

THE CANADIAN CHEMISTRY CONTEST 2007
for high school and CEGEP students
(formerly the National High School Chemistry Examination)
PART A - MULTIPLE CHOICE QUESTIONS (60 minutes)

All contestants should attempt this part of the examination before proceeding to Part B (the CIC Exam) and/or Part C (the CCO Exam).
A CIC/CCO Periodic Table is required, but no other data may be given. Answers should be marked on the Answer Grid provided.

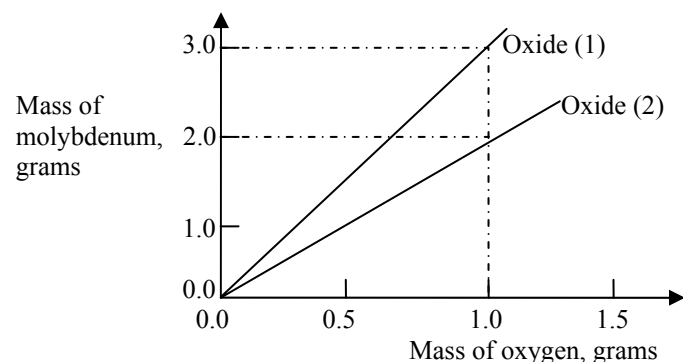
- The following substances have all been used in general anaesthetics. Which one **MUST** be kept away from flames?
 - Xenon, Xe
 - Nitrous oxide, N₂O
 - Chloroform (trichloromethane), CHCl₃
 - Ether (ethoxyethane), CH₃CH₂-O-CH₂CH₃
 - Isoflurane (2-chloro-2-(difluoromethoxy)-1,1,1-trifluoroethane), CF₃-CHCl-O-CHF₂
- Which one of the following species has only one lone pair (non-bonding pair) of electrons on the central atom?
 - NH₃
 - BrF₃
 - H₂O
 - CH₄
 - NH₄⁺
- Which of the following atoms has the smallest atomic radius?
 - Br
 - Cl
 - P
 - S
 - Se
- Which of the following atoms has the largest first ionization energy?
 - Al
 - B
 - C
 - N
 - Si
- Which one of the following responses correctly identifies the structure of all the substances shown in the table? All the substances are pure and in their **solid state**.

Substance \ Response	LiCl	HCl	CH ₃ OCH ₃	C(graphite)	K
A.	Ionic	Ionic	Molecular	Covalent network	Atomic
B.	Ionic	Metallic	Molecular	Covalent network	Atomic
C.	Ionic	Molecular	Molecular	Covalent network	Metallic
D.	Ionic	Molecular	Metallic	Atomic	Metallic
E.	Molecular	Ionic	Ionic	Atomic	Metallic
- Select the response below that lists the bonds in order of **increasing** polarity (least polar to most polar):
 - O-F, C-F, Be-F
 - O-F, Be-F, C-F
 - Be-F, O-F, C-F
 - Be-F, C-F, O-F
 - C-F, O-F, Be-F
- Magnesium hydroxide, Mg(OH)₂, is used in antacid tablets. It is a strong base, which is completely dissociated in water. What is the pH of a solution of Mg(OH)₂ with a concentration of 0.0001 mol L⁻¹ at 25°C?
 - 3.7
 - 4.0
 - 8.0
 - 10.0
 - 10.3
- The ionic product of water, K_w, is 1.0 x 10⁻¹⁴ at 298 K. Given that the **neutralisation** of a strong acid with a strong base is an exothermic reaction, which one of the following is likely to be the value of K_w at 273 K?
 - 1.2 x 10⁻¹⁵
 - 1.2 x 10⁻¹³
 - 1.0 x 10⁻¹⁴
 - 1.2 x 10⁻¹⁴
 - 1.2 x 10⁻¹⁵
- Aluminum hydroxide (M_r = 78.0) is used in the dyeing industry. What mass (in kg) will be required to saturate 1000 L of water at 298 K if the solubility product constant K_{sp}{Al(OH)₃} = 1.0 x 10⁻³² at 298 K?
 - {1.0 x 10⁻³²/27}^{1/4} x 78.0
 - {1.0 x 10⁻³²/27}^{1/4} ÷ 78.0
 - {1.0 x 10⁻³²/27}^{1/3} x 78.0
 - {1.0 x 10⁻³²/81}^{1/3} ÷ 78.0
 - {1.0 x 10⁻³²/81}^{1/4} x 78.0
- The iodate ion (IO₃⁻) can oxidize Fe²⁺ to Fe³⁺ in acid solution. If IO₃⁻ is reduced to iodide (I⁻) in this reaction, then the number of moles of Fe²⁺ that can be oxidized by 1 mole of IO₃⁻ is
 - 2
 - 3
 - 4
 - 5
 - 6

