1999 NATIONAL CHEMISTRY EXAMINATION

CIC National High School Chemistry Examination
CCO National Selection Examination

PART A: MULTIPLE CHOICE QUESTIONS (60 minutes)

1. Which two atoms have the same number of neutrons?
   a) ^{24}Na and ^{24}Mg b) ^{14}C and ^{14}N c) ^{23}Na and ^{24}Mg
   d) ^{12}C and ^{14}C e) ^{12}C and ^{14}N

2. The element rubidium (Rb) has two naturally occurring isotopes of mass 84.91 and 86.91. The natural abundance of the lighter isotope (^{85}Rb) is:
   a) 23.5% b) 76.5% c) 50% d) 28% e) 72%

3. What is the oxidation state of chromium in the chromate ion (CrO_4^{2-})?
   a) +8 b) +6 c) +4 d) +2 e) 0

4. The explosive trinitrotoluene (TNT) can be made by the (unbalanced) chemical reaction $C_7H_8 + HNO_3 \rightarrow C_7H_5N_3O_6 + H_2O$. What mass of nitric acid (HNO_3) is needed to react with 276 g of toluene (C_7H_8)?
   a) 828 g b) 566 g c) 63 g d) 189 g e) 126 g

5. What volume of HCl 0.100 mol/L is required to neutralize a solution containing 92.6 mg of $Ca(OH)_2$?
   a) 32.5 mL b) 12.5 mL c) 50.0 mL d) 25.0 mL e) 16.2 mL

6. The formula for aspirin (acetylsalicylic acid) is $C_9H_8O_4$. How much dioxygen is required for total combustion of 1 mole of aspirin to carbon dioxide and water?
   a) 9 mol O_2 b) 18 mol O_2 c) 22 mol O_2 d) 11 mol O_2 e) 7 mol O_2

7. Which one of the following represents an **excited state** electron configuration for a magnesium atom?
   a) $1s^2 2s^2 2p^6 3s^2 3p^1$ b) $1s^2 2s^2 2p^6$ c) $1s^2 2s^2 2p^6 3s^1 3p^1$
   d) $1s^2 2s^2 2p^6 3s^1$ e) $1s^2 2s^2 2p^6 3s^2$

8. Which one of the following molecules contains a pair of atoms which share six electrons?
   a) C_2H_6 b) CO_2 c) C_2H_2 d) C_6H_6 e) C_2H_4

9. Consider the two gases H_2 and CO_2 at 0°C. According to the kinetic theory of gases:
   a) the molecules of both gases have zero kinetic energy at 0°C
   b) the molecules of each gas have the same average speed at 0°C
   c) all the molecules of both gases have the same speed at 0°C
   d) the molecules of each gas have the same average kinetic energy at 0°C
   e) all the molecules of both gases have the same kinetic energy at 0°C

10. A mixture of gases contains equal masses of He, H_2, O_2 and CH_4. If the partial pressure of CH_4 is 120 kPa, what is the partial pressure of O_2?
    a) 480 kPa b) 30 kPa c) 120 kPa d) 60 kPa e) 240 kPa

11. Which one of the following elements has the largest atomic radius?
    a) As b) Br c) P d) S e) Se

12. What is the shape of the ammonia molecule (NH_3)?
    a) linear b) square c) H--N--H (angles 90 deg)
    d) a pyramid with a triangular base |
    e) a planar triangle with N at the centre H

13. Which metal is extracted in large quantities in Canada from imported ore because of the availability of cheap hydroelectric power?
    a) Ni b) Au c) Cu d) Al e) Fe

14. The combustion of 1 mole of propane (C_3H_8) to CO_2 and liquid water liberates 2220 kJ of heat. If the heat of vaporisation of water is 44 kJ/mol, how much heat is given off by the combustion of 1 mole of propane to CO_2 and water vapour?
a) 1868 kJ b) 2044 kJ c) 2264 kJ d) 2176 kJ e) 2396 kJ

15. A "concentrated" aqueous solution of HCl is 37% HCl by weight and has a density of 1.19 g/mL. What is the concentration of HCl in this solution?
a) 16.1 mol/L b) 12.1 mol/L c) 32.6 mol/L d) 9.1 mol/L e) 10.2 mol/L

