2021/2022 學年澳門高中學生化學競賽
High school chemistry competition – Macau 2021/2022

Question	1	2	3	4	5	6	7	8	9		Point total
points	30	10	11	11	7	7	6	9	9		100
scores											
Grader											

Question 1	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8
Answer(s)								
Question 1	1-9	1-10	1-11	1-12	1-13	1-14	1-15	
Answer(s)								

Relative molecular mass, g/mol

H 1.008																	He 4.003
Li 6.941	Be 9.012											B 10.81	C 12.01	N 14.01	O 16.00	F 19.00	Ne 20.18
Na 22.99	Mg 24.31											Al 26.98	Si 28.09	P 30.97	S 32.07	Cl 35.45	Ar 39.95
K 39.10	Ca 40.08	Sc 44.96	Ti 47.88	V 50.94	Cr 52.00	Mn 54.94	Fe 55.85	Co 58.93	Ni 58.69	Cu 63.55	Zn 65.39	Ga 69.72	Ge 72.61	As 74.92	Se 78.96	Br 79.90	Kr 83.80
Rb 85.47	Sr 87.62	Y 88.91	Zr 91.22	Nb 92.91	Mo 95.94	Tc 98.91	Ru 101.1	Rh 102.9	Pd 106.4	Ag 107.9	Cd 112.4	In 114.8	Sn 118.7	Sb 121.8	Te 127.6	I 126.9	Xe 131.3
Cs 132.9	Ba 137.3	La-Lu	Hf 178.5	Ta 180.9	W 183.9	Re 186.2	Os 190.2	Ir 192.2	Pt 195.1	Au 197.0	Hg 200.6	Tl 204.4	Pb 207.2	Bi 209.0	Po [210]	At [210]	Rn [222]
Fr [223]	Ra [226]	Ac-Lr	Rf	Db	Sg	Bh	Hs	Mt									

Student full name: _____

Seat number: _____

Student ID number: _____

High school: _____

Contact phone number: _____

This paper consists of ten 10 pages.

Question 1 (30 points)

Multiple choice questions: each question has 1 to 2 good answers; write your answers in the table on the first page.

1-1. Indicate which of the following sets of quantum numbers (n, l, m_l, m_s) in an atom is/are acceptable

A · (3, 1, +2, +1/2) B · (3, 2, -1, -1/2)
C · (2, -1, +1, -1/2) D · (4, 3, +2, +1/2)

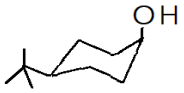
1-2. In the following chemical reactions, atom A $\xrightarrow{+ne^-}$ A^{n-} with $\triangle H_1 < 0$, and atom B $\xrightarrow{+ne^-}$ B^{n-} with $\triangle H_2 < 0$, and that $\triangle H_1 < \triangle H_2$. The correct statement(s) is/are

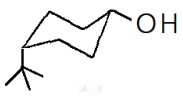
A · Oxidizing power: A < B B · Reducing power: $A^{n-} < B^{n-}$
C · Stability of atom: A < B D · Stability of ions: $A^{n-} < B^{n-}$

1-3. According to the VSEPR model, which of the following molecules/ions assume the shape of trigonal planar?

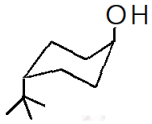
A · ClF_3 B · SO_3
C · SO_3^{2-} D · CH_3^+

1-4. The correct conformation of 4-*tert*-butylcyclohexanol is/are

A · 

B · 

C · 

D · 

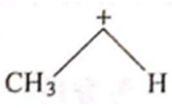
1-5. Which of the following action(s) is(are) considered an means to mitigate environmental pollution?

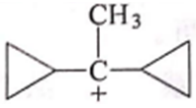
A · Oil refining from disposed polymer materials.
B · Adding calcium oxide to coal for combustion.
C · Removal of oily materials with porous absorbents.
D · Disposal of nuclear wastes by burying them deep within underground rock formation.