11. Vitamin C is ascorbic acid, which is a monoprotic acid of formula $C_6H_8O_6$. When a 500-mg tablet of pure vitamin C is dissolved in 100 mL of water, the pH of the solution is measured as 2.83. The acid dissociation constant, K_a , of ascorbic acid is therefore:

- A. 1.0×10^{-14} B. 2.2×10^{-6} C. 8.1×10^{-5}
 D. 1.5×10^{-3} E. 5.5×10^{-2}

12. A group of researchers did an experiment to determine the mass ratio of molybdenum to oxygen in two different oxides. They combined their results to give the graph shown below:



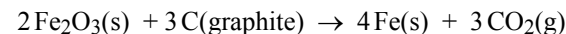
From these results it can be deduced that the formulae of the two metal oxides are:

	A	B	C	D	E
Oxide (1)	MoO	Mo ₂ O	Mo ₃ O	MoO ₂	MoO ₃
Oxide (2)	Mo ₂ O ₃	Mo ₃ O	Mo ₂ O	MoO ₃	MoO ₂

13. Flutamide (Eulexin[®]) is an important organic compound containing three fluorine atoms in each molecule. It is used in the treatment of prostate cancer. An analytical chemist extracted flutamide from a commercial tablet weighing 203.21 mg leaving a residue (containing non-medicinal ingredients) that weighed 128.23 mg. Elemental analysis of the extracted flutamide revealed the presence of 15.47 mg of fluorine. What is the molar mass (in $g\ mol^{-1}$) of flutamide?

- A. 232.8 B. 254.5 C. 276.2 D. 286.9 E. 303.1

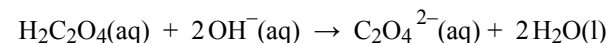
14. An example of a highly exothermic “thermite” reaction is used in the production of iron by the blast furnace process. The equation for this reaction is:



What is the maximum mass of iron metal can be obtained from 1235 kg of iron(III) oxide and 154.0 kg of graphite?

- A. 477.5 kg B. 863.8 kg C. 714.8 kg
 D. 953.1 kg E. 955.7 kg

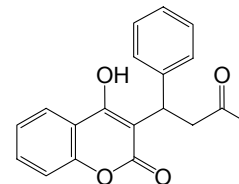
15. Oxalic acid (ethanedioic acid, $H_2C_2O_4$) has many uses in metal cleaning, textile dyeing and photography. Suppose you dissolve a 1.034-g sample of *impure* oxalic acid in some water, add an acid-base indicator, and titrate with NaOH ($0.485\ mol\ L^{-1}$). The sample requires 34.47 mL of the NaOH solution to reach the equivalence point. The equation for the titration reaction is:



What is the **mass** of oxalic acid and what is its **mass percent** in the sample?

