(\text{NO}_3)_2$
- C. CuSO_4
- D. FeI_2
- E. PbSO_4

SECTION B – Long Answers**QUESTION ONE (9 marks)**

A compound contains only C, H, and N.

Combustion of 0.125 g of the compound produces 0.172 g of H₂O and 0.279 g of CO₂.

- a) Calculate the mass of H and C in 0.125 g of the compound.
- b) Show that the empirical formula of this compound is C₃H₉N.
- c) Assume the empirical formula of the compound is also the molecular formula. Draw structures for the four different isomers that are possible for a compound with this formula.
- d) The boiling point of molecular substances depends on the strength of attractive forces between the molecules. These depend on the polarity and also on the size and the shape of the molecule. When considering isomeric compounds, one type of intermolecular attractive force is stronger for linear molecules than for branched ones because in linear molecules, the surface area over which the interaction can occur is larger.

Electronegativity: C = 2.6; N = 3.0; O = 3.4; H = 2.2

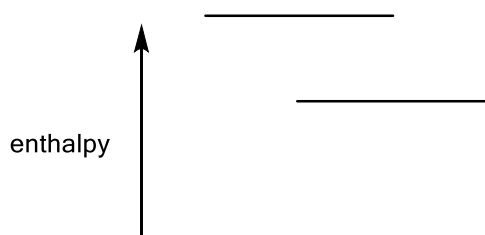
The four isomers in part c) have boiling points that range from 3 °C to 48 °C. Identify the isomers that have the **lowest** and **highest** boiling points. Explain your answers in terms of the intermolecular forces.

QUESTION TWO (6 marks)

- a) The standard enthalpy change for the reaction in which one mole of CO_2 is formed from its elements is -394 kJ mol^{-1} . The standard enthalpy change for the combustion of one mole of CO is -283 kJ mol^{-1} .

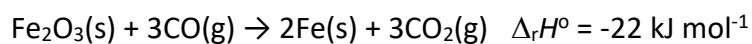
For each of the reactions above, complete the diagram below by writing the reactants of the balanced equation for the reaction on one line and the product on a different line.

Show all states.



- b) Use the information above to calculate the enthalpy change for formation of one mole of CO from its elements. Show how you arrived at your answer.

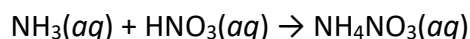
- c) Iron is prepared from Fe_2O_3 by reaction with CO as shown in the equation given below.



Calculate ΔH for the reaction that produces 100 g iron.

QUESTION THREE (10 marks)**Part A (5 marks)**

This question is concerned with solutions of the reactants and the product of the reaction given below:



- a) As shown below, H_3O^+ and OH^- are present in all of these solutions. Complete the table by firstly giving, for each solution, formulae for any other species (molecules or ions excluding H_2O) that are present. These species may arise either by dissolving or by reaction with water. Then identify species which fit descriptions given in the first column at the left of the table below

	NH₃	HNO₃	NH₄NO₃
All species in each solution (not H ₂ O)	H_3O^+ and OH^-	H_3O^+ and OH^-	H_3O^+ and OH^-
Species present in equal concentration			
Species in lowest concentration			

- b) Circle the solute in the solution with the lowest conductivity.

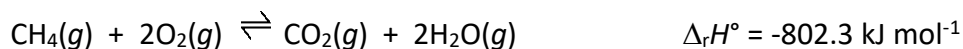
**Part B (5 marks)**

Write net equations for the reaction of each of the combinations of reactants below. Use appropriate ionic and molecular formulae, omitting any ions or molecules that do not take part in the reaction. You need not balance the equations. All reactions occur in aqueous solution unless otherwise indicated.

- (i) Solutions of magnesium sulfate and barium hydroxide are mixed.
- (ii) Water is added to magnesium nitride (an acid base reaction).
- (iii) Excess concentrated sodium hydroxide is added to a solution of zinc nitrate.
- (iv) Excess concentrated ammonia is added to aqueous copper(II) nitrate.
- (v) Excess carbon dioxide is bubbled through a solution of calcium hydroxide.

QUESTION FOUR (9 marks)**Part A (5 marks)**

Consider two flasks in which the reaction system below is at equilibrium. CO_2 is added to one flask. The temperature of the other flask is increased. In both cases the mixture is allowed to stand until equilibrium is restored.

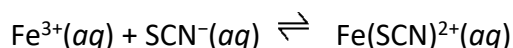


Compare the final equilibrium concentration with that prior to the change being applied. Describe the direction of change (if any) in the concentrations of species and in K_c (the equilibrium constant) by writing **increase, decrease or no change** in the boxes below.

