Chemical Institute of Canada | **For Our Future**
Institut de chimie du Canada | **Pour notre avenir**

CANADIAN CHEMISTRY OLYMPIAD | OLYMPIADE DE CHIMIE DU CANADA

**THE CANADIAN CHEMISTRY CONTEST 2022**
**PART A – MULTIPLE CHOICE QUESTIONS (60 minutes)**
**All contestants should attempt this part of the contest before proceeding to Part B and/or Part C.**
**The only reference material allowed is the CIC/CCO Periodic Table provided. You must complete your answers online, directly in the TestInvite program. Students may use a scientific calculator. No phones or communication devices are allowed.**

1) Which of the following substances does not require the following WHMIS symbol (*oxidizer*)?

A) $Cl_2$ B) $O_2$ C) NaClO D) $Pb(NO_3)_2$ E) $H_2$

2) Which combination of atoms will form stable compounds with the following molecular geometries: bent, see-saw, octahedral?

A) sulfur and fluorine
B) xenon and fluorine
C) bromine and fluorine
D) two of the combinations of atoms
E) all three combinations of atoms

3) Consider the two species He and $Li^+$. Which statement best describes the comparison of their ionization energies and radii?

A) $Li^+$ has a smaller radius and greater ionization energy than He
B) $Li^+$ has a larger radius and lower ionization energy than He
C) He has an equal radius and ionization energy compared to $Li^+$
D) He has a smaller radius and lower ionization energy than $Li^+$
E) $Li^+$ has a smaller radius and lower ionization energy than He

4) A chemist combines 10.0 mL of 0.25 mol $L^{-1}$ antimony (III) nitrate, $Sb(NO_3)_3$, with 10.0 mL of 0.35 mol $L^{-1}$ sodium sulfide, $Na_2S$. What is the theoretical yield of the precipitate?

A) 0.40 g B) 0.42 g C) 0.60 g D) 0.85 g E) 3.6 g

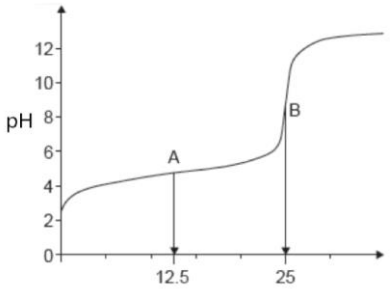
5) 1. 0 L of 0.010 M NaOH is added to 0.50 L of water. What is the pH of the solution?

A) 2.00 B) 2.18 C) 9.18 D) 11.82 E) 12.18

6) Chemistry students learn that, under many environmental conditions, the behaviour of gases can be approximated using the Ideal Gas Law. However, in practice, many gases deviate somewhat from ideal gas behaviour. Using your knowledge of intermolecular forces, determine which of the following gases should have the lowest pressure when all other variables remain constant.

A) $Cl_2$ B) Xe C) $CH_4$ D) $NH_3$ E) CO

7) The graph represents the titration of 25.00 mL of 0.100 mol $L^{-1}$ aqueous HA with 0.100 mol $L^{-1}$ aqueous sodium hydroxide.




Which of the following statements is false?

A) HA is not 100% ionized in water.
B) At point A, other than $H_2O$ and $Na^+$, the major species are HA and $A^-$.
C) Adding silver nitrate at point B will not affect the pH of the solution.
D) At point A, the $pK_a$ of HA is equal to the pH of the solution.
E) The acid dissociation constant of HA is less than one.

8) If 2.38 g of a gas are released into an evacuated 2.00 L vessel at 22.5°C and the pressure inside the container rises to 104.4 kPa, what is a possible identity of the gas? The ideal gas constant is 8.314 kPa L $mol^{-1}$ $K^{-1}$; assume ideal behaviour of the gas.

A) $CO_2$ B) $N_2$ C) $F_2$ D) Xe E) $CH_4$

9) If you prepared 0.25 mol $L^{-1}$ aqueous solutions of each of three electrolytes, which list of three would all have a pH > 7?