- A. 0.547 g, 52.9% B. 0.654 g, 63.2% C. 0.729 g, 70.5%
 D. 0.752 g, 72.8% E. 0.856 g, 82.8%

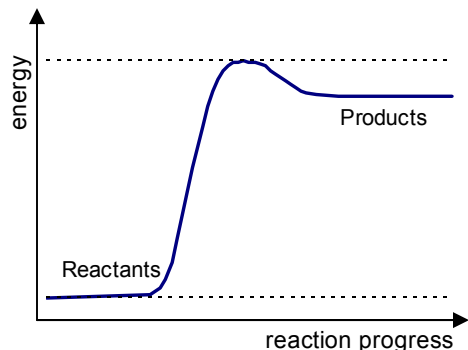
16. Warfarin is an anticoagulant used to decrease the clotting ability of blood so that thrombosis is prevented, while avoiding spontaneous bleeding. The structural formula of Warfarin is given below:



Four of the functional groups present in Warfarin are:

- A. ether, alkene, ketone, ester
 B. ether, alkene, ester, alcohol
 C. ester, alkene, alcohol, ketone
 D. ether, ketone, alkene, alcohol
 E. ester, alcohol, alkene, aldehyde

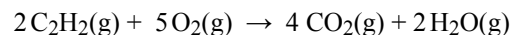
17. The following diagram shows the energy profile of a reaction:



Which one of the following correctly identifies the type of reaction shown in the diagram, together with the correct reason for this choice?

	Type of reaction	Reason
A.	Exothermic	Energy is supplied to the reactants
B.	Exothermic	Energy is given out by the reaction
C.	Exothermic	The products have a higher potential energy than the reactants
D.	Endothermic	Energy is given out by the reaction
E.	Endothermic	The products have a higher potential energy than the reactants

18. Acetylene (ethyne) is burned in oxy-acetylene blowtorches, which are used for cutting and welding metals. The combustion reaction is represented by the following equation:



Given the following enthalpies of formation:

$$\Delta H_f^\ominus\{\text{C}_2\text{H}_2(\text{g})\} = +226.7\text{ kJ mol}^{-1}, \Delta H_f^\ominus\{\text{CO}_2(\text{g})\} = -393.5\text{ kJ mol}^{-1}$$

and $\Delta H_f^\ominus\{\text{H}_2\text{O}(\text{g})\} = -241.8\text{ kJ mol}^{-1}$

what is the enthalpy of combustion (ΔH_c^\ominus) per mole of ethyne?

- A. -1256 kJ mol^{-1} B. -2511 kJ mol^{-1} C. -1604 kJ mol^{-1}
 D. $+1256\text{ kJ mol}^{-1}$ E. $+2511\text{ kJ mol}^{-1}$

19. The table below gives the solubilities of sodium nitrate and lithium chloride in 100 g of water at 20°C and 60°C.

Solubility in 100 g of water	20°C	60°C
Sodium nitrate	87.5 g	125 g
Lithium chloride	78.0 g	103 g

A 40.0-g sample of a mixture that is 50.0% by mass in each of sodium nitrate and lithium chloride is stirred in 20.0 g of water at 60°C until all of it dissolves. When the solution is cooled down to 20°C, white crystals appear and the latter are carefully recovered by filtration. Which one of the following gives the correct mass of recovered solid and the percent by mass of lithium chloride in it?

- A. 6.9 g of solid containing 36% LiCl
 B. 6.9 g of solid containing 64% LiCl
 C. 20.0 g of solid containing 22.0% LiCl
 D. 33.1 g of solid containing 63.8% LiCl
 E. 33.1 g of solid containing 47.1% LiCl

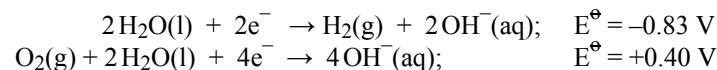
20. Consider the following reactions:

- I) $\text{C}(\text{graphite}) + \text{S}_2(\text{g}) \rightleftharpoons \text{CS}_2(\text{g})$
 II) $\text{CO}_2(\text{g}) + \text{C}(\text{graphite}) \rightleftharpoons 2\text{CO}(\text{g})$
 III) $\text{CH}_4(\text{g}) + 2\text{S}_2(\text{g}) \rightleftharpoons \text{CS}_2(\text{g}) + 2\text{H}_2\text{S}(\text{g})$
 IV) $\text{CO}(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons \text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g})$

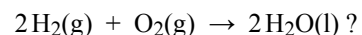
Assuming that each of these reactions has achieved equilibrium, which two would NOT then be affected by an increase in pressure (by reducing the volume, and with the temperature kept constant)?