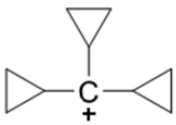
1-6. Dissolve 0.544g sodium tungstate ($Na_2WO_4 \cdot 2\ H_2O$) with water, followed by addition of a certain amount of zinc and diluted H_2SO_4. A blue compound was formed without the evolution of H_2 gas. The blue compound was titrated exactly with acidified 8.26mL of 0.024mol/L $KMnO_4$, forming a yellow oxide. What is the identity of the blue compound?

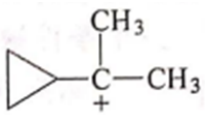
A · $W_{10}O_{21}$ B · W_8O_{22}
C · $W_{10}O_{27}$ D · W_5O_{14}

1-7. Which of the following carbonium ion is the most stable?

A · 

B · 

C · 

D · 

1-8. Al and Ga in Group IIIA are both amphoteric elements. The acidity of $Ga(OH)_3$ is stronger than that of $Al(OH)_3$. When CO_2 is passed through a solution containing $NaAlO_2$ and $NaGaO_2$, which oxide will first precipitate from the solution mixture?

A · $Al(OH)_3$ B · $Ga(OH)_3$ C · Both oxides at the same time. D · $M(OH)_3$ are both insoluble amphoteric oxides.

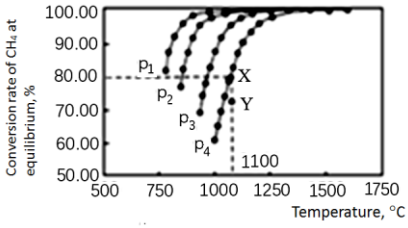
1-9. In a nickel-copper battery, radioactive 63($^{63}_{28}$Ni) isotope and copper are used as the electrodes. The electron emitted by β-decay of ^{63}Ni is accepted by copper plate through an external circuit to supply electric power. The correct statement(s) is/are

A · The decay of ^{63}Ni is $^{63}_{28}Ni \rightarrow {}^{0}_{-1}e + {}^{63}_{27}Cu$ B · The decay of ^{63}Ni is $^{63}_{28}Ni \rightarrow {}^{0}_{-1}e + {}^{64}_{29}Cu$

C · Current flows from Ni to Cu.

D · When the circuit is close, the electromotive force of ^{63}Ni is greater than that of Cu.

1-10. Under a certain condition, the following reaction occurs in a confined vessel: $CO_2(g) + CH_4(g) \rightleftharpoons 2CO(g) + 2H_2(g)$. The conversion rate of CH_4 at equilibrium was determined to have a variation as shown in the following graph. The correct statement(s) is/are



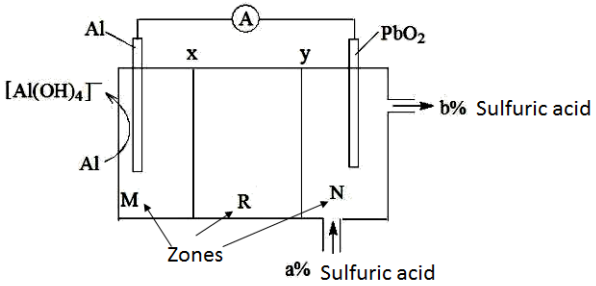
A · Pressure: $P_4 > P_3 > P_2 > P_1$ B · At P_4, point Y: $v_{forward} < v_{reverse}$

C · A suitable catalyst may increase CH_4 conversion. D · The heat of reaction is $\Delta H > 0$.

1-11. In a solution containing Fe^{3+}, Cr^{3+}, Zn^{2+}, Mg^{2+}, and other ions, all at 0.010 mol/L. Given that $K_{sp}Fe(OH)_3 = 2.6\times10^{-39}$, $K_{sp}Cr(OH)_3 = 7.0\times10^{-31}$, $K_{sp}Zn(OH)_2 = 1.0\times10^{-17}$,& $K_{sp}Mg(OH)_2 = 1.8\times10^{-11}$, when hydroxide starts to precipitate, which of the following ions require the least pH?

A · Fe^{3+} B · Cr^{3+} C · Zn^{2+} D · Mg^{2+}

1-12. In the Al-PbO_2 battery, the electrolytes are K_2SO_4, H_2SO_4 (where a% > b%), and KOH. The electrolytes are separated by membranes through the ionic exchange at x and y, such that three zones **M**, **R**, and **N** are formed in the electrolytic solution in the following diagram. The correct statement(s) is/are



A · K^+ ions pass through x into zone **M**.

