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 2021**
**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 answers on the Scantron Sheet provided. Students may use a scientific calculator. No phones or communication devices are allowed.**

1) What mass of cobalt (II) chloride hexahydrate must be used in order to make 500.0 mL of a solution that has a chloride ion concentration of $[Cl^-] = 0.300$ mol $L^{-1}$?

A) 9.74 g B) 17.8 g C) 35.7 g D) 143 g E) 150 g

2) Which of the following statements are TRUE about reactions 1 and 2?
Reaction 1: $N_2\,(g) + 3H_2\,(g) \rightarrow 2NH_3\,(g)$
Reaction 2: $NaOH\,(aq) + HCl\,(aq) \rightarrow H_2O\,(l) + NaCl\,(aq)$

i) Reaction 1 is a redox reaction
ii) Reaction 2 is a redox reaction
iii) Hydrogen is the reducing agent in both reaction 1 and 2
iv) One of the products in each reaction has a bond angle of < 109.5°

A) i, ii and iii B) i, ii and iv C) ii and iv
D) i and iv E) i, ii, iii and iv

3) A student combines 25.00 mL of a 0.125 mol $L^{-1}$ solution of potassium iodide KI with 10.00 mL of a 0.250 mol $L^{-1}$ solution of lead (II) nitrate $Pb(NO_3)_2$. What mass of precipitate will be formed?

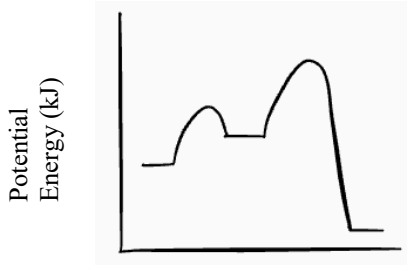
A) 0.316 g B) 0.720 g C) 0.980 g D) 1.15 g E) 1.44 g

4) Respiration is an example of a catabolic process in which energy is released. Which statement best explains why energy is released in this reaction?

$$C_6H_{12}O_6\,(s) + 6\,O_2\,(g) \rightarrow 6\,CO_2 + 6\,H_2O$$

A) Breaking the bonds in glucose releases energy
B) Burning calories converts molecules into energy
C) Bond formation in carbon dioxide and water is highly exothermic
D) The larger a molecule is, the more potential energy it contains.
E) Kinetic energy is converted into potential energy in this reaction.

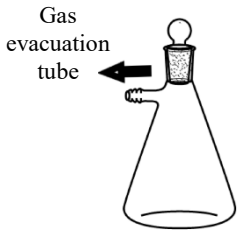
5) The following reaction diagram represents a two step reaction. Which of the statements about this reaction are correct?




i) The rate determining step is endothermic.
ii) The overall reaction enthalpy is negative.
iii) Producing reaction intermediates releases energy.

A) i only B) ii only C) iii only D) i and iii E) i, ii and iii

6) Some air is evacuated from a 400.0 mL Erlenmeyer flask at 25.0°C. Assuming Ideal Gas Law behaviour, what is the partial pressure of $O_2$ inside the container if $1.21 \times 10^{-2}$ mol gas remain in the container, consisting of $9.44 \times 10^{-3}$ mol $N_2$, $1.17 \times 10^{-4}$ mol Ar and $O_2$ is the only other gas in the container?

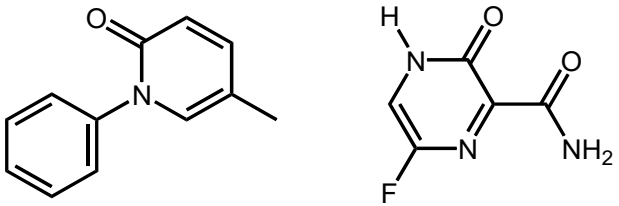



A) 75.0 kPa B) 63.9 kPa C) 47.1 kPa D) 39.3 kPa E) 15.8 kPa

7) Scientists have discovered that one of the twenty-eight artificially created zirconium isotopes, zirconium-88, had an unusually high affinity for neutrons. In zirconium-88, a proton absorbs an atomic electron, forming a neutron and emitting a neutrino. What is the correct notation for the atom that forms as a result of this transition?

