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CANADIAN CHEMISTRY OLYMPIAD | OLYMPIADE DE CHIMIE DU CANADA

THE CANADIAN CHEMISTRY CONTEST 2023
MULTIPLE CHOICE QUESTIONS (60 minutes)

The only reference material allowed is the CIC/CCO Periodic Table provided. You must complete answers on the Scantron Sheet provided.
Students may use a scientific calculator. No phones or communication devices are allowed.

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1) Manganese dioxide, a black solid, catalyzes the decomposition of hydrogen peroxide according to the following chemical equation:

$$2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$$

What chemical designation best characterizes the chemical properties of manganese dioxide?

A) Oxidizer  B) Flammable  C) Reactivity Hazard 

D) Toxic  E) Corrosive 

2) The Haber Process is the reaction used for the commercial production of ammonia

$$N_{2\,(g)} + 3\,H_{2\,(g)} \rightarrow 2\,NH_{3\,(g)}$$

If 48.0 L of hydrogen gas are combined with 21.0 L of nitrogen gas at 300 atm and 500°C, what volume of NH_3 gas will be produced?

A) 42.0 L B) 32.0 L C) 96.0 L D) 14.0 L E) 63.0 L

3) What volume of O_2 at 22.0°C and 100.0 kPa will be produced if 0.378 g of potassium chlorate is allowed to decompose completely on heating according to the following ***unbalanced*** chemical equation?

$$KClO_3(s) \rightarrow KCl(s) + O_2(g)$$

A) 0.114 L B) 0.0504 L C) 0.0757 L D) 0.123 L E) 0.0730 L

4) Between which pair of molecules can hydrogen bonding occur?

A) H_2O and HCl B) C_2H_5OH and CH_2O C) HF and HCN
D) NH_3 and CH_3CONCl_2 E) CH_3NH_2 and CH_3OH

5) According to VSEPR Theory, which of the following pairs of chemical species will have the same molecular shape?

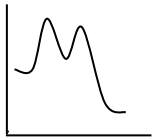
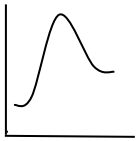
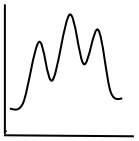
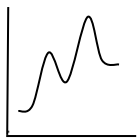
A) $BrCl_4^-$ and ClO_4^- B) $TeCl_4$ and CH_4 C) $BrCl_4^-$ and CH_4
D) NH_4^+ and ClO_4^- E) $TeCl_4$ and NH_4^+

6) A 100 g piece of copper at 150°C is submerged in 100 mL of water at 20°C. Which statement(s) is/are true as the water and copper system reaches a final temperature of 31°C?

I) The process is endothermic for copper because the final temperature is lower than its initial temperature.
II) Copper experiences the greatest temperature change because it has the greatest change in heat energy (Q).
III) Water experiences a smaller temperature change because it has a higher specific heat capacity (c).

A) I only B) II only C) III only D) I and III only E) I, II, and III

7) Which of the following reaction coordinate diagrams of potential energy vs. time represents an endothermic reaction with one reaction intermediate?

A) 
B) 
C) 
D) 
E) 

8) When 11.06 g of an unknown metal, M, reacts completely with excess chlorine gas 0.174 mol of the metal chloride is produced. What is the identity of the metal?

A) Cu B) Na C) Ag D) K E) Au

9) Changes in effective nuclear charge and electron shielding are two main factors used to explain observed trends in the periodic table. Which of the following trends is affected the most by electron shielding?

A) Electronegativity increases - Mg, Al, S, Cl
B) Radius decreases - F^-, Ar, K^+, Ca^{2+}
C) Ionization energy decreases - Be, Mg, Ca, Sr
D) Electron affinity decreases - Br, Se, As, Ge
E) Metallic character increases - P, Si, Al, Mg

10) Barium ions are often used to precipitate sulfate ions from solution. If 37.34 g of barium chloride fully precipitate all of the sulfate ions in 2.37 L of a solution of unknown concentration, calculate the concentration of sulfate ions in the original solution.