B · Electroylitic concentrataion decrease in zone **R**.

C · When discharged, reaction at Al electrode is: $Al - 3e^- + 4OH^- = [Al(OH)_4]^-$

D · After 0.9 g Al is consumed, 8.0 g is reduced in zone **N**.

1-13. To the same composition and quality of two sets of mixture Na_2O_2 and Na_2CO_3, diluted sulfuric acid was added to the first set, releasing gas amounting to 4.48 L. This gas was passed into the second set. After sufficient time for reaction, the gas volume decreased to 4.032 L. Both volumes were measured under standard conditions. What is the ratio of Na_2O_2 and Na_2CO_3 in the original mixture?

A · 9:2 B · 3:2 C · 2:1 D · 8:1

1-14. Which of the following statements concerning the functions of artificial rain induced by silver iodide is/are correct?

A · As silver iodide decomposes, temperature in cloud drops so that water condenses.

B · The distance between silver and iodide ions is comparable to that between two adjacent oxygen atoms, therefore has a “pseudo ice crystal” effect.

C · Silver iodide is strongly hydroscopic, leading to condensation of water vapor.

D · Silver iodide is hydrolyzed in cloud, leading to heavy droplets for precepitation.

1-15. At room temperature, $K_a(CH_3COOH) = K_b(NH_3 \cdot H_2O) = 1.75 \times 10^{-5}$, the correct statement(s) is/are

A · When ammonium acetate is added to sodium acetate, pH of the solution decreases.

B · The amount of ammonium acetate can be determined from direct acid-base titration.

C · When equimolar of hydrochloric acid (pH=3) and ammonia (pH=11) are mixed, the resultant solution has $c(NH_3 \cdot H_2O) > c(Cl^-) > c(NH_4^+)$.

D · Phenolphthalein can be used as the indicator for the titration between 0.1 $mol \cdot L^{-1}$ hydrochloric acid and 0.1 $mol \cdot L^{-1}$ ammonia.

Question 2 (10 points)

Write the corresponding ionic equation according to the information provided.

2-1. Dissolve arsenic into nitric acid.

2-2. Add I_2 in $KClO_3(aq)$, the products include $KH(IO_3)_2$ and another pure substance.

2-3. When small quantity of NaClO reacts with $FeSO_4(aq)$, $Na_2Fe_6(SO_4)_4(OH)_{12}(s)$ is precipitated out.

2-4. Under basic condition, $Fe(CN)_6^{3-}$ can oxidize Cr_2O_3.

2-5. Under alkaline condition, $(C_6H_6)_2Cr^+$ and $S_2O_4^{2-}$ react to form 1:1 oxidized and reduced products.

Question 3 (11 points)

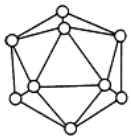
Using elements in the boron groups, it is possible to generate many variety of compounds involving single, double, multiple center(s), or ions.

3-1. Please write the valence shell electron configuration of boron group.

3-2. BF_3 is considered a compound with electron deficiency. Please state the reaction type for the reaction between BF_3 and F^- ion.

3-3. $Al(Me)_3$ exists as a dimer in room temperature. Draw its structure.

3-4. Unit cell of the crystalline boron is composed of B atoms in an icosahedron, where B_{12} exists in the crystal face (figure) of the icosahedron. What is (a) the number of valence electrons in B_{12}, and (b) the type of hybridization of B atom?



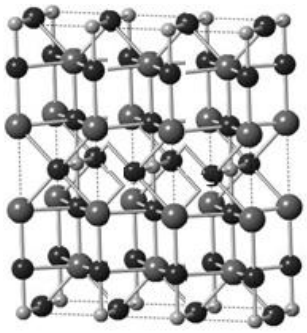
3-5. There are four BO_3 trigonal planar and one BO_4 tetrahedron in $[B_5O_6(OH)_4]^-$. Please draw the structure of the ion.

3-6. The major component in borax is $Na_2B_4O_7$, whose solution can be used as a common buffer solution. Please explain the reasons for its buffering ability.