A) ${}^{88}_{39}Y$ B) ${}^{89}_{39}Y$ C) ${}^{89}_{39}Zr$ D) ${}^{88}_{40}Zr$ E) ${}^{89}_{41}Nb$

8) The COVID-19 pandemic triggered an intense effort worldwide to screen *existing* "small-molecule" drugs in the development of a treatment. The structures of two such compounds of interest are shown below. What is the difference in the molecular weight of the compounds in g mol$^{-1}$?




A) 14.1 B) 26.1 C) 27.1 D) 28.1 E) no difference

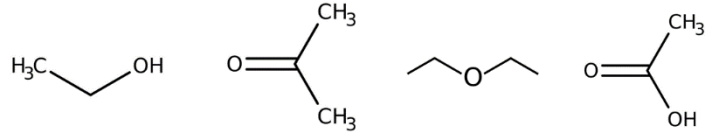
9) Which statement is **TRUE** for the two compounds in Question 8?

A) only one compound contains one amide functional group
B) both compounds have the same number of lone pair electrons
C) both compounds contain one amide functional group
D) both compounds contain a benzene ring
E) only one compound contains one amine functional group

10) The kinetic molecular theory describes the behaviour of ideal gases. Which of the following aspects of the particle theory of matter does not correspond to the kinetic molecular theory?

A) Particles are always moving.
B) Different substances are made of different particles.
C) Particles move faster at higher temperatures.
D) Particles are all attracted to each other.
E) Identical substances are made of identical particles

11) Arrange the following compounds in order of increasing volatility




I II III IV

A) IV, I, II, III
B) I, III, II, IV
C) I, IV, II, III
D) IV, I, III, II
E) III, II, IV, I

12) For the titration of a weak base with a strong acid, which of the following indicators would be best to visualize the equivalence point?

A) Cresol red (pKa = 1.0)
B) Methyl red (pKa = 5.0)
C) Thymol blue (pKa = 8.9)
D) Phenolphthalein (pKa = 9.4)
E) Alizarin yellow (pKa = 11.2)

13) Methylamine is a weak base with a pKb of 3.36. What is the pH of a 0.500 M solution of methylamine?

A) 1.84 B) 10.08 C) 12.16 D) 12.32 E) 13.70

14) An acid-base titration is performed using formic acid (HCOOH) and sodium hydroxide (NaOH) as the titrant, according to the equation below:

$$HCOOH\ (aq) + NaOH\ (aq) \rightarrow H_2O\ (\ell) + NaHCOO\ (aq)$$

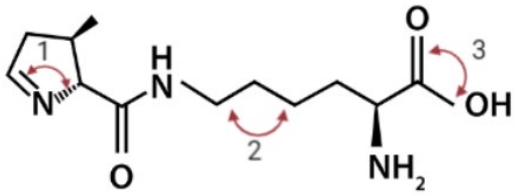
If 15.00 mL of 0.400 M sodium hydroxide solution was required to neutralize a 30.00 mL sample of formic acid, what will be the pH at the equivalence point of this titration? The $K_a$ of formic acid is $1.77 \times 10^{-4}$.

A) 5.562 B) 7.000 C) 8.438 D) 11. 686 E) 13.651

15) Tums® tablets contain the active ingredient calcium carbonate, which eases the symptoms of acid-indigestion by neutralizing hydrochloric acid in the stomach and inhibiting peptic activity. The standard dose for the treatment of acid-indigestion with Tums® is two tablets, which each contain 500 mg of calcium carbonate. Suppose an individual with a stomach volume of 1 L and pH of 1.64 ingests the recommended dose of Tums®. What will be the resulting pH of the contents of the stomach once the reaction is complete?

A) 2.53 B) 1.78 C) 2.87 D) 2.72 E) 1.89

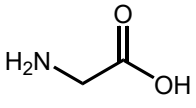
16) The α amino acid pyrrolysine is absent in humans, but found in some methanogenic bacteria and archeobacteria for synthesis of proteins. The structure of pyrrolysine is shown below:



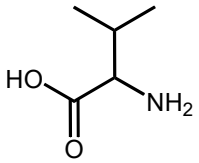

What are the approximate values of the bond angles labelled 1, 2, and 3, respectively?