16. Which one of the following compounds forms an acid solution in water?
a) CH_3CH_2COOH b) $CH_3CH_2NH_2$ c) CH_3CH_2OH
d) $CH_3CH_2CH_3$ e) CH_3OCH_3

17. If the equilibrium constant of the reaction A → B is less than one, then at equilibrium:
a) the concentration of product B exceeds the concentration of reactant A.
b) the rate of the forward reaction exceeds that of the reverse reaction.
c) the rate of the reverse reaction exceeds that of the forward reaction.
d) the concentration of product B equals the concentration of reactant A.
e) the concentration of reactant A exceeds the concentration of product B.

18. For the reaction $2\ S(s) + 3\ O_2(g) \rightarrow 2\ SO_3(g)$, which combination of equilibrium concentrations is equal to the equilibrium constant K_c?

a) $\frac{[S]^2[O_2]^3}{[SO_3]^2}$ b) $\frac{[O_2]^3}{[SO_3]^2}$ c) $\frac{[SO_3]^2}{[S]^2[O_2]^3}$ d) $\frac{[SO_3]}{[S][O_2]}$ e) $\frac{[SO_3]^2}{[O_2]^3}$

19. For the equilibrium $H_2(g) + I_2(g)$ æ $2\ HI(g)$ at 200°C, $\Delta H = -9.5$ kJ. What would be the effect of increasing the temperature further?
a) the equilibrium constant (K_{eq}) of the reaction would increase
b) the concentration of HI would increase
c) the concentration of I_2 would increase
d) there would be no effect on the equilibrium
e) the concentration of H_2 would decrease

20. Which one of the following chlorine-containing compounds has been identified as a menace to the protective ozone layer in the stratosphere?
a) DDT ($C_{14}H_9Cl_5$) b) CF_2Cl_2 c) HCl d) $HClO_4$ e) NaCl

21. Nitrous acid (HNO_2) is a weak acid for which $K_a = 4.0 \times 10^{-4}$ mol/L? What is the concentration of un-ionized HNO_2 in a solution whose pH is 2.0?
a) 0.025 mol/L b) 0.0063 mol/L c) 0.25 mol/L
d) 0.0025 mol/L e) 4×10^{-8} mol/L

22. In aqueous solution the ion Fe^{3+} is surrounded by six molecules of water to form the hydrated ion $Fe(H_2O)_6^{3+}$. If this hydrated ion is a weak acid, what is its conjugate base?
a) $Fe(H_2O)_5(H_3O)^{3+}$ b) $Fe(H_2O)_5(H_3O)^{4+}$ c) $Fe(H_2O)_5(OH)^{2+}$
d) $Fe(H_2O)_6^{3+}$ e) $Fe(H_2O)_5(OH)^{3+}$

23. The solubility product of silver chromate (Ag_2CrO_4) is 9.0×10^{-12} $mol^3\ L^{-3}$. The solubility of this salt is
a) 1.31×10^{-4} mol/L b) 2.08×10^{-4} mol/L c) 1.5×10^{-6} mol/L
d) 2.12×10^{-6} mol/L e) 3.0×10^{-6} mol/L

24. For the reaction $2\ NO(g) + 2\ H_2(g) \rightarrow N_2(g) + 2\ H_2O(g)$, the following kinetic data were collected at 500°C:

Experiment	Initial [NO]	Initial [H_2]	Initial rate

1	0.10 mol/L	0.20 mol/L	2.6 mol L^{-1} s^{-1}
2	0.10	0.50	6.3
3	0.25	0.20	16.3
4	0.35	0.50	77

The rate law for this reaction is

a) $k[NO][H_2]^2$ b) $k[NO]^2[H_2]^2$ c) $k[NO][H_2]$

d) $k[NO]^2[H_2]$ e) $k[NO]^2$

25. If an oxidation-reduction reaction is described by the equation

$Cu + 2\ Ag^+ \rightarrow Cu^{2+} + 2\ Ag$ what is the equation for the oxidation half-reaction?