Question 4 (11 points)

The following figure shows the structural formula of a crystalline material consisting of Ba, Pb, and O. The size of these atoms follow the descending order: Ba, O to Pb. The parameters of the unit cell is as follows: $\alpha = \beta = \gamma = 90°$, a = b = 383.6 pm, and c = 1333.5 pm. Please answer the following questions:

4-1. Write down the chemical formula of the crystal and draw the unit cell using Ba as the top point.



4-2. State the lattice form to which the crystal belong.

4-3. Please state the coordinates for Ba, Pd, and O in the crystal and state the number of chemical type(s) for oxygen in the crystal.

4-4. Calculate the density of the crystal Ba_2PdO_3.

Question 5 (7 points)

Mononuclear complex **M** differs to the *R*-*S*- characteristics as those in platinum compounds. In **M**, the number of atoms for C, H, N, and O is 4:7:1:2. **M** is synthesized from the reaction between potassium tetrachloroplatinate, (1S, 2S)-1,2-diaminocyclohexane, and ammonium oxalate.

5-1. Draw the structural formula for (1S, 2S)-1,2-diaminocyclohexane.

5-2. Write the electronic configuration of the Pt(II) ions, and determine whether its complex **M** is paramagnetic.

5-3. Write the molecular and structural formula for complex **M**.

Question 6 (7 points)

In polluted air, the mechanism for reactions involving ozone is as follows:

$NO_2(g) \xrightarrow{K_1} NO(g) + O(g)$ (first order) $K_1 = 6.0\times10^{-3}\ s^{-1}$

$O(g) + O_2(g) \xrightarrow{K_2} O_2(g)$ (second order) $K_2 = 1.0\times10^{6}\ dm^3\cdot mol^{-1}\cdot s^{-1}$

Given that the concentration of NO_2 and O_2 in polluted air is 3.0×10^{-9} mol/dm^3 and 1.0×10^{-2} mol/dm^3, respectively. Assume the concentration of atomic O tends to a steady state condition, that is, at a long-term low level. Under this condition, reaction rate of oxygen in the second reaction is equal to that of the production rate in the first reaction.

6-1. Calculate the steady state concentration of O(g) in polluted air.

6-2. Calculate the production rate of O_3 in polluted air.

6-3. If the rate of production of ozone remains constant, calculate the time required for the ozone to reach an amount equal to $\frac{1}{10,000}$ of the concentration of ozone in air under 25°C and 1 atm. (Under the conditions described above, assume the concentration of O_3 is about 0.04 mol/dm^3 in air.)

Question 7 (6 points)

Dissolve 1:1 I_2S_2 and $BeCl_2$ in cyclohexane (solvent), a white solid **A** is formed. Analysis of **A** involves the following steps:

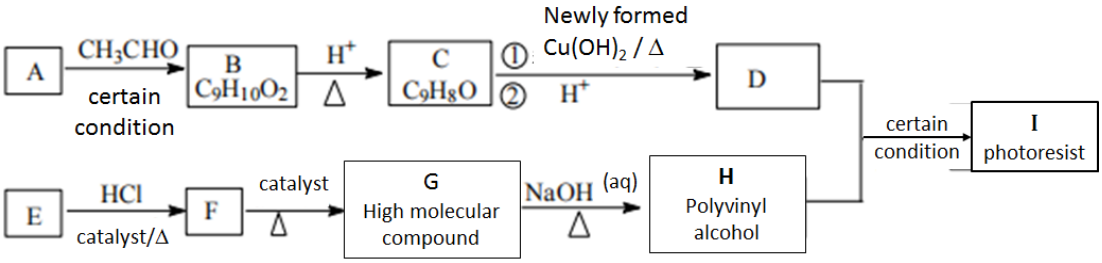
(1) Dissolve 39.21 g pure CaC_2O_4 into diluted acid, titrate the solution with 76.28 mL $KMnO_4$ of unknown concentration to the end point.
(2) When **A** is dissolved with water, I_2S_2 is immediately dissociated. Isolate I_2S_2 to a 250-mL conical flask.
(3) Add 30.00 mL of the standardized (step 1) $KMnO_4$ solution to the solution in step (2); three equimolar anions are now present in the solution mixture.
(4) Titrate the solution in step (3) with 25.21 cm^3 of 2.325 mol·L^{-1} H_2O_2 to the end point.