A) $NH_4NO_3$, NaOH, $Na_2CO_3$
B) $Al(NO_3)_3$, $NaCH_3COO$, $NaHCO_3$
C) $NaNO_3$, $NaClO_4$, $Na_2SO_4$
D) $Na_3PO_4$, NaF, NaClO
E) $Na_2S$, $Ca(NO_3)_2$, $Fe(NO_3)_3$

10) Biodiesels are an alternative to fossil fuels. Unlike fossil fuels, biodiesels are derived from recently grown plants that consumed greenhouse gases while they were growing. A 0.435 g sample of $C_{14}H_{28}O_2$ biodiesel fuel combusts in a bomb calorimeter containing 500.0 g of water initially at 20.00°C. After the combustion, the final temperature of the water is 49.70°C. The calorimeter has a heat capacity of 390 J $°C^{-1}$ and the specific heat capacity of water is 4.184 J $g^{-1}$ $°C^{-1}$. What is the heat of combustion of the biodiesel?

A) - 7.37 x $10^1$ kJ $mol^{-1}$ B) - 3.87 x $10^4$ kJ $mol^{-1}$ C) - 6.21 x $10^1$ kJ $mol^{-1}$
D) - 1.15 x $10^3$ kJ $mol^{-1}$ E) - 5.05 x $10^3$ kJ $mol^{-1}$

11) Many cars expose fuel to 1.50 L of atmospheric air every 2 revolutions. Assume atmospheric air contains 21.0 % oxygen gas by volume. If the combustion reaction is standardized to SATP conditions and uses an excess amount of pure octane ($C_8H_{18}$), calculate the volume of carbon dioxide produced in 30 seconds when the engine idles at 1500 revolutions per minute. Use the following balanced chemical reaction:

$$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$$

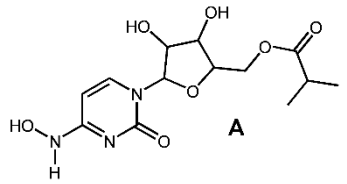
A) 360 L B) 263 L C) 184 L D) 118 L E) 75.6 L

12) How many chloride ions are present in 35 mL of a 0.70 mol $L^{-1}$ solution of $CaCl_2$ (aq)?

A) 0.025 B) 49 C) 1.5 x $10^{22}$ D) 3.0 x $10^{22}$ E) 6.0 x $10^{23}$

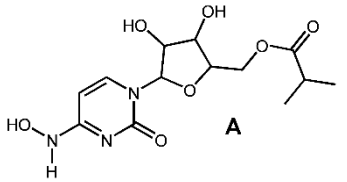
13) The ongoing COVID-19 pandemic has led to the development of an antiviral drug compound (**A**) which was approved for medical use in late 2021. The structure of compound **A** is shown below. How many carbon atoms and hydrogen atoms are there in this compound?

A) 12 carbon and 18 hydrogen atoms
B) 12 carbon and 19 hydrogen atoms
C) 13 carbon and 18 hydrogen atoms
D) 13 carbon and 19 hydrogen atoms
E) 13 carbon and 20 hydrogen atoms



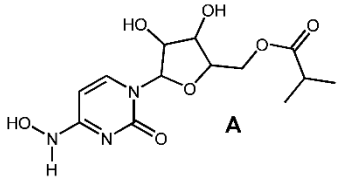

14) Which list of functional groups are **all** present in compound **A**?

A) alcohol, carboxylic acid, amide
B) amine, ether, carboxylic acid
C) alcohol, ketone, amine
D) ether, ketone, amide
E) ether, alcohol, ester




15) Two compounds structurally related to **A** were synthesized and subjected to medical testing. These two new compounds were labelled **B** and **C**. In the structure of compound **B**, the nitrogen atoms in compound **A** are replaced by phosphorus atoms. In the of compound **C**, the oxygen atoms in compound **A** are replaced by sulfur atoms. What is the difference in the molecular weight of compounds **B** and **C**?