A) 0.512 mol L^{-1} B) 0.0757 mol L^{-1} C) 0.216 mol L^{-1}
D) 0.0912 mol L^{-1} E) 0.425 mol L^{-1}

11) A student uses an analytical balance to measure 9.86 g of distilled water at 5°C and pours it into a 7.0 L container which is equalized to the lab's atmospheric pressure of 101.3 kPa. The container is sealed and the student heats the water to 90°C. Calculate the percent of water in the vapor phase at 90°C, given that water has a vapor pressure of 70.1 kPa at 90°C.

A) 36% B) 42% C) 30% D) 16% E) 4%

12) What is the pH of the solution created when 20.00 mL of a 0.15 mol L^{-1} solution of hydrochloric acid is added to 32.00 mL of 0.15 mol L^{-1} solution of ammonia? $K_b(NH_3) = 1.8 \times 10^{-5}$

A) 9.03 B) 4.97 C) 4.74 D) 9.25 E) 11.04

13) A space shuttle uses the reaction of H_2 and O_2 to power its processes as follows:

$$2H_2 + O_2 \rightarrow 2H_2O$$

The shuttle consumes 1730 kJ of energy daily. Calculate the total volume of H_2 and O_2 gases 27°C and 3.2 atm that the shuttle would need to operate for one week at.

Use the table below for any necessary values (at 27°C).

	H_2	O_2	$H_2O_{(l)}$
ΔH_f (kJ mol^{-1})	0	0	-285.8
S (J/mol·K)	130.6	205.0	69.9

A) 84.3 L B) 590 L C) 418 L D) 197 L E) 489 L

14) For the following redox reaction occurring under basic conditions, how many moles of hydroxide ions are required to balance the equation, and on which side of the equation would they appear?

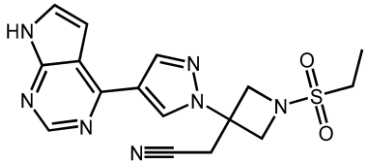
$$MnO_4^-(aq) + I^-(aq) \rightarrow MnO_4^{2-}(aq) + IO_4^-(aq)$$

A) 4 OH^- (aq) on reactant side B) 4 OH^- (aq) on product side
C) 8 OH^- (aq) on reactant side D) 8 OH^- (aq) on product side
E) no OH^- (aq) are required to balance this equation

15) For the reaction: $MnO_4^-(aq) + I^-(aq) \rightarrow MnO_4^{2-}(aq) + IO_4^-(aq)$, which species is the reducing agent?

A) MnO_4^- (aq) B) I^- (aq) C) MnO_4^{2-} (aq) D) IO_4^- (aq) E) OH^- (aq)

16) The drug compound below is a painkiller which has also recently been used in the treatment of the COVID-19 disease.



Which of the following statements is **TRUE** regarding this compound?

A) it contains an even number of nitrogen atoms
B) it contains an odd number of hydrogen atoms
C) it contains an odd number of carbon atoms
D) it contains an amide functional group
E) it contains a benzene ring

17) Given the following equilibrium reactions:

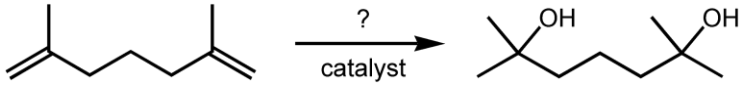
$$H_2S + H_2O \leftrightharpoons H_3O^+ + HS^- \qquad K_1$$
$$HS^- + H_2O \leftrightharpoons H_3O^+ + S^{2-} \qquad K_2$$

For the overall reaction $2H_3O^+ + S^{2-} \leftrightharpoons H_2S + 2H_2O$, what would the equilibrium constant be equivalent to?