7-1. Calculate the standardized concentration of $KMnO_4$.

7-2. Calculate the amount of **A**.

Question 8 (9 points)

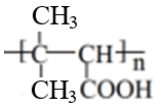
Ester **I** belongs to a class of photoresist. It is one of key materials for micro-pattern processing in microelectronics technology. It can also be used in printing industry. The synthetic route is given as follows: (in this question, some reagents and products are intentionally omitted.)



Consider that there is an eight-electron-π bond in **A**.

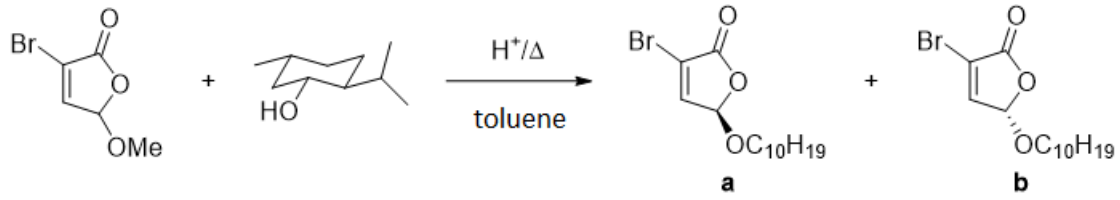
8-1. Please write the structure formula of **B** and its IUPAC name.

8-2. Please write reaction equation for **D** + **H** → **I**.

8-3. Based on the above information, using isopropanol and ethanal as the starting materials, suggest a synthetic route for  . (You may choose any inorganic reagents.)

Question 9 (9 points)

9-1. Based on the following reaction,



9-1-1. The correct statement is:

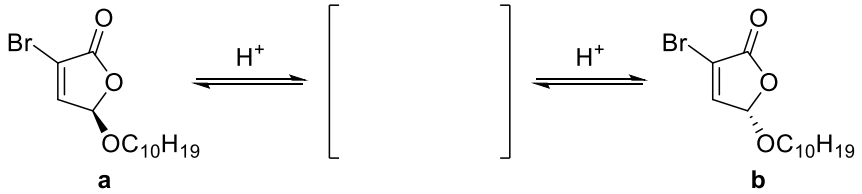
A · Products **a** and **b** are a pair of enantiomers.

B · The oxygen atoms in the products originate from the first reactant.

C · The amounts of product **a** and **b** differ.

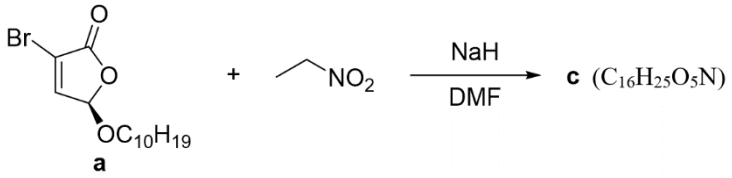
D · This reaction is considered a substitution reaction.

9-1-2. Under acidic condition, **a** and **b** can interconvert:



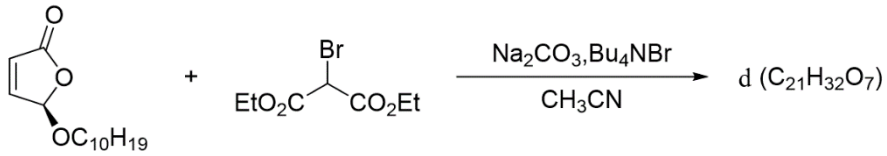
Draw the structural formula of the intermediate.

9-2. Draw the structural formula of the product **c** in the following reaction.



It is known that the electronegativity is stronger at the nitrogen end relative to the oxygen end in nitromethane. The carbon end undergoes a Michael reaction. There is a strong steric effect from the top side of the molecule, so that the reaction preferentially occurs through the bottom side.

9-3. In the following reaction, the major product is **d**. Please draw the structural formula of **d**.



[End]