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

21. Given the following standard reduction potentials:

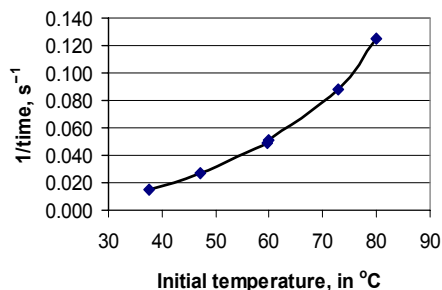


What is the electromotive force of a fuel cell with the overall reaction:



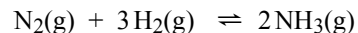
- A. -1.23 V B. -0.43 V C. $+0.43\text{ V}$ D. $+1.23\text{ V}$ E. $+2.06\text{ V}$

22. The following graph shows the effect of initial temperature on the rate of reaction for a series of experiments performed on the same reaction, with the same initial concentrations of reactants. (Note that each experiment is performed as a “clock” reaction, so it is only timed up to a certain point, and you can assume that the rate is proportional to 1/time.)



Which one of the following statements can be correctly deduced from this graph:

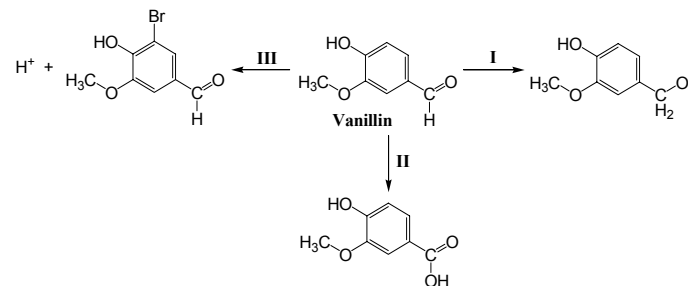
- A. The reaction is exothermic
 - B. The reaction is endothermic
 - C. The rate of reaction increases with initial temperature
 - D. The rate of reaction decreases with initial temperature
 - E. The time taken for the reaction to be completed increases with initial temperature
23. The following equilibrium reaction is the basis for the production of ammonia used in fertilizers:



If the equilibrium constant for this reaction is K , then which one of the following will be the equilibrium constant when the concentration of hydrogen gas in the mixture is doubled (at the same temperature)?

- A. $K/8$ B. $K/4$ C. K D. $2K$ E. K^2

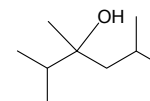
24. Vanillin, the primary component of the extract of the vanilla bean, undergoes several chemical reactions as shown below:



Identify which type of reaction is taking place during steps **I**, **II** and **III**.

- | | I | II | III |
|----|-----------|-----------|--------------|
| A. | reduction | oxidation | substitution |
| B. | oxidation | reduction | substitution |
| C. | reduction | oxidation | elimination |
| D. | reduction | oxidation | addition |
| E. | oxidation | reduction | addition |

25. Treatment of the organic substance 2,3,5-trimethyl-3-hexanol (structure below) with aqueous sulfuric acid causes a dehydration reaction. Three alkene products are formed in unequal amounts: 2,3,5-trimethyl-2-hexene (**I**), 2-isopropyl-4-methyl-1-pentene (**II**), and 2,3,5-trimethyl-3-hexene (**III**).



Which of these three alkenes can exist as geometric isomers?

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

**This is the end of Part A of the contest.
 Now go back and check your work.**



THE CHEMICAL INSTITUTE OF CANADA L'INSTITUT DE CHIMIE DU CANADA

“Chemists, engineers and technologists working together.”

“Les chimistes, les ingénieurs et les technologistes travaillant ensemble.”