A) $K_1 - K_2$ B) $-(K_1 \times K_2)$ C) $1/(K_2 - K_1)$

D) $1/(K_1 \times K_2)$ E) K_1/K_2

18) The reaction below takes place to form a product that contains two new functional groups:



Which two terms can be used to appropriately describe this type of reaction?

A) hydrogenation, elimination
B) hydration, addition
C) hydration, elimination
D) hydrogenation, addition
E) hydration, substitution

19) The following system is at equilibrium:

$$2\ NO_2Cl\ (g) \leftrightharpoons 2\ NO_2\ (g) + Cl_2\ (g) \qquad \Delta H_{rxn} = -228\ kJ\ mol^{-1}$$

Which of the following would cause the equilibrium to shift towards the reactants?

A) decreasing the concentration of NO_2
B) increasing the volume of the system
C) adding an inert gas, such as Ar (g)
D) increasing the temperature of the system
E) adding a catalyst

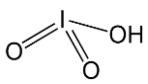
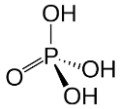
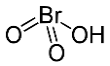
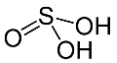
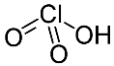
20) Given the data for the following reaction of a metal (M) chloride and $C_2O_4^{2-}$, determine the rate constant for the reaction:

$$2\ MCl_2(aq) + C_2O_4^{2-}(aq) \rightarrow 2\ Cl^-(aq) + 2\ CO_2(g) + M_2Cl_2(s)$$

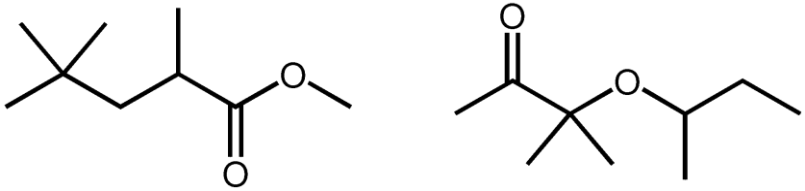
Experiment	$[MCl_2]$	$[C_2O_4^{2-}]$	Initial Rate (mol L^{-1} min^{-1})
1	0.106	0.15	1.8×10^{-5}
2	0.053	0.30	3.6×10^{-5}
3	0.053	0.15	9.0×10^{-6}

A) $k = 7.5 \times 10^{-3}\ L^2\ mol^{-2}\ min^{-1}$
B) $k = 1.1 \times 10^{-3}\ L\ mol^{-1}\ min^{-1}$
C) $k = 1.1 \times 10^{-3}\ L^2\ mol^{-2}\ min^{-1}$
D) $k = 1.1 \times 10^{-2}\ L^2\ mol^{-2}\ min^{-1}$
E) $k = 7.5 \times 10^{-2}\ L\ mol^{-1}\ min^{-1}$

21) All but one of the following oxo-acids have been paired with the correct pK_a. Based on their comparative structure, which acid has an incorrect pK_a? Note that some or all of the structures have lone pairs that are not depicted.

A)  pKa = 0.75	B)  pKa =1.1	C)  pKa = -2.0
D)  pKa = 1.9	E)  pKa = 2.2	

22) The relationship between the following two organic compounds is best described as



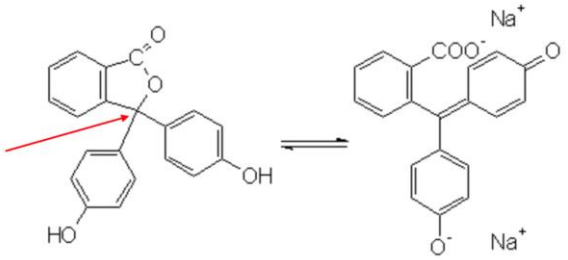
A) non-superimposable mirror images
B) geometric isomers
C) compounds with different molecular formulae
D) identical
E) structural isomers

23) When 0.50 g Mg (s) reacts in a calorimeter with ***excess*** HCl (aq) at volume V and concentration C, the temperature of the solution increases by 13 °C. How much would the temperature of the solution in the calorimeter increase if 0.50 g Mg (s) was combined with HCl (aq) with a volume of 2V and a concentration of 2C?