A) 29.4
B) 45.5
C) 61.5
D) 78.6
E) 94.8



16) Which of the following elements forms a stable +4 ion with the following shorthand electron configuration: [noble gas] *(n-1)* $d^3$?

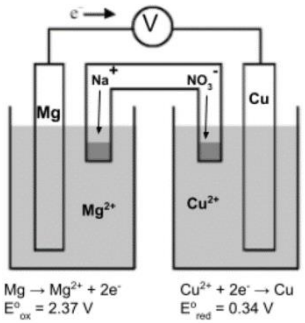
A) Mn B) Co C) Pb D) V E) Ti

17) For the hypothetical reaction, $2\ A + 3\ B \rightarrow A_2B_3$, when the initial [A] = 0.100 mol $L^{-1}$ and the initial [B] = 0.100 mol $L^{-1}$, the reaction rate is $1.4 \times 10^{-1}$ mol $L^{-1}$ $s^{-1}$, Which experiment in the table below would be consistent with the rate law, rate = $k[A][B]^2$?

| Experiment | Initial [A] (mol $L^{-1}$) | Initial [B] (mol $L^{-1}$) | Reaction Rate (mol $L^{-1}s^{-1}$) |
|---|---|---|---|
| A) | 0.200 | 0.200 | $4.48 \times 10^0$ |
| B) | 0.200 | 0.300 | $1.68 \times 10^0$ |
| C) | 0.300 | 0.200 | $1.68 \times 10^0$ |
| D) | 0.300 | 0.300 | $1.13 \times 10^1$ |
| E) | 0.200 | 0.400 | $2.24 \times 10^0$ |

18) Which statement about this electrochemical cell setup is **incorrect**?

A) The voltmeter reading would be 2.71 V
B) The direction of electron movement is correct in the diagram
C) The direction of the salt bridge ion movement is correct in the diagram
D) The cathode half-cell reaction is correct in the diagram
E) The magnesium electrode would become lighter as the cell operated




19) When the following redox reaction is balanced with the lowest possible integer coefficients, what is the sum of the coefficients of all reactants and products?

$$Cr_2O_7^{2-} + H^+ + Fe^{2+} \rightarrow Fe^{3+} + Cr^{3+} + H_2O$$

A) 6 B) 18 C) 26 D) 30 E) 36

20) A chemist performs a Karl Fischer titration to calculate the water content of a 26.0 mg unknown sample of a powder. Assume all of the water in the unknown sample reacts. If 11.2 mg of $I_2$ were consumed during the titration, use the following balanced equation for the Karl Fischer reaction to determine the percent water content by mass in the unknown sample.

$$H_2O + SO_2 + I_2 \rightarrow SO_3 + 2HI$$

A) 1.70 % B) 3.06 % C) 4.42 % D) 6.12 % E) 21.5 %

21) 1.0 mol of sulfur dioxide and 1.0 mol of oxygen gas react and establish an equilibrium as follows:

$$O_{2\,(g)} + 2\ SO_{2\,(g)} \rightleftharpoons 2\ SO_{3\,(g)} \qquad K_{eq} > 1$$

Which addition of reactants to the equilibrium reaction system will cause the greatest increase in the amount of sulfur trioxide? Assume both the volume and the temperature of the reaction mixture remain constant.

| | Moles of $O_{2\,(g)}$ added | Moles of $SO_{2\,(g)}$ added |
|---|---|---|
| A) | 0.8 | 1.2 |
| B) | 0.9 | 1.1 |
| C) | 1.0 | 1.0 |
| D) | 1.1 | 0.9 |
| E) | 1.2 | 0.8 |