A) 120°, 120°, 120°
B) 109.5°, 109.5°, 120°
C) 109.5°, 120°, 120°
D) 109.5°, 109.5°, 109.5°
E) 120°, 109.5°, 120°

17) An equimolar mixture of two amino acids, glycine and valine, (structures below) underwent a condensation reaction. How many dipeptide products were formed which have different atom connectivity?



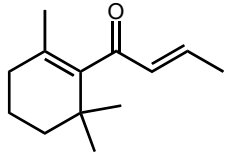

**glycine**



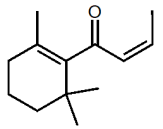

**valine**

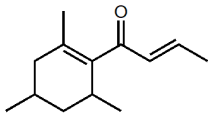
A) 2 B) 3 C) 4 D) 5 E) 6

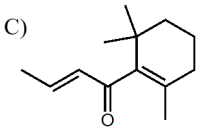
18) The organic substance below is a component of a variety of essential oils and belongs to a family of compounds known as "rose ketones".

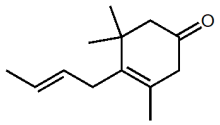


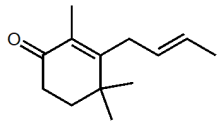

Which of the following compounds is **NOT** an isomer of this substance?

A)



B)



C)



D)



E)


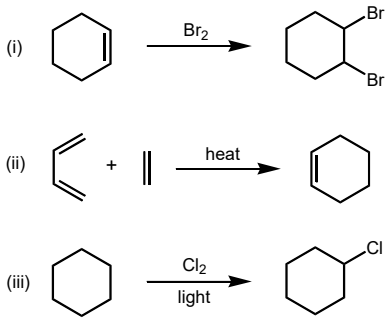

19) The human body is approximately 60% water (specific heat capacity of water, c = 4.184 J $g^{-1}$ $K^{-1}$). When not dressed properly on a 5 °C day, body temperature drops at 2.0 °C $h^{-1}$. For a 60.0 kg person, what mass of glucose ($C_6H_{12}O_6$, $\Delta H_c$ = -2880 kJ $mol^{-1}$) must be burned per hour to maintain a constant body temperature?

A) 9.4 g B) 16 g C) 19 g D) 31 g E) 47 g

20) An ice calorimeter measures the heat released in a reaction using the mass of ice melted during a chemical process. The heat of fusion of ice ($\Delta H_{fus}$) is 333 J $g^{-1}$. Assuming there is some energy lost in the process, if 1.75 g of ice melt when 0.250 g of an unknown metal react with excess hydrochloric acid to produce the metal chloride $XCl_2$ and hydrogen gas. In a separate experiment, the volume of hydrogen gas evolved in the reaction of excess hydrochloric acid and 0.250 g of the metal was 0.0850 L at 0°C and 101.3 kPa. What is the approximate enthalpy of this reaction?

A) 154 kJ B) 198 kJ C) 258 kJ D) 396 kJ E) 761 kJ

21) The "atom economy" of a chemical reaction is the fraction of starting material atoms that end up in a desired product. It is important for both sustainable development and economic reasons to use reactions with high atom economy as much as possible.
Which of the following three reactions occur with 100% atom economy, based on forming the desired product shown?

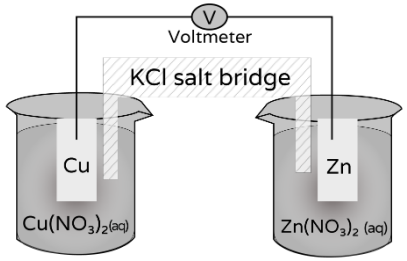



A) i only B) ii only C) iii only D) i and ii E) i, ii & iii

22) Consider the following galvanic cell for Questions 22-24

$$E^{o}_{Cu^{2+}/Cu} = +0.34\ V$$

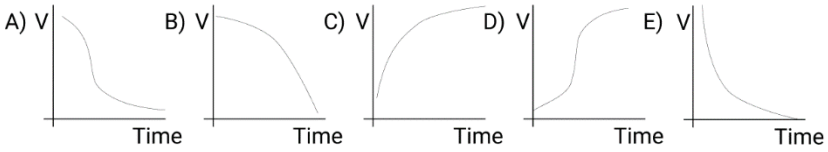
$$E_{Zn^{2+}/Zn} = -0.76\ V$$




Which of the statements is true about $[Cl^-]$ at the anode and the cathode after the cell has operated for 5 minutes?