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PART B – EXTENDED RESPONSE SECTION (90 minutes)

In this section you should respond to **TWO** topics only, writing in the form of scientific essays (or, for Question 4, an experimental description) including any appropriate equations, formulae and diagrams. Some suggestions are made about the direction(s) you could take, but these are not exclusive. Each essay/experiment is of equal value, and the quality of **both** responses will be considered in the final competition: you should therefore allocate approximately equal time to each of the subjects you choose. The judging of the responses will be based on both factual accuracy and presentation. A clear, concise and well-organized piece of written work will be rated more highly than a long rambling one that contains the same information.

1. Period 3

In this essay you should discuss the properties of the Period 3 elements (from sodium to argon) with particular reference to how these elements and their compounds illustrate trends in properties across the Periodic Table. Although it is appropriate to consider atomic scale properties such as atomic and ionic radii, ionization energies, electron affinities and electronegativity, your essay will be more interesting if it shows how these factors are related to macro-scale physical properties such as molar volume, melting points and boiling points, and also to chemical reactivity. With regard to compounds of the elements you might like to consider the periodicity of the formulae of oxides, chlorides and hydrides, together with their chemical properties. You might also wish to discuss the structure and bonding of the elements and their compounds.

2. The Greenhouse Effect

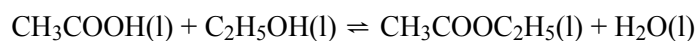
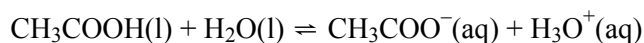
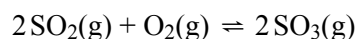
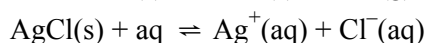
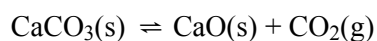
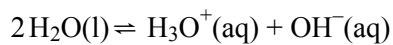
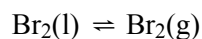
This essay should be written in the form of a magazine article. You should explain what is meant by the greenhouse effect, and how it is important in controlling the climate of the Earth. Some of the gases that you might like to consider are: water vapour, carbon dioxide, methane, ozone, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and halons (bromine-containing halogenoalkanes). Using some or all of these examples, or other gases of your choice, you should explain the differences between natural greenhouse gases and those that are produced by human activity, and indicate the mechanisms by which the gases are produced by writing chemical equations. You could also discuss the problems that might arise if the concentration of greenhouse gases becomes significantly elevated, and how these difficulties might be averted by human intervention.

/continued overleaf

3. Chemical Equilibrium

In answering this question you should explain what is meant by dynamic equilibrium systems and how these relate to reversible reactions: in doing this you need to specify the characteristics of dynamic equilibrium. You should also discuss the effect of changing conditions, such as concentration, pressure and temperature, on the position of equilibrium. You should consider Le Châtelier's principle, and how this relates to the equilibrium law expression (equilibrium constant). You might also like to compare equilibrium constants for homogeneous and heterogeneous processes, and to consider "special case" equilibrium constants, such as those governing acid dissociation (K_a), solubility (K_{sp}), and the ionisation of water (K_w). You could also discuss how equilibrium considerations are used to optimise steady state conditions for industrial processes, with appropriate examples.

You may use some or all of the following equations as examples, and/or other reaction equations if you so wish.



4. Experimental Design

In this question you are required to design an experiment to determine the enthalpy change of solution (heat of solution) of anhydrous copper sulfate in water, which is a very exothermic reaction.

In your response you should state what you understand by enthalpy change of solution, and outline your experimental procedure, giving details of the apparatus and materials you would need for performing the experiment in a high school laboratory. It is important to specify any safety precautions that might be required. You should indicate what readings you would take and how you would use these readings to calculate a result. You should consider any problems that you might encounter when performing your experiment (including what might happen if the copper sulfate is partly hydrated), and how these factors might give rise to errors in the final value obtained. You might also like to discuss how your experiment could be improved in order to overcome these problems.