22) A 25.00 mL sample of 0.800 M sodium acetate was titrated to equivalence with 15.00 mL of hydrochloric acid solution. Which of the following represents the calculations needed to determine the pH of the final solution? (acetic acid $K_a$ = 1.8 x $10^{-5}$)

A) $1.8 \times 10^{-5} = \frac{x^2}{(0.800 - x)}$

B) $-\log((0.800)(\frac{0.02500}{(0.02500+0.01500)}))$

C) $-\log\sqrt{(1.8 \times 10^{-5})(0.800)(\frac{0.02500}{(0.02500+0.01500)})}$

D) $14 - (-\log\sqrt{(\frac{1.8\times10^{-5}}{1\times10^{-14}})(0.800)(\frac{0.02500}{(0.02500+0.01500)})})$

E) $-\log\sqrt{(1.8 \times 10^{-5})(0.800)}$

23) The green chemistry metric called *process mass intensity* (PMI) allows a chemist to calculate the total material used to synthesize a certain amount of desired product in a chemical reaction:

PMI = [(mass of all input materials) / (actual mass of desired product)]

Consider the following laboratory procedure used to synthesize benzocaine, a local anesthetic used to treat oral ulcers:

0.0144 moles of 4-aminobenzoic acid hydrochloride (formula: $C_7H_8ClNO_2$) was dissolved in 20.0 mL of ethanol (density: 0.790 g/mL) and 1.1 mL concentrated $H_2SO_4$ (density: 1.82 g/mL) was added. The mixture was then rapidly stirred and heated vigorously for two hours. After cooling to room temperature, the reaction mixture was neutralized with 20.0 mL of a 10% aqueous sodium carbonate solution (density: 1.10 g/mL) and transferred to a separatory funnel. Extraction of the product was performed with 30.0 mL of dichloromethane (density: 1.325 g/mL) and the dichloromethane was subsequently dried with 6.0 g of anhydrous sodium sulfate. Removal of this drying agent and evaporation of the dichloromethane left 0.0102 moles of pure benzocaine (formula: $C_9H_{11}NO_2$).

The PMI for this reaction is

A) 46.6 B) 48.8 C) 50.9 D) 51.2 E) 52.3

24) Consider the table below with the relative strength of acids and bases. Assuming all reactant species have the same concentration, which of the following equilibria would you expect to have the lowest $K_{eq}$ value?

A) $CH_3COOH(aq) + NH_3(aq) \rightleftharpoons CH_3COO^-(aq) + NH_4^+(aq)$
B) $H_2S(aq) + H_2O(l) \rightleftharpoons HS^-(aq) + H_3O^+(aq)$
C) $HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$
D) $HF(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + F^-(aq)$
E) $HCN(aq) + NH_3(aq) \rightleftharpoons CN^-(aq) + NH_4^+(aq)$

| Strongest Acid | HCl | $Cl^-$ | Weakest Base |
|---|---|---|---|
| ↓ | $H_2SO_4$ | $HSO_4^-$ | ↑ |
| | $H_3O^+$ | $H_2O$ | |
| | $H_2SO_3$ | $HSO_3^-$ | |
| | HF | $F^-$ | |
| | $CH_3COOH$ | $CH_3COO^-$ | |
| | $H_2CO_3$ | $HCO_3^-$ | |
| | $H_2S$ | $HS^-$ | |
| | HCN | $CN^-$ | |
| | $NH_4^+$ | $NH_3$ | |
| Weakest Acid | $H_2O$ | $OH^-$ | Strongest Base |

25) For a reaction that is spontaneous at -100°C but non-spontaneous at 200°C. what must be true about the reaction?

A) The reaction is endothermic and $K_{eq} < 0$
B) The reaction is exothermic and $K_{eq} > 0$
C) The reaction is endothermic and decreases entropy
D) The reaction is exothermic and increases entropy
E) $\Delta H < 0$ and $\Delta S < 0$

**End of Part A of the contest**
**Go back and check your work**