A) $[Cl^-] = 0\ M$ in both half cells.
B) Both half cells contain $[Cl^-] = 0.1\ M$ due to diffusion.
C) $[Cl^-]$ is greatest at the cathode. A precipitate forms at the anode.
D) $[Cl^-]$ is greatest at the cathode as the ions migrate to make the cell work.
E) $[Cl^-]$ is greatest at the anode as ions move to neutralize the charge difference.

23) If the anode and cathode were connected with a wire with constant resistance, which would be the expected graph of voltage of the cell vs. time?




24) Assuming no energy is lost in the system, how much work can the cell do at 298 K if there are 2 mols of $Cu^{2+}$ at the cathode and 2 mols of $Zn^{2+}$ at the anode? The potential of the cell is 1.10 $V$.

A) 1.10 J B) 2.20 J C) 106.15 kJ D) 212.3 kJ E) 424.5 kJ

25) The *Ksp* value for $SrSO_4$ is $7.6 \times 10^{-7}$, and the *Ksp* value for $SrF_2$ is $7.9 \times 10^{-10}$. $Sr(NO_3)_2(s)$ is added to 1.00 L of solution containing 0.020 mol $F^-$ and 0.20 mol of $SO_4^{-2}$ with constant volume. Which salt **precipitates first**, and what is the **$[Sr^{2+}]$** in solution when the precipitate forms?

A) $SrF_2$ and $SrSO_4$ both precipitate when $[Sr^{2+}] = 3.8 \times 10^{-4}$ mol $L^{-1}$
B) $SrF_2$ precipitates first, when $[Sr^{2+}] = 2.0 \times 10^{-6}$ mol $L^{-1}$
C) $SrF_2$ precipitates first, when $[Sr^{2+}] = 1.6 \times 10^{-7}$ mol $L^{-1}$
D) $SrSO_4$ precipitates first, when $[Sr^{2+}] = 7.7 \times 10^{-8}$ mol $L^{-1}$
E) $SrSO_4$ precipitates first, when $[Sr^{2+}] = 5.3 \times 10^{-9}$ mol $L^{-1}$

**End of Part A 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**<br>**Symbole** | **Value**<br>**Quantité numérique** | |
|---|---|---|---|
| Atomic mass unit | *amu* | $1.66054 \times 10^{-27}$ kg | Unité de masse atomique |
| Avogadro's number | $N_A$ | $6.022 \times 10^{23}$ | Nombre d'Avogadro |
| Charge of an electron | $e$ | $1.60218 \times 10^{-19}$ C | Charge d'un électron |
| Dissociation constant ($H_2O$) | $K_w$ | $1.00 \times 10^{-14}$ (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 $K^{-1}$ $mol^{-1}$<br>0.08206 L atm $K^{-1}$ $mol^{-1}$ | Constante des gaz |
| Mass of an electron | $m_e$ | $9.10939 \times 10^{-31}$ kg | Masse d'un électron |
| Mass of a neutron | $m_n$ | $1.67493 \times 10^{-27}$ kg | Masse d'un neutron |
| Mass of a proton | $m_p$ | $1.67262 \times 10^{-27}$ kg | Masse d'un proton |
| Planck's constant | $h$ | $6.62608 \times 10^{-34}$ J s | Constante de Planck |
| Speed of light | $c$ | $2.997925 \times 10^{8}$ m $s^{-1}$ | Vitesse de la lumière |
| Rydberg constant | $R_H$ | $1.096 \times 10^{7}$ $m^{-1}$ | Constante de Rydberg |

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

| **STP/TPN** | **SATP/TPAN** |
|---|---|
| 273.15 K | 298 K |
| 100 kPa | 100 kPa |

Scratch paper