a) $Cu^{2+} + 2e^- \rightarrow Cu$ b) $Ag^+ + e^- \rightarrow Ag$ c) $Ag \rightarrow Ag^+ + e^-$

d) $Cu \rightarrow Cu^+ + e^-$ e) $Cu \rightarrow Cu^{2+} + 2e^-$

NATIONAL HIGH SCHOOL CHEMISTRY EXAMINATION (1999)
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. Carbon has a tendency to form polymeric chains such as polyethylene $H-(CH_2)_n-H$, where n can be large. On the other hand, nitrogen does not form $H-(NH)_n-H$ and oxygen does not form $H-(O)_n-H$ chains, where $n > 2$.
   For the case n = 2: Draw Lewis diagrams for C,N,O chains. What are the common names of these three molecules? Compare the physical states (gas, liquid or solid) of these substances. In what state are they usually found in a laboratory? Compare the chemical reactivity and stability of the three molecules. Give examples of how each is used commercially.
   For the general case: What do you think causes the difference in tendency to polymerize? Discuss using concepts of bonding and bond energies where appropriate.

2. Sodium hypochlorite is a household reagent which is often used for swimming pool maintenance.
   a) Give the formula of sodium hypochlorite as well as its hydrolysis reaction in water. Explain how this reaction affects the pH of the pool.
   b) Hypochlorite ion undergoes a slow redox reaction in the pool, generating chlorate and chloride ions. What are the oxidation states of the various species in solution? Balance the equation for this reaction in basic solution. What type of redox reaction is this?
   c) In addition to hypochlorite, what other chemicals are commonly used to disinfect pools? How do hypochlorite and these other chemicals kill bacteria?

3. a) How would one measure the rate of a chemical reaction? Choose a specific reaction and describe an experiment to measure its rate.
   b) The dependence of rate on reactant concentration is not always obvious. For example the rate of the gas-phase reaction $NO_2 + CO \rightarrow NO + CO_2$ is given by $v = k[NO_2]^2$ and not $v = k[NO_2][CO]$ as one might expect. Suggest a reason why the first rate law is correct.

c) How does the rate of a chemical reaction vary with temperature? How is the activation energy obtained by studying this variation? Draw an energy diagram which shows the activation energy. Explain the diagram in terms of the molecular changes occurring.

Final Selection Examination 1999 (IChO)
Part C: Free Response Development Problems

1. The equilibrium constant for the reaction of Fe^{3+} and SCN^- to form $FeSCN^{2+}$ is done by examining the absorbance of solutions. The absorbance is known to be directly related to the concentration of the complex $FeSCN^{2+}$ and follows Beer's Law:

   $\log(Po/P) = \varepsilon bC = A$ where *Po* is the radiant power of the incident beam upon the solution containing *C*mol/L of absorber, *P* is the power of the beam after it has traversed *b* cm (usually 1 cm) of solution; and ε is a constant called "molar absorptivity".

   a) One literature source reports that at 580 nm, the wavelength of its maximum absorption, the complex $FeSCN^{2+}$ has a molar absorptivity of 7.00×10^3 L cm^{-1} mol^{-1}. Calculate the absorbance of a 4.00×10^{-5} mol/L solution of this complex at 580 nm when measured in a 1.00-cm cell.

   b) A student was to determine the equilibrium constant for this reaction and followed the procedure outlined, getting the specified results. A standard reference solution was prepared by mixing 18.0 mL of a 0.200 mol/L Fe^{3+} solution with 2.0 mL of 0.0020 mol/L SCN^- The absorbance of this solution was 0.520. Several other solutions were prepared with the same 0.0020 mol/L SCN^- and dilute 0.0020 Fe^{3+} solutions. The data are provide only for #2.

Test Tube Number	$Fe(NO_3)_3$ (mL)	KSCN (mL)	H_2O (mL)	Absorbance A
#2	5.0	2.0	3.0	0.138

   Assuming $[FeSCN^{2+}]$ and absorbance are related directly (Beer's Law), the concentration of $FeSCN^{2+}$ for any equilibrium system can be found by:

   $$[FeSCN^{2+}]_{eq} = \frac{A_{eq}}{A_{std}} \times [FeSCN^{2+}]_{std}$$

   Calculate the equilibrium constant for the reaction under experimental conditions.

   c) For this same reaction the following results have been reported. Briefly account for each result on the basis of equilibrium concepts.
      I) Heat to 65-70°C; red colour decreases.
      ii) Add -0.2 mol/L KSCN; red colour deepens.
      iii) Add 1 mol/L NaOH; red colour changes and it becomes opaque.
      iv) Add 0.1 M NaF; loss of colour and more transparent.

