1998 NATIONAL CHEMISTRY EXAMINATION

CIC National High School Chemistry Examination

CCO National Selection Examination

PART A: MULTIPLE CHOICE QUESTIONS (60 minutes)

1. Which one of the following isotopes has exactly 19 neutrons?

   a) ^{35}Cl b) ^{19}F c) ^{35}S d) ^{39}K e) $^{35}Ca^{+}$

2. The principal ingredient listed for chocolate bars is sugars, typically about 47% of milk chocolate bars. If these sugars are represented by sucrose, $C_{12}H_{22}O_{11}$, how many sugar molecules are in a 43 g chocolate bar?

   a) 9.8×10^{26} b) 1.6×10^{23} c) 7.8×10^{22} d) 3.6×10^{22} e) 6.0×10^{23}

3. The correct formula for aluminium nitrate is:

   a) $AlNO_3$ b) Al_3NO_3 c) $Al_2(NO_3)_3$ d) $Al(NO_3)_2$ e) $Al(NO_3)_3$

4. An 0.5000 g sample of magnetite ore (impure Fe_3O_4) is treated so that the iron is precipitated as iron(III) hydroxide. The precipitate is heated and converted to 0.4980 g Fe_2O_3. What is the percent Fe_3O_4 in the ore?

   a) 69.0% b) 96.3% c) 99.6% d) 35.0% e) 48.1%

5. Which one of the following tests *specifically* indicates the presence of an *acid* in an aqueous solution?

   a) Red litmus paper remains red when a drop of the solution is added.

   b) Bubbles of gas are given off when the solution is added to a calcium carbonate solution.

   c) The solution conducts electricity.

   d) The solution is colourless.

   e) The solution turns pink when phenolphthalein is added.

6. The antacid "Milk of Magnesia" is an aqueous slurry of magnesium hydroxide, containing about 80 mg $Mg(OH)_2$ per mL. What volume of gastric juice (stomach acid) which is about 0.17 mol/L HCl can be neutralized by 1 tablespoon (15 mL) of "Milk of Magnesia"?

   a) 7.1 L b) 0.00122 L c) 0.0611 L d) 0.122 L e) 0.242 L

7. A plastic bottle contains 0.60 g of nitrogen, N_2. Another bottle of the same size is filled at the same temperature and pressure with an unknown gas. If the mass of the second gas is 1.52 g, this gas can be:

   a) air b) Cl_2 c) O_2 d) CH_4 e) CO_2

8. A balloon probe is filled with 150 L of helium at ground level where the atmospheric pressure is 102 kPa and the temperature is 30°C. The balloon bursts at an altitude where the temperature is –5°C and the pressure 50 kPa. What is the volume of the balloon just before it bursts?

   a) 270 L b) 346 L c) 51 L d) 65 L e) 83 L

9. In which of the following substances is the bonding the most ionic?

   a) H_2 b) NaBr c) Br_2 d) Na e) HBr

10. Which of the following substances has the lowest normal boiling point?

    a) NH_3 b) H_2O c) HF d) CH_3OH e) CH_4

11. The heats of formation of methane, CH_4, and propane, C_3H_8, are given by the equations:

    $C(s) + 2\ H_2(g) \rightarrow CH_4(g)$ $\Delta H = -74.9$ kJ

    $3\ C(s) + 4\ H_2(g) \rightarrow C_3H_8(g)$ $\Delta H = -103.8$ kJ

    What is the heat of reaction for the transformation of 3 mol methane into 1 mol propane: $3\ CH_4(g) \rightarrow C_3H_8(g) + 2\ H_2(g)$?

    a) -178.7 kJ b) -328.5 kJ c) +120.9 kJ d) +28.9 kJ e) -28.9 kJ

12. A solution containing 12.0% sodium hydroxide by mass has a density of 1.131 g/mL. What volume of this solution contains 5.00 mol of NaOH?

    a) 0.0240 L b) 1.67 L c) 1.47 L d) 1.00 L e) 0.177 L

13. As the temperature of a solution increases:

    a) the solubilities of most solids increase and those of gases do not vary

    b) the solubilities of most solids decrease and those of gases decrease

    c) the solubilities of most solids decrease and those of gases increase

    d) the solubilities of most solids increase and those of gases decrease

    e) the solubilities of most solids increase and those of gases increase

14. Which one of the following compounds is an alcohol?

a) $CH_3—CO—CH_3$ b) $CH_3—\overset{\overset{H}{|}}{C}=O$ c) $CH_3—OH$ d) CH_4 e) $CH_3—COOH$