Change	$[\text{CH}_4(g)]$	$[\text{O}_2(g)]$	$[\text{CO}_2(g)]$	$[\text{H}_2\text{O}(g)]$	K_c
Add CO_2					
Increase in temperature					

Part B (4 marks)

Ammonium thiocyanate is a reagent used to test for iron(III) ions in solution. The equation for the reaction forming the complex ion $\text{Fe}(\text{SCN})^{2+}$ is given below.



In an experiment to find the equilibrium constant (K_c) for the reaction at this temperature, 45.00 mL of a solution containing $0.200 \text{ mol L}^{-1} \text{Fe}^{3+}$ is mixed with 5.00 mL of a solution containing $0.00200 \text{ mol L}^{-1} \text{SCN}^{-}$. Colorimetric analysis shows that the equilibrium concentration of $\text{Fe}(\text{SCN})^{2+}$ is $1.99 \times 10^{-4} \text{ mol L}^{-1}$.

- a) Complete the table below to show, for each of the species involved in the reaction, the initial concentration (after mixing, before reaction occurs), the change in concentration (due to reaction to reach equilibrium) and equilibrium concentration.

Reaction	$\text{Fe}^{3+}(aq) + \text{SCN}^{-}(aq) \rightleftharpoons \text{Fe}(\text{SCN})^{2+}(aq)$		
	Fe^{3+}	SCN^{-}	$\text{Fe}(\text{SCN})^{2+}$
Initial conc/mol L^{-1}			0.00
Change in conc/mol L^{-1}			
Equilibrium conc / mol L^{-1}			1.99×10^{-4}

- b) Calculate K_c at the temperature at which the experiment is carried out.

QUESTION FIVE (8 marks)

Compound **A** ($C_5H_{12}O$) reacts with $SOCl_2$ to form compound **B** ($C_5H_{11}Cl$) which, on heating with alcoholic KOH , forms two alkenes (C_5H_{10}), compounds **C** and **D**. Neither of compounds **D** and **E** can exist as *cis-trans* isomers. Addition of HCl to compound **C** forms compound **E**, an isomer of **B**, as the major product, while addition of HCl to compound **D** gives **B**.

a) Deduce the structures and names of compounds **A** to **E**.

Space for working

Structure Cpd A

Structure Cpd B

Name of A _____

Name of B _____

Structure Cpd C

Structure Cpd D

Name of C _____

Name of D _____

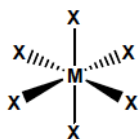
Structure Cpd E

Name of E _____

b) Draw a section of the polymer formed by addition polymerisation of compound **C**.

QUESTION SIX (8 marks)**Part A (3 marks)**

The octahedral compound MX_6 has X in six equivalent positions.



- a) Sketch the two possible isomers for the octahedral compound MA_2X_4 in which two groups are different from the other four.
- b) Sketch the two possible isomers for the octahedral compound MA_3X_3 in which three groups are different from the other three.

Part B (5 marks)

A salt of vanadium(V) contains vanadium in the +5 oxidation state.

A **one litre** solution contains **2.55 g** of vanadium as a vanadium(V) salt.

25.0 mL of the solution was treated with acidified aqueous SO_2 to reduce the vanadium (V).

The vanadium ion formed was reoxidised to vanadium(V) by acidified KMnO_4 solution.

12.5 mL of 0.0200 mol L⁻¹ KMnO_4 solution was required for complete reaction.

Deduce the oxidation state to which vanadium was reduced by SO_2 .

PERIODIC TABLE OF THE ELEMENTS

											18						
											1 H 1.0						2 He 4.0
Atomic Number											Molar Mass / g mol ⁻¹						
1	2											13	14	15	16	17	18
3 Li 6.9	4 Be 9.0											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
11 Na 23.0	12 Mg 24.3	3	4	5	6	7	8	9	10	11	12	13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 40.0
19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.9	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.	32 Ge 72.6	33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8
37 Rb 85.5	38 Sr 87.6	39 Y 88.9	40 Zr 91.2	41 Nb 92.9	42 Mo 95.9	43 Tc 98.9	44 Ru 101	45 Rh 103	46 Pd 106	47 Ag 108	48 Cd 112	49 In 115	50 Sn 119	51 Sb 122	52 Te 128	53 I 127	54 Xe 131
55 Cs 133	56 Ba 137	57–71 Lanthanide Series	72 Hf 179	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	81 Tl 204	82 Pb 207	83 Bi 209	84 Po 210	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226	89–103 Actinide Series	104 Rf 261	105 Db 262	106 Sg 263	107 Bh 262	108 Hs 265	109 Mt 266									

Lanthanide Series

57 La 139	58 Ce 140	59 Pr 141	60 Nd 144	61 Pm 145	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 163	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175
89 Ac 227	90 Th 232	91 Pa 231	92 U 238	93 Np 237	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 255	103 Lr 262

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