Assume the mass of the magnesium is negligible compared to the mass of the solution and the heat lost or absorbed by the calorimeter is negligible.

A) 6.5 °C B) 13 °C C) 26 °C D) 39 °C E) 52 °C

24) Consider the carbon atom indicated by the arrow in the structure of the indicator phenolphthalein



The structure on the left is phenolphthalein in acidic solution and on the right is the structure of phenolphthlalein in basic solution. As the colourless structure of phenolphthalein in acidic solution on the left changes to the structure on the right which appears fuschia in basic solution, which of the following statements would be FALSE?

A) The hybridization on the marked carbon changes from sp^3 to sp^2.
B) The bond angles surrounding the marked carbon change from approximately 109.5° to approximately 120°.
C) On the marked carbon, a sigma bond is lost and a pi bond is formed.
D) The number of occupied unhybridized p orbitals in the marked carbon increases from 1 to 2.
E) The deprotonation of a hydroxyl group leads to the transfer of electrons that creates a carboxylate ion.

25) A saturated solution of an alkaline earth metal hydroxide was prepared by adding 5.00 g of the solid hydroxide to 1.00 L of deionized water with continuous stirring. The pH of the solution was determined to be 10.35. What is the value of the solubility product constant, K_{sp}, for the alkaline earth metal hydroxide according to this experiment?

A) 5.61×10^{-12} B) 4.49×10^{-11} C) 1.12×10^{-11}
D) 1.40×10^{-12} E) 2.80×10^{-12}

End of the contest
Go back and check your work

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Data Sheet
Fiche de données

CHEMISTRY Olympiads
CANADA
Olympiades CHIMIE

1																	18
1 H 1.008	2											13	14	15	16	17	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31	3	4	5	6	7	8	9	10	11	12	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (269)	111 Rg (272)	112 Cn (285)	113 Nh (284)	114 Fl (289)	115 Mc (288)	116 Lv (292)	117 Ts (294)	118 Og (294)

Relative Atomic Masses (2012, IUPAC)
***For the radioactive elements the atomic mass of an important isotope is given**

Masses Atomiques Relatives (UICPA, 2012)
***Dans le cas des éléments radioactifs, la masse atomique fournie est celle d'un isotope important**

58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
90 Th 232.0	91 Pa (231.0	92 U (238.0)	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 (259)	103 Lr (262)

	Symbol **Symbole**	**Value** **Quantité numérique**	
Atomic mass unit	*amu*	1.66054×10^{-27} kg	Unité de masse atomique
Avogadro's number	N_A	6.022×10^{23}	Nombre d'Avogadro
Charge of an electron	*e*	1.60218×10^{-19} C	Charge d'un électron
Dissociation constant (H_2O)	K_w	1.00×10^{-14} (25°C)	Constante de dissociation de l'eau (H_2O)
Faraday's constant	*F*	96 485 C mol^{-1}	Constante de Faraday
Gas constant	*R*	8.31451 J K^{-1} mol^{-1} 0.08206 L atm K^{-1} mol^{-1}	Constante des gaz
Mass of an electron	m_e	9.10939×10^{-31} kg	Masse d'un électron
Mass of a neutron	m_n	1.67493×10^{-27} kg	Masse d'un neutron
Mass of a proton	m_p	1.67262×10^{-27} kg	Masse d'un proton
Planck's constant	*h*	6.62608×10^{-34} J s	Constante de Planck
Speed of light	*c*	2.997925×10^{8} m s^{-1}	Vitesse de la lumière
Rydberg constant	R_H	1.096×10^{7} m^{-1}	Constante de Rydberg

1 Å	$= 1 \times 10^{-10}$ m
1 atm	= 101.325 kPa
1 bar	$= 1 \times 10^{5}$ Pa

STP	**SATP**
273.15 K	298 K
100 kPa	100 kPa