15. Which one of the following classes of molecules, important in biology, contains nitrogen?

a) fatty acids b) carbohydrates c) proteins d) sugars e) fats

16. Which of the following metals is protected by an almost impenetrable surface oxide coating?

a) Ag b) Al c) Au d) Fe e) Cu

17. The decomposition of nitrosyl chloride is described by the equation:

$$2\ NOCl(g) \rightarrow 2\ NO(g) + Cl_2(g)$$

A round flask initially contains pure NOCl gas at 400 K and a pressure of 2.75 atm. When equilibrium is reached, the total pressure equals 3.58 atm. What is the value of the equilibrium constant K_P?

a) 0.36 atm b) 0.16 atm c) 0.045 atm d) 1.93 atm e) 1.26 atm

18. The Mond process for the refining of nickel involves the exothermic reaction

$$Ni(s) + 4\ CO(g) \rightarrow Ni(CO)_4(g)$$

If this reaction is at equilibrium at 200°C, which one of the following operations does not result in a net reaction?

a) addition of CO b) addition of $Ni(CO)_4$ c) heating to 250°C

d) reducing the volume e) addition of Ni

19. Nitrous acid, HNO_2, is a weak monoprotic acid in aqueous solution whose acid equilibrium constant $K_a = 4.5 \times 10^{-4}$ at 25°C. Its conjugate base is the nitrite ion, NO_2^-, is expected to be:

a) unreactive with acids b) a strong base

c) a stronger base than hydroxide ion, OH^-

d) a weak base e) a weaker base than water

20. At 50°C the ion product of water has the value $K_w = 5.5 \times 10^{-14}\ mol^2\ L^{-2}$. What is the pH of a neutral aqueous solution at 50°C?

a) 7.00 b) 13.26 c) 2.3×10^{-7} d) 1.0×10^{-7} e) 6.63

21. In which one of the following molecules are the atoms not all in one plane?

a) CH_4 b) C_2H_4 c) C_6H_6 d) H_2O e) H_2CO

22. Codeine is a derivative of morphine used as an analgesic, formerly used in over-the-counter cough syrups but now only available by prescription because it is addictive. Codeine is a weak monoprotic base of formula $C_{18}H_{21}NO_3$ and basicity constant $K_b = 8.9 \times 10^{-7}$. Estimate the pH of a solution containing 10.0 mg of codeine dissolved in 20.0 mL of water.

a) 10.24 b) 9.59 c) 7.95 d) 6.05 e) 4.41

23. Which one of the following statements about catalytic reactions is correct?

a) The activation energy of the catalytic reaction is smaller than that of the non-catalytic reaction.

b) The activation energy of the catalytic reaction is larger than that of the non-catalytic reaction.

c) Either the reactants or the products of the catalytic reaction are different than those of the non-catalytic reaction.

d) The heat of reaction of the catalytic reaction is smaller than that of the non-catalytic reaction.

e) The heat of reaction of the catalytic reaction is larger than that of the non-catalytic reaction.

24. The mechanism for the thermal decomposition of ozone (with no catalyst) in an excess of oxygen is believed to be:

$$O_3 \rightleftharpoons O_2 + O \qquad \text{(fast equilibrium)}$$

$$O + O_3 \longrightarrow 2\,O_2 \qquad \text{(slow)}$$

What is the rate law according to this mechanism?

a) rate = $k[O_3]^2/[O_2]$ b) rate = $k[O_2][O]/[O_3]$ c) rate = $k[O_3]/[O_2][O]$

d) rate = $k[O_3]$ e) rate = $k[O_3]^2$

25. Which one of the following statements is correct for an electrochemical cell in which the reaction $2\,Al + 3\,Co^{2+} \rightarrow 2\,Al^{2+} + 3\,Co$ takes place?

a) The mass of the cobalt electrode decreases b) Co(s) is the anode

c) $Al^{3+}(aq)$ is the oxidizing agent

d) $Co^{2+}(aq) + 2\,e^- \rightarrow Co(s)$ represents the reduction reaction

e) $Co^{2+}(aq)$ is the reducing agent

NATIONAL HIGH SCHOOL CHEMISTRY EXAMINATION (1998)

PART B - ESSAY QUESTIONS (Choose 2)

Answer TWO questions only in the form of scientific essays including any appropriate equations, formulas and diagrams. Each question is of equal value. The judging of the essays will be based on both factual accuracy and presentation. A clear, concise and well-organized essay will be rated higher than a long rambling one which contains the same information.

1. The year 1997 saw major new developments in the petroleum industry off the east coast of Canada. The first crude oil was pumped from the Hibernia oil field and development of the Sable Island gas field was approved.

