IONA PRESENTATION COLLEGE

Year 12 Chemistry

Semester One Examination, 2004

Student Name : _____

TIME ALLOWED FOR THIS PAPER

Reading time before commencing work: Ten minutes

Working time for paper: Three hours

MATERIAL REQUIRED/RECOMMENDED FOR THIS PAPER

TO BE PROVIDED BY THE SUPERVISOR

This Question Paper/Answer Booklet
Separate Multiple Choice Answer Sheet
Chemistry/Data Sheet (inside front cover of this Question/Answer booklet)

TO BE PROVIDED BY THE CANDIDATE

Standard Items: Pens, pencils, eraser or correction fluid, ruler
Special Items: Calculators satisfying the conditions set by the Curriculum Council and a 2B, B or HB
                pencil for the separate Multiple Choice Answer Sheet.

IMPORTANT NOTE TO CANDIDATES

It is your responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor BEFORE reading any further.

STRUCTURE OF THIS PAPER

Part	Format	No. of Questions Set	No. of Questions to be Attempted	Marks Allocated	Recommended Time (Approx) /Minutes
1.	Multiple choice	30	ALL	60 (30%)	55
2.	Short answers	11	ALL	70 (35%)	60
3.	Calculations	5	ALL	50 (25%)	45
4.	Extended answers	2	1	20 (10%)	20

Total marks for paper = 200 (100%)

INSTRUCTIONS TO CANDIDATES

Reading Time: The examiners recommend that candidates spend the reading time mainly reading the Instructions to Candidates and Parts 2, 3 and 4.

Part 1 — Multiple Choice

Answer **ALL** questions, using a pen, on the separate Multiple Choice Answer Sheet.

If you consider that two or more of the alternative responses are correct, choose the one you think is best. If you think you know an answer, mark it even if you are not certain you are correct. Marks will **not** be deducted for incorrect answers.

FEEL FREE TO WRITE OR DO WORKING ON THE QUESTION PAPER; many students who score high marks in the Multiple Choice Section do this.

Parts 2, 3 and 4

Use a ballpoint or ink pen. **Do not** answer in pencil. Write your answers in this Question/Answer Booklet.

Questions containing specific instructions to show working should be answered with a complete, logical, clear sequence of reasoning showing how the final answer was arrived at; correct answers which do not show working will not be awarded full marks.

CHEMICAL EQUATIONS

For full marks, chemical equations should refer only to those species consumed in the reaction and the new species produced. These species may be **ions** [for example $Ag^+(aq)$], **molecules** [for example $NH_3(g)$, $NH_3(aq)$, $CH_3COOH(l)$, $CH_3COOH(aq)$] or **solids** [for example $BaSO_4(s)$, $Cu(s)$, $Na_2CO_3(s)$].

SEE NEXT PAGE

PART 1 – MULTIPLE CHOICE

(60 marks = 30% of the total)
Answer **ALL** questions in Part 1 on the Separate Multiple Choice Answer Sheet provided.

1.   Which of the following physical properties best suggests that a particular substance being examined is a covalent molecular solid?

(a)   It fractures easily to form thin plates
(b)   It does not conduct electricity
(c)   It dissolves in water
(d)   It melts at 56 ^{0}C

2.   Which of the following is the ground state electronic configuration of the sulfide ion?

(a) $1s^2, 2s^2, 2p^6, 3s^2, 3p^6$
(b) $1s^2, 2s^2, 2p^6, 3s^2, 3p^8$
(c) $1s^2, 2s^2, 2p^6, 3s^2, 3p^4$
(d) $1s^2, 2s^2, 2p^6, 3s^2, 3p^2$

3.   When 1.0 mol L^{-1} solutions of the following are mixed, which combinations will result in the formation of precipitates.

        1) Ba(NO$_3$)$_2$ and H*Cl*
        2) Ca(NO$_3$)$_2$ and Na$_2$CO$_3$
        3) Cu(NO$_3$)$_2$ and CsOH
        4) Pb(NO$_3$)$_2$ and H$_2$SO$_4$