2. A steel-gray, lustrous metal was analyzed by X-ray diffraction. The results of the analysis indicated that this metal crystallizes in a body-centered cubic (bcc) structure and has an estimated atomic radius of 125 pm. The density of the metal was found to be 7.14 g/cm^3.

   a) What is the volume of the bcc unit cell in cm^3?
   b) What is the metal?)
   c) What is the coordination number of each metal atom in this bcc structure?
   d) What type of holes (or interstices) is found in this bcc structure? Give the name and the coordination number of the holes.
   e) Calculate (in cm) the radius of the largest atom that can fit into the holes found in the crystal structure of the metal mentioned in (b).

3. Organometallic complexes are defined as compounds containing at least one carbon-metal bond. A certain organometallic complex contains carbon, hydrogen, and a metal from the first transition (one metal atom per molecule). In a non-protic, complexing solvent like diethylether, this compound dissociates into ions. In a non-polar solvent like benzene, the compound does not dissociate. Below are data obtained from freezing-point depression and boiling-point elevation measurements, and elemental analysis carried out on samples of this compound.
   i) The freezing point (f.p.) of a benzene solution containing 1.514 g of the complex in 36.4 g of solvent is 4.35°C (f.p. of pure benzene: 5.50°C; K_f of benzene: 5.12°C kg mol^{-1}).
   ii) The boiling point (b.p.) of a diethylether solution containing 0.4735 g of the complex in 10.0 g of the solvent is 36.05°C (b.p. of pure diethylether: 34.50°C; K_b of diethylether: 2.02°C kg mol^{-1}).
   iii) Elemental analysis of the complex gives the following results: 64.88%C and 5.45%H.

   a) In how many ions is the complex dissociated when dissolved in the complexing solvent?
   b) Knowing that the metal contained in this complex can show very high oxidation states, what is this metal?
   c) Write the molecular formula of the complex.

4. In the upper atmosphere, ozone is produced from dioxygen: $3\ O_2(g) \rightarrow 2\ O_3(g)$

Thermodynamic data at 25°C	ΔH^o_f /kJ mol^{-1}	ΔG^o_f /kJ mol^{-1}	ΔS^o/J K^{-1} mol^{-1}
$O_2(g)$	-----	-----	205.138
$O_3(g)$	142.7	163.2	239.93

   a) Compute ΔH^o, ΔS^o, and ΔG^o for the production of ozone from dioxygen.
   b) Is there a temperature at which this reaction becomes spontaneous when both dioxygen and ozone are at standard pressure (1.00 atm or 101.3 kPa), i.e., when $K^o = 1$? If so, what is this temperature? If not, explain why one does not exist.
   c) Assume an atmosphere with the partial pressure of dioxygen equal to 0.20 atm (20.26 kPa), i.e., $P(O_2) = 0.20$ atm, and a temperature of 298 K. Below what pressure of ozone will ozone production be spontaneous, *i.e.*, will ΔG be less than zero?
   d) In view of your answers to questions (a) to (c), how can the ozone layer form?

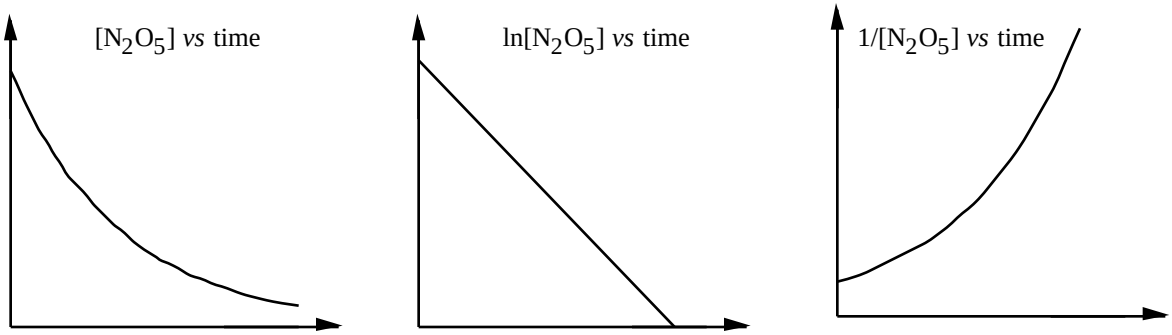
5. `The thermal decomposition of dinitrogen pentoxide was studied in both liquid dibromine (Reaction 1) and in the gas phase (Reaction 2). In each case the reaction proceeds according to the equation:

$$2\ N_2O_5 \rightarrow 4\ NO_2 + O_2$$

For the experiment in liquid dibromine the concentration of N_2O_5 varied with time as follows:

Time /s	0	200	400	600	1000
$[N_2O_5]$ /mol/L	0.110	0.073	0.048	0.032	0.014

Below are the graphs obtained from these data:

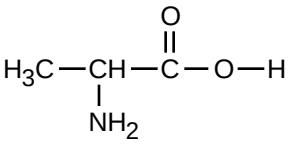


   a) Confirm, by observing the graphs the order of this reaction.
   b) Calculate the rate constant, *k*, for the reaction under these conditions.
   c) In the gas phase, the first-order decomposition of N_2O_5 was found to have a rate constant of 4.8×10^{-4} s^{-1}. Calculate the half-life of this reaction.

d) If the initial pressure of $N_2O_5(g)$ was 66.75 kPa in the gas phase reaction, what is the total pressure of the system after 10 minutes?

e) The rate constant for the gas phase decomposition of N_2O_5 differs from that of the decomposition in liquid dibromine. Coment on the difference in activation energy for the two processes.

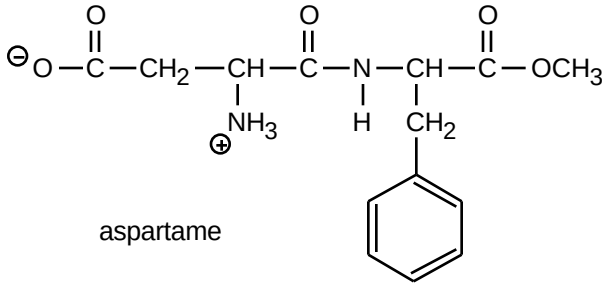
6. a) Given that the pK_a of ethanoic acid (CH_3CO_2H) is *ca.* 4.8 and the pK_b of methylamine (CH_3NH_2) is *ca.* 3.4, draw the dominant form of the amino acid alanine as it exists at:(3 marks)



alanine

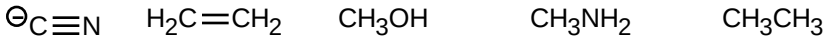
i) pH *ca.* 1
ii) pH *ca.* 6
iii) pH *ca.* 12

b) The artificial sweetener aspartame (sold under the trade name Equal) is a modified dipeptide. Aqueous acid hydrolysis of aspartame yields methanol (CH_3OH) along with two amino acids. Draw the structures of these two amino acid hydrolysis products.

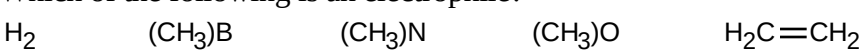


aspartame

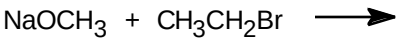
c) i) Which of the following is NOT a nucleophile?

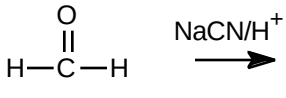


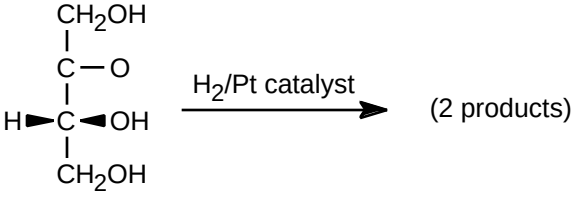
ii) Which of the following is an electrophile?



d) Draw the structures of the products of the following reactions.
Circle any of the products which will be optically active.

i) 

ii) 

iii) 

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