   List and give structures for some important molecules found in crude oil and natural gas. Describe the overall processes used to convert crude oil or natural gas into useful fuels, and comment on the removal of unwanted impurities from the crude materials. Discuss the chemistry of burning oil and gas, and the correct stoichiometry for efficient combustion. Explain how carbon monoxide can be produced by incorrect combustion of hydrocarbon fuels, and why nitrogen oxides are significant byproducts of diesel engines. Mention possible environmental effects of these compounds.

2. Water is a liquid with many exceptional properties. Compare the properties of water with those of other liquids. Explain these properties with reference to the structure of water molecules and the forces between these molecules. Give examples of the importance of the properties of water in chemistry and in biology.

3. In recent years, several new forms of elemental carbon have been discovered. Describe the structures and compare the properties of the various forms of carbon, both old and new.

INTERNATIONAL CHEMISTRY OLYMPIAD and CHEMICAL INSTITUTE OF CANADA

Final Selection Examination 1998

PART C: Free Response Development Problems 60% Time: 1.5 hours

This segment has six (6) questions. A normal requirement is that a student attempt **only** 4 questions for a complete examination in 1.5 hours. Each of the 4 questions you select is worth 15%.

Your answers are to be written on the paper provided by your test supervisor. Be sure to number each question attempted clearly and place your name on the top of the page. This cover page is to be stapled securely to your answers.

1. Among the tests that are carried out to evaluate the air quality of polluted sites is the determination of the concentration of carbon dioxide, CO_2, in air. This analysis involves the passage of a given volume of air through lime-water [an aqueous suspension of $Ca(OH)_2$], so that all the CO_2 present is precipitated as calcium carbonate, $CaCO_3$.

   a) A 10.0-L sample of polluted air at a temperature of 25.0°C and atmospheric pressure of 98.66 kPa was treated by this method and 0.0650 g of $CaCO_3$ were obtained. Calculate the percentage by volume of CO_2 in the air sample.

      The acidity of natural waters is influenced by gas absorption. On sites where the quantities of nitrogen and sulfur oxides are negligible, the most important gas having an effect on water acidity is carbon dioxide. It is the case for the polluted site mentioned in (a).

   b) From the data given in (a), and assuming that equilibrium has been reached between gaseous and aqueous CO_2, calculate the pH of the water in a lake that is located on the polluted site. Appropriate constants at 25°C are:

      $K_H(CO_2) = 3.35 \times 10^{-4}$ mol L^{-1} kPa^{-1} (Henry's Law constant for CO_2)

      $K_b(HCO_3^-) = 2.24 \times 10^{-8}$,

      $K_b(CO_3^{2-}) = 2.14 \times 10^{-4}$.

2. a) Silver chloride, AgCl, is sparingly soluble in water; its solubility product constant, K_{sp}, has the value: $K_{sp} = 1.8 \times 10^{-10}$ mol^2 L^{-2}.

   i) Calculate the solubility of silver chloride in water.

   ii) Would you expect the solubility of silver chloride in an aqueous solution of sodium chloride, NaCl, to be larger or smaller than in water? Briefly explain your answer; including chemical equations, if useful.

   iii) Would you expect the solubility of silver chloride in an aqueous solution of ammonia, NH_3(aq), to be larger or smaller than in water? Briefly explain your answer; including chemical equations, if useful.

   b) The standard molar (Gibbs) free energies of formation at 25°C are:

solid silver sulfate, Ag_2SO_4(s)	$\Delta G^o_f = -618.5$ kJ mol^{-1}
solid silver chloride, AgCl (s)	$\Delta G^o_f = -109.8$ kJ mol^{-1}
aqueous chloride ion, Cl^- (aq)	$\Delta G^o_f = -132.3$ kJ mol^{-1}
aqueous sulfate ion, SO_4^{2-} (aq)	$\Delta G^o_f = -744.6$ kJ mol^{-1}

   From the information in this question, determine the solubility product for silver sulfate, Ag_2SO_4, at 25°C.