(a)   1. 2 and 3 only
(b)   3 only
(c)   3 and 4
(d)   nd 4 only

4.   Consid   elements labelled V to Z on the diagram below. Which pair of these is most likely to form a   ent compound?
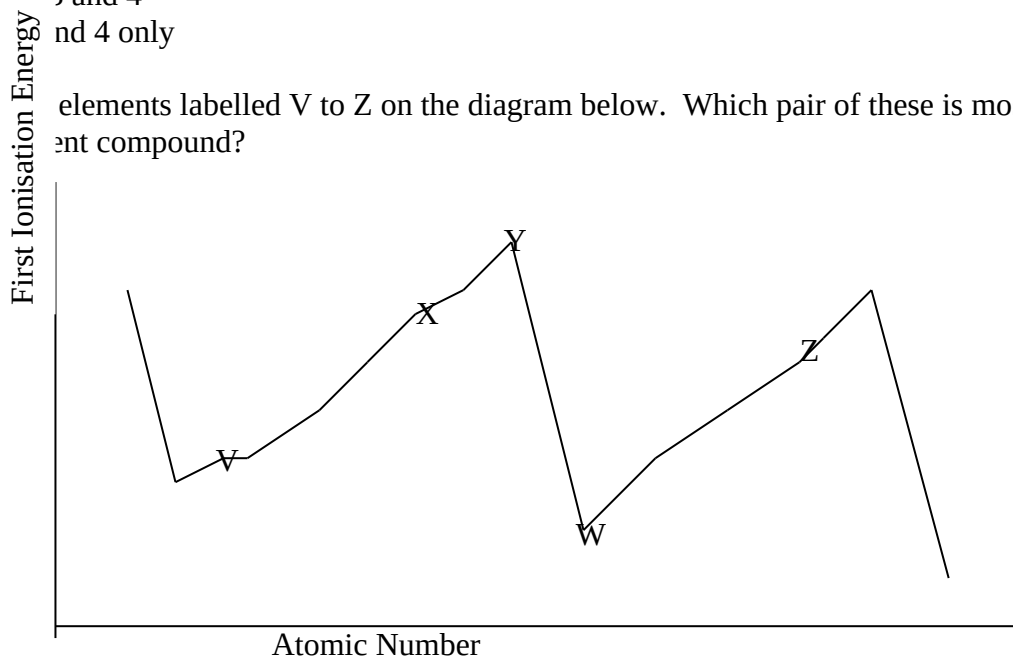

(a) X and Y   (c)   X and Z
(b) X and V   (d)   W and V

SEE NEXT PAGE

5. Which of the following has non-polar molecules?

   (a) SF_2
   (b) SO_2
   (c) CO_2
   (d) H_2S

6. Which of the following statements is the best description of a single covalent chemical bond

   (a) It is the overlapping of two electron-filled orbitals.
   (b) It is the simultaneous attraction between a pair of electrons and two nuclei
   (c) It is the attraction between the outer electrons of one atom and those of another atom.
   (d) It is the transfer of electrons from a highly electropositive element to a highly electronegative element.

7. Which of the following practices will lead to an error when titrating a solution of sodium hydroxide with dilute hydrochloric acid?

   (a) Washing the burette with distilled water, then with a little of the acid and then filling it with the acid.
   (b) Always reading to the bottom of the meniscus in the burette.
   (c) Washing the pipette with distilled water and then using it to dispense the sodium hydroxide solution.
   (d) Washing down the sides of the conical flask with distilled water during the titration.

8. The oxidation of sulfur dioxide to sulfur trioxide is an exothermic reaction which may reach a state of equilibrium as represented by:

   $$2SO_2(g) + O_2(g) \leftrightarrow 2SO_3(g)$$

   Which of the following changes will increase the equilibrium concentration of sulfur trioxide?

   (a) Increasing the temperature of the reaction mixture
   (b) Using a suitable catalyst
   (c) Increasing the pressure in the reaction vessel by decreasing its volume
   (d) Reducing the pressure of the oxygen gas.

9. In which of the following substances would you expect the bonding to be most ionic?

   (a) Solid ammonia
   (b) Solid lead bromide
   (c) Solid silicon dioxide
   (d) Hydrogen chloride gas

10. Which one of the following has linear molecules at 25^0C?

   (a) CS_2
   (b) $CaCl_2$
   (c) SiO_2
   (d) SCl_2

SEE NEXT PAGE

11.   Which one of the following statements about the following reversible reaction is TRUE?

$$3H_2 (g) + N_2(g) \leftrightarrow 2 NH_3(g)$$
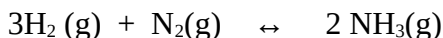
(Equilibrium constant = K. Heat of reaction = ΔH)

(a) $K = \dfrac{[H_2]^3[N_2]}{[NH_3]^2}$

(b)   K is constant under all conditions

(c)   A catalyst increases the yield of ammonia by increasing ΔH.
(d)   Ammonia is being formed when the gases are at equilibrium.

12.   For the chemical reaction:

$$A(aq) + B(s) \rightarrow C(g) + D(aq) \qquad \Delta H = -50 \text{ Kj mol-1}$$

Which one of the following actions would increase the rate of the reaction?

(a)   Using the same mass of B, but in larger lumps.
(b)   Increasing the pressure inside the reaction vessel.
(c)   Heating the reaction mixture.
(d)   Increasing the volume of the reaction mixture.

13.   In which one of the following pairs do both atoms contain valence-shell electrons in d sublevels?

(a)   Sn and Fe
(b)   S and Al
(c)   Cs and In
(d)   Cu and Fe

14.   Which one of the following, in the solid state, has a crystal structure which contains discrete molecules?

(a)   Magnesium chloride
(b)   Hydrogen chloride
(c)   Iron(II) chloride
(d)   Aluminium oxide.

15.   Which of the following represents the most common cation of Gallium (atomic number 31)?

(a) Ga^{5+}
(b) Ga^{3+}
(c) Ga^{3-}
(d) Ga^{2+}

SEE NEXT PAGE

16.   Consider the reaction:

$$2NO(g) + O_2(g) \leftrightarrow 2NO_2(g)$$
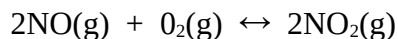
Increasing the pressure of this system by halving the volume causes the rate of the reaction to increase. Which of the following statements best explains this observation?

(a)   The volume of the reactants is greater than that of the products.
(b)   The number of reactant molecules with energies greater than the activation energy for the reaction will increase.
(c)   The particles will collide more often.
(d)   The average kinetic energy of the reactant molecules will increase.

17.   Which of the following elements is the most electronegative?

(a)   Na
(b)   S
(c)   Cl
(d)   I

18.   Below is the potential energy diagram for the reaction:

$$A(g) + B(g) \rightarrow AB(g)$$

Reaction Progress
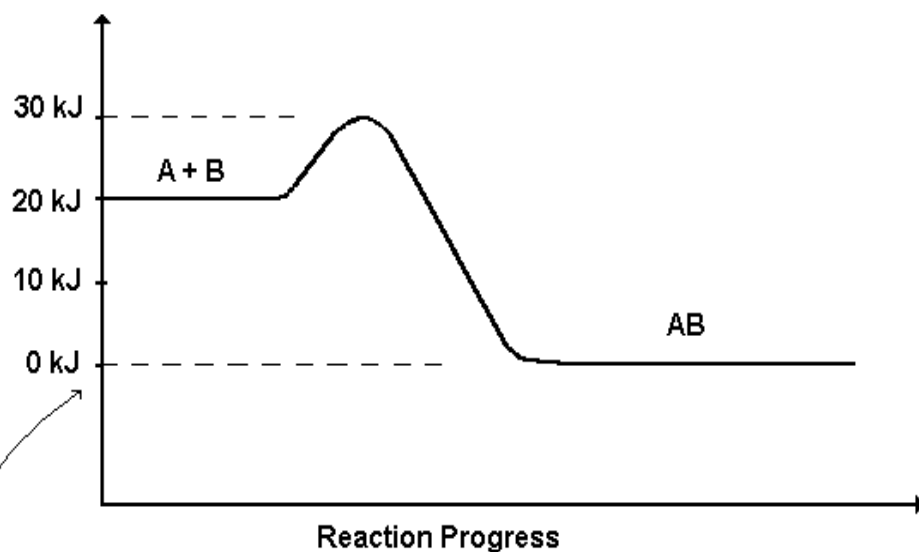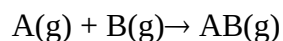
This energy level is arbitrarily assigned a value of 0 kJ.

Which one of the following statements is TRUE?

(a) ΔH for this reaction is 20 kJ.
(b) ΔH for this reaction is -20 kJ.
(c) ΔH for this reaction is -30 kJ.
(d)   The activation energy for this reaction is 30 kJ.

SEE NEXT PAGE

19.   Which one of the following CANNOT be a typical property of vanadium (atomic number 23)

       (a)   Vanadium might form more than one oxide.
       (b)   The element vanadium might be a strong oxidising agent.
       (c)   Vanadium might form complex ions.
       (d)   Vanadium might form blue ions.

20.   A common experiment used in the laboratory to demonstrate chemical equilibrium involves the
       chromate/dichromate equilibrium. This can be represented by the equation:

              $2CrO_4^{2-} (aq) + 2H^+(aq) \leftrightarrow Cr_2O_7^{2-} (aq) + 2H_2O(l)$
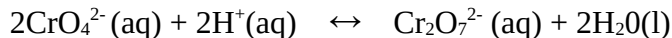
       If 2 g of sodium dichromate is dissolved in 100 mL of distilled water, which one of the following
       actions will increase the concentration of the chromate ion in the mixture?

       (a)   Adding 100 mL of distilled water to the mixture.
       (b)   Adding a solution of sodium hydroxide to the mixture.
       (c)   Adding dilute sulfuric acid to the mixture.
       (d)   Gently stirring the mixture.

21.   Arrange F_2, HF and LiF in order so that their bonds have increasing ionic character.

       (a)   HF F_2 LiF
       (b) F_2 LiF   HF
       (c)   LiF F_2 HF
       (d) F_2 HF   LiF

22.   Sodium chloride NaCl melts at 801^0C and cyclohexane C_6H_{12} melts at 66^0C. Such evidence supports
       the hypothesis that:

       (a)   ionic bonds are much stronger than dispersion forces.
       (b)   ionic bonds are much stronger than covalent bonds.
       (c)   the melting of sodium chloride involves the conversion of ionic bonds to covalent bonds.
       (d)   the melting of cyclohexane involves the conversion of covalent bonds to hydrogen bonds.

23.   Which of the following best describes the molecular shape and molecular polarity in the CH$_3$Cl
       molecule?

       (a)   Pyramidal, non polar
       (b)   Pyramidal, polar
       (c)   Tetrahedral, polar
       (d)   Tetrahedral, non polar

24.   Which one of the following is TRUE?

       (a)   Both CO_2 and SO_2 are polar, with CO_2 more polar.
       (b)   Neither molecule is polar.
       (c) CO_2 is polar, but SO_2 is not.
       (d) SO_2 is polar, but CO_2 is not.

SEE NEXT PAGE

25.   For the reaction: $A(g) + B(s) \leftrightarrow C(s) + D(g)$ $\Delta H = X$ kJmol^{-1}

Which of the following statements is FALSE?

   (a)   Increasing the pressure of A will increase the reaction rate.
   (b)   Adding a suitable catalyst will increase the rate of production of substance C.
   (c)   Continuous removal of gas D could prevent an equilibrium situation being created.
   (d)   Increasing the temperature will speed up the reaction only if X is positive.

26.   Which expression gives the equilibrium constant, K, for the following reaction **in the gas phase**.

$$2H_{2\,(g)} + O_{2(g)} \leftrightarrow 2H_2O_{(g)}$$
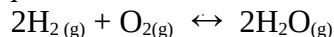
   (a) $K = \dfrac{[H_2O]^2}{[H_2]^2[O_2]}$ (c) $K = [H_2]^2[O_2]$

   (b) $K = \dfrac{1}{[2H_2]^2[O_2]}$ (d) $K = \dfrac{[2H_2O]^2}{[2H_2]^2[O_2]}$

27.   An element has the first five successive ionisation energies
       0.6   1.8   2.8   11.6   14.8   MJ mol-1
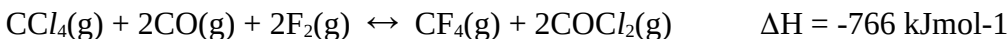
   Which one of the following is it?

   (a)   aluminium   (c)   calcium
   (b)   argon   (d)   carbon

28.   Each of the following examples is a set of three water-solutions. In which one of the sets could all
       three solutions be distinguished from one another by colour alone?

   (a)   calcium chloride, mercury (II) nitrate, potassium chromate.
   (b)   cobalt nitrate, cobalt sulfate, sodium carbonate.
   (c)   copper (II) sulfate, silver nitrate, zinc nitrate.
   (d)   nickel sulfate, potassium dichromate, zinc chloride.

Questions 29 and 30 refer to the following reaction:

   $CCl_4(g) + 2CO(g) + 2F_2(g) \leftrightarrow CF_4(g) + 2COCl_2(g)$ $\Delta H = $ -766 kJmol-1

29.   When the system has reached equilibrium which one of the following statements is TRUE?

   (a)   The number of moles of CCl_4 must equal the number of moles of CF_4.
   (b)   The rate of the forward reaction is greater than the rate of the reverse reaction.
   (c)   The forward reaction and the reverse reaction have stopped.
   (d)   Reaction is continuing but the concentrations of all components remain constant.

30.   Which set of reaction conditions would produce the highest yield of products?

   (a)   High pressure, low temperature.   (c)   Low pressure, low temperature.
   (b)   Low pressure, high temperature.   (d)   High pressure, high temperature.

SEE NEXT PAGE

PART 2 – (70 marks = 35% of paper

Answer ALL questions in Part 2 in the spaces provided below.

_____

1.   Write equations for any reactions that occur in the following procedures. If no reaction occurs write 'no reaction'.

In each case describe **in full** what you would observe, including any
- colours
- odours
- precipitates (give the colour)
- gases evolved (give the colour or describe as colourless).

If no change is observed, you should state this.

(a)   Copper (II) nitrate solution is added to sodium carbonate solution.

Equation _____

Observation _____

_____

[3 marks]

(b)   Freshly precipitated copper (II) hydroxide is shaken with an excess of ammonia solution.

Equation _____

Observation _____

_____

[3 marks]

(c)   Lead nitrate solution is added to iron (II) sulfate solution.

Equation: _____

Observation: _____

_____

[3 marks]

(d)   Manganese dioxide pellets are added to hydrogen peroxide solution.

Equation _____

Observation _____

_____

[3 marks]

SEE NEXT PAGE

2.   For each species listed in the table below
       (a)   draw the structural formula,

              including all valence shell electron pairs and representing each either as : or as −

                                    ..   _
              [for example, water   _ H :O :H or H – O – H and so on]
                                    ..

       (b)   indicate the shape of each species by either sketch or a name

       (c)   indicate the polarity of each species. Write 'non-polar' or 'polar'.

Species	Structural formula (showing all valence shell electrons)	Shape (sketch or name)	Polarity ('non-polar' or 'polar')
Phosphorus Trihydride PH_3			
Hydrogen Cyanide HCN			
Hydrogen carbonate ion HCO_3^-			

[12 marks]

SEE NEXT PAGE

3. The electron configuration of the lithium atom is $1s^2\,2s^1$. Using the same notation, give the electron configuration of: [4 marks]

(a)   A silicon atom _____

(b)   A calcium ion _____

4.   Using the axes provided, draw sketch graphs of the following. You are not required to place any numbers on the scales

(a)   The electronegativities of the elements of group I.

Electonegativity

Li   Na   K   Rb   Cs
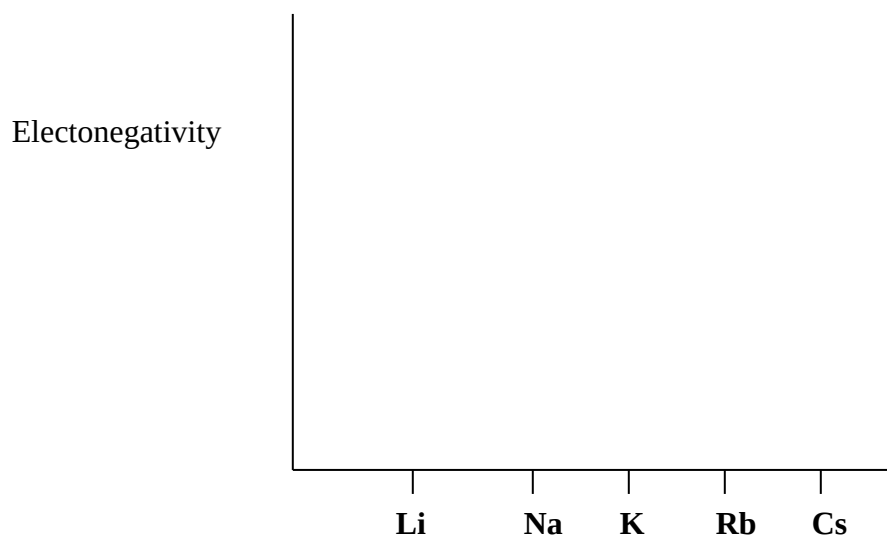
(b)   The first six successive ionization energies of Silicon.

Successive
Ionisation
Energy

1   2   3   4   5   6
Number of ionisations
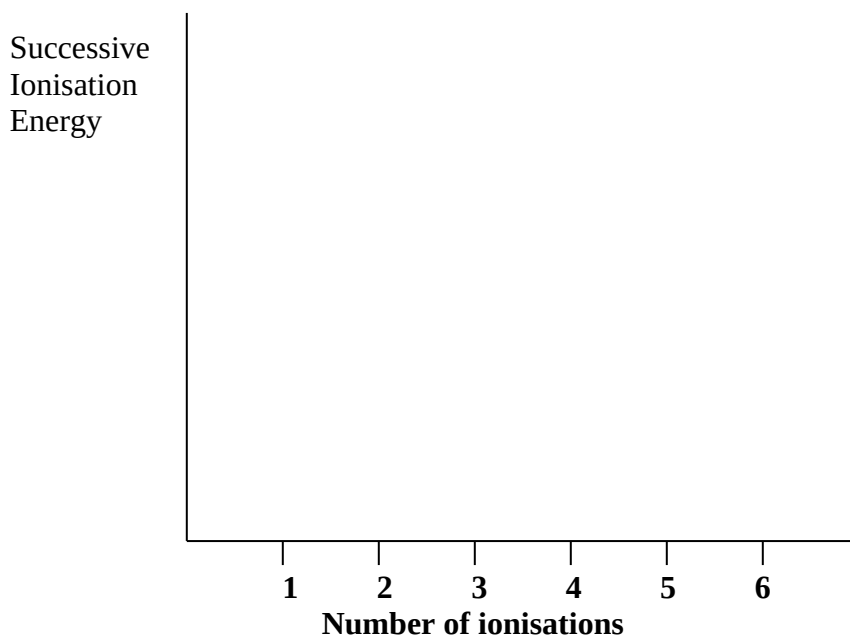
SEE NEXT PAGE

(c)   The boiling points of the hydrides of group VI elements.

Boiling Point

| | | | |
| H₂O | H₂S | H₂Se | H₂Te |
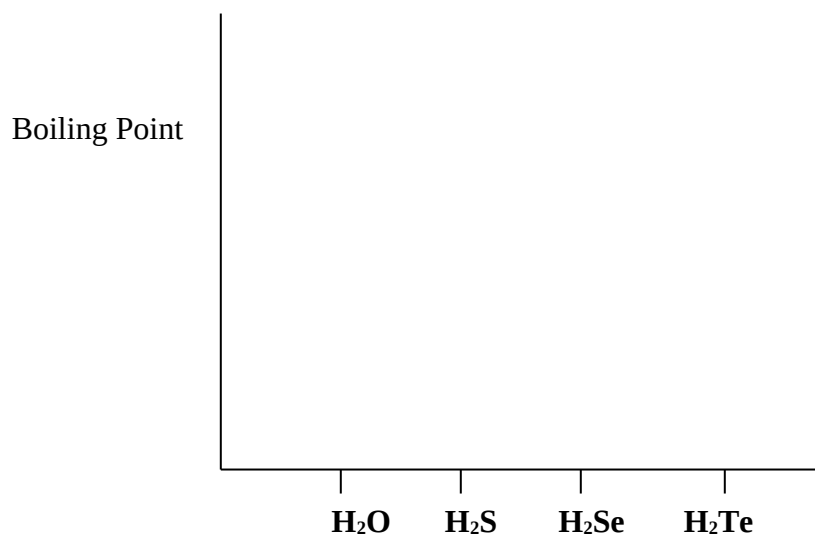
(d)   The molecular polarity of chloro derivatives of methane (CH_3Cl , CH_2Cl_2 , $CHCl_3$, CCl_4) as a
       function of the number of chlorine atoms in a molecule

Molecular
Polarity

0

0   1   2   3   4

Number of Chlorine atoms

[8 marks]

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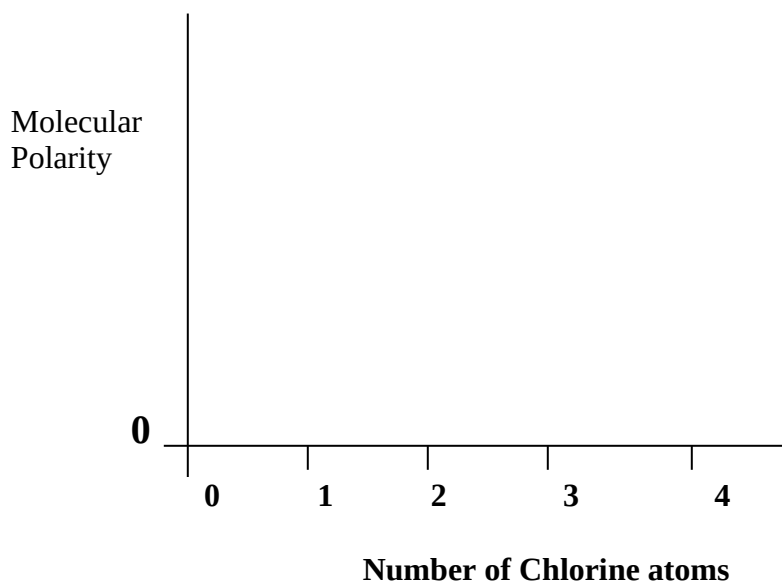
5.   Consider the equilibrium
      $Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq) \leftrightarrow CoCl_4^{2-}(aq) + 6 H_2O(l)$
         red   blue
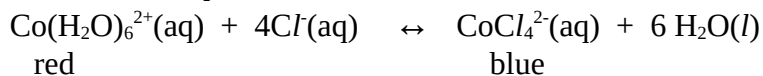
An equilibrium mixture is set up by dissolving cobalt chloride in water to make a concentrated solution, and then adding concentrated hydrochloric acid until the mixture is purple. The solution is divided into three parts, and each part is treated as described in the table. Explain the observations. [A statement such as 'nc', ' → ', or ' ← ' is not sufficient as an explanation.]

Experiment and Observation	Explanation
A little concentrated hydrochloric acid is added and the mixture turns more blue and less red.	
A little silver nitrate solution is added. There is a precipitate and the mixture turns more red and less blue.	
The solution is warmed and the mixture turns more blue and less red.	

[6 marks]

SEE NEXT PAGE

6.   Write the equilibrium constant expression and the units for each of the following: [4 marks]

Equation	$2H_2O(l) + 4\,Au(s) + O_2(g) + 8\,CN^-(aq) \leftrightarrow 4\,Au(CN)_2^-(aq) + 4\,OH^-(aq)$
Equilibrium constant expression	

Equation	$H_2(g) + I_2(g) \leftrightarrow 2\,HI(g)$
Equilibrium constant expression	

7.   Using the information in the table, identify the substances A, B, C, and D from the following list:

Sodium oxide
Cobalt nitrate
Copper
Silicon dioxide
Sucrose (cane sugar)

Sub-stance	Electrical conductivity			Solubility in water	Colour of solid	Name of substance
	Solid	Liquid	Water solution			
A	nil	nil	nil	Soluble	White	
B	nil	nil	nil	Insoluble	White	
C	nil	conducts	conducts	Soluble	Pink	

[6 marks]

SEE NEXT PAGE

8.   For each of the following pairs of substances predict which one of the pair will have the highest boiling point. Give reasons for your choice in each case.

Pairs of substances	Predictions – which substance has the highest boiling point	Reasons
Propane and Ethanol		
Hydrogen sulfide and water		
Ammonia and Phosphorous trihydride		

[6 marks]

9.   Element X has the outer electron structure s^2p^3.

(a)   Write the formula for the hydride of X._____

SEE NEXT PAGE

(b) What monoatomic ion would X be likely to form? _____[4

marks]

10.   Write the equation for the industrial synthesis of ammonia.

This reaction takes place exceedingly slowly at room temperature and pressure. List three ways in which chemists control reaction conditions to **speed up** the process and explain in terms of the collision theory of reaction rates why the change in conditions will speed up the reaction.

i

ii

iii

[8 marks]

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PART 3

Answer ALL questions in Part 3. The calculations are to be set out in detail in this Question/Answer Booklet. Marks will be allocated for correct equations and clear setting out, even if you cannot complete the problem. When questions are divided into sections, working for each section must be clearly distinguished using a, b, etc. Final numerical answers MUST be corrected to three (3) significant figures where appropriate and units MUST be provided where applicable. Information, which may be necessary for solving the problems, is located on the Separate Chemical Data Sheet. Failure to show reasoning clearly will result in loss of marks. This part carries 50 marks (25% of the total).

_____

1.   (a)   A pure compound, which is a colourless liquid at room temperature, boils at 138^0C, and analysis shows it to contain 90.49% carbon and 9.48% hydrogen by mass. Calculate the empirical formula of the compound.

[6 marks]

   (b)   Explain why the empirical formula calculated in (a) cannot be its molecular formula?

[2 marks]

   (c)   A known mass of the liquid is vaporised, and from the volume of gas produced the molecular weight of the compound is calculated to be about 105. What is the molecular formula of the compound

[2 marks]

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2.   A sample of industrial waste water is analysed and found to contain magnesium sulfate as the only significant impurity.

A 5.00 L sample of this waste water is evaporated to about 200 mL and sufficient barium nitrate solution is added to precipitate all the sulfate ion. The precipitate is washed with distilled water, filtered and dried. The mass of the precipitate is found to be 1.70g.

(a)   Determine the concentration in mg L^{-1} of magnesium sulfate in the waste water.

[5 marks]

(b)   What mass of washing soda, $Na_2CO_3 \cdot 10H_2O$, would need to be added to 100.00 L of the waste water to precipitate all the magnesium ion?

[5 marks]

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3.   When 1.000 g of an organic compound containing only carbon, hydrogen and nitrogen was completely burned in air, the carbon dioxide produced had a volume of 1.250 L when measured at 101.3 kPa and 27^0C.

All of the nitrogen from a further 1.00 g sample was converted into ammonia, and this was dissolved in water and titrated with a standard 0.500 mol L^{-1} hydrochloric acid solution. The volume of hydrochloric acid necessary was 33.90 mL.

(a)   What mass of nitrogen is in 1.000 g of the organic compound? (5 marks)
(b)   Determine the empirical formula of the compound. (5 marks)
(c)   Given that the empirical formula and the molecular formula are identical, draw one possible structure for the compound. (2 marks)

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4.   The active ingredient of a drain cleaning powder is sodium hydroxide. A sample of this powder weighing 11.40g is dissolved in water and made up to 250.0 mL in a volumetric flask. A 20.00 mL sample of the resulting solution required 18.75 mL of 0.320 mol L^{-1} sulfuric acid for complete neutralisation. You may assume that none of the other ingredients of the drain cleaning powder react with the sulfuric acid.

   (a)   How many moles of sulfuric acid were used? (2 marks)
   (b)   How many moles of sodium hydroxide were in the 20.00 mL sample? (2 marks)
   (c)   What is the molar concentration of the sodium hydroxide solution? (2 marks)
   (d)   How many grams of sodium hydroxide are contained in 1.00 kg of the drain cleaning powder? (2 marks)

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5.   12.00 L of gas mixture known to contain butane, C_4H_{10}, and nitrogen was mixed with an excess of oxygen and ignited. The products were cooled to 25.0^0C and dried. The volume of the products was 77.00 L. The products were then passed through a solution of potassium hydroxide to absorb the carbon dioxide and the remaining gas mixture dried. The volume of this final mixture was found to be 37.00 L. All gas measurements were carried out at 25.0^0C and 101.3kPa.

(a)   Write the equation for the combustion of butane. (2 marks)

(b)   Determine the volume of butane in the original sample. (3 marks)

(c)   Determine the volume of oxygen mixed with the original butane/nitrogen mixture (measured at 25^0C and 101.3kPa). (2 marks)

(d)   Calculate the percentage by mass of the butane in the original sample. (3 marks)

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PART 4   (20 marks = 10% of paper)

Answer ONE of the following two extended answer questions. Where applicable use equations, diagrams and illustrate examples of the chemistry you are describing.

Marks are awarded for the relevant chemical content of your answer, and also for coherence and clarity of expression. Your answer should be presented in about 1 ½ – 2 pages. Write your extended answer on the lined sheets at the end of these questions.

Either:
(If it makes it easier detach page 29 so you can refer to this question more easily while writing your answer on the lined pages)

1.   Read this information about Graphite then answer the questions below.

The graphite structure, as you would expect, is different from diamond. Carbon atoms are held tightly together in layers. Each carbon atom has three covalent bonds to other carbon atoms. Hexagons of carbon atoms are formed. Weak bonds hold every layer to the one above and the one below. The forces between layers are weak, so they can slide past each other. This explains why graphite is soft and flaky. The electrons between the layers are free to move, as in metals, allowing graphite to conduct electricity in the direction of the layers. The layers themselves are very strong. Graphite fibres with the layers arranged along the fibre are stronger than steel. They are used as reinforcement in metals. Graphite fibres have even been used to reinforce broken bones in animals.

(a)   Describe briefly the structure and bonding in each of the following solids: Lead, Iodine, Diamond.

(b)   Use your descriptions and the information about graphite above to explain, in terms of structure and bonding, the physical properties of graphite and compare these to iodine, which has a melting point of 114°C and is a soft flaky solid. Comment how the differences in structure and bonding account for any similarities and differences in their physical properties.

(c)   Pencil "leads" are a mixture of graphite and clay. They get their name because graphite was confused with lead metal. What properties of graphite and lead are similar? Why, in terms of their structures and bonding are lead and graphite similar in these ways?

(d)   Diamond is one of the hardest substances known. Explain why it is so different to graphite in this respect.

OR:
(If it makes it easier detach this page so you can refer to it while writing your answer on the lined pages)
2.   The following is a summary of the Production of Nitric Acid.

Production of Nitric Acid
The first stage produces nitric acid which has concentrations ranging from 30% to 70%. This is then converted into high-strength nitric acid that contains more than 90 % nitric acid.

1.   Ammonia Oxidation
A 1:9 ammonia/air mixture is oxidised at a temperature of 1380 °C to 1470 °C as it passes through a catalytic convertor, according to the following reaction:

$$4NH_{3(g)} + 5O_{2(g)} \rightleftharpoons 4NO_{(g)} + 6H_2O_{(g)}$$
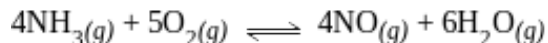
The most commonly used catalyst is made of 90% platinum and 10% rhodium gauze constructed from squares of fine wire. Under these conditions the oxidation of ammonia to nitric oxide (NO) proceeds in an exothermic reaction with a range of 93-98% yield. Higher catalyst temperatures increase NO production.

2.   Nitric Oxide Oxidation
The nitric oxide formed during the ammonia oxidation must be oxidised. The gases are cooled to 100 °C or less at pressures up to 8 atm. The nitric oxide reacts non-catalytically with residual oxygen to form nitrogen dioxide (NO_2)

$$2NO_{(g)} + O_{2(g)} \rightleftharpoons 2NO_{2(g)}$$
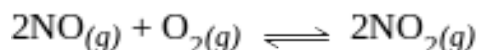
This slow, homogeneous reaction is highly temperature and pressure dependent. Operating at low temperatures and high pressures promotes maximum production of NO_2 within a minimum reaction time.

3.   Absorption
An exothermic reaction occurs between NO_2 and steam as follows:

$$3NO_{2(g)} + H_2O_{(g)} \rightleftharpoons 2HNO_{3(g)} + NO_{(g)}$$
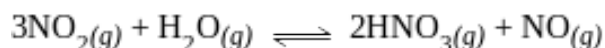
A secondary air stream is introduced into the column to re-oxidise the NO that is formed in the Reaction. This secondary air also removes NO from the product acid. The acid concentration can vary from 30% to 70% nitric acid.

4.   High-Strength Nitric Acid Production
Concentrated nitric acid