3. A 2.00-L flask contains a gas, A_2, at 0.100 kPa and 300 K. The reaction

$$A_2(g) + h\nu \rightarrow 2\,A(g)$$

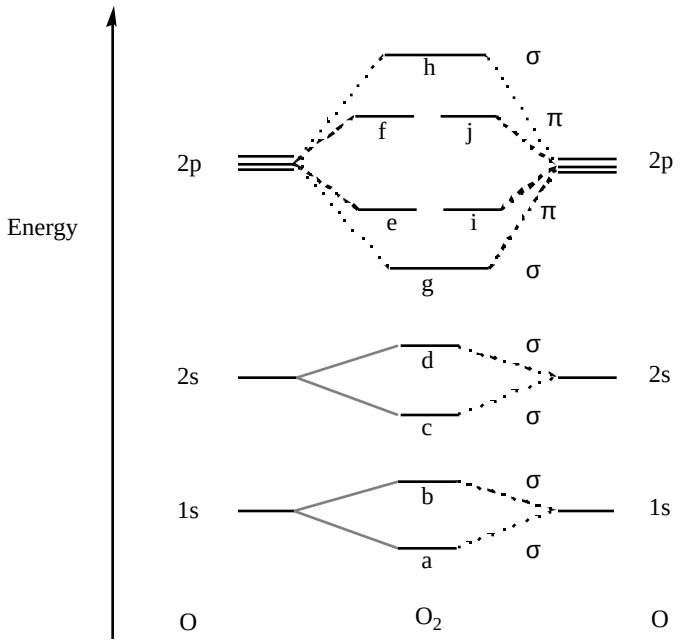
   is performed photochemically with a UV radiation of 200 nm. Each molecule of A_2 will react after absorption of one photon.

   a) Assuming that 10^{15} photons are absorbed per second, calculate the rate of the reaction.

   b) Calculate the half-life of the reaction.

   c) Variation of the concentration of A with time can be followed via the UV-VIS absorption of A at 400 nm in a gas cell with a path length of 10.0 cm. If the absorption is of 0.182 after 3.00 hours, calculate the molar extinction coefficient (molar absorptivity) of A.

4. The molecular orbital energy-level diagram illustrated below may be used for dioxygen and difluorine, but not the other diatomic molecules (B_2, C_2, N_2) in this same row of the periodic table. In fact, for B_2, C_2, N_2, the 2p atomic orbitals give rise to π bonding molecular orbitals which are of lower energy than the σ bonding molecular orbital.



a) Write the ground-state electron configuration for an oxygen atom.

b) Write the ground-state electron configuration for a dioxygen molecule.

c) Why do orbitals labelled as "e" and "i" have the same energy?

d) Use the molecular orbital energy-level diagram to determine the bond order of dioxygen and difluorine.

e) State if dioxygen and difluorine are diamagnetic or paramagnetic molecules.

f) How does the fact that B_2 is paramagnetic prove that the molecular orbital energy-level diagram for dioxygen is not correct for the B_2 diatomic species?

g) Using these energy level diagrams, what is the bond order for each of the diatomic CN, NN, and NO molecules?

h) Which of CN, N_2, and NO has the highest IE (ionization energy)? Which has the lowest IE?

[IE(X) = $\Delta H^{o}_{f}(X^{+}) - \Delta H^{o}_{f}(X)$]

5. a) Draw a structure for the organic compound 2-chloro-3-methylhex-3-ene.

   b) Indicate the hybridization of carbon 2 and carbon 3.

   c) Give the approximate bond angles at carbon 2 and carbon 3.

   d) Give the total number of carbon-carbon sigma (σ) bonds in the molecule.

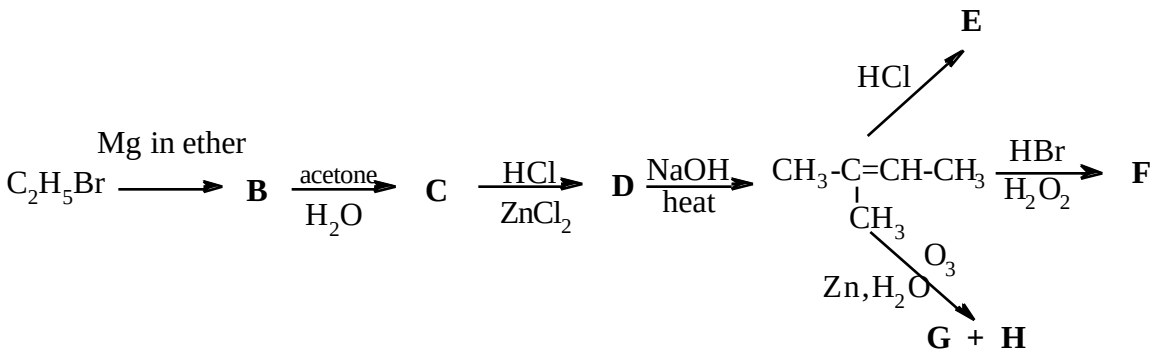
   e) Give the total number of pi (π) bonds in the molecule.

   f) How many asymmetric centres are there in the molecule?

   g) How many stereoisomers exist for this molecule?

   h) Draw a three dimensional representation of each of the stereoisomers and indicate the appropriate stereochemistry using the labels R, S, E, and Z.

6. Give the structures of the compounds **B, C, D, E, F, G, and H** involved in the reactions below.



(End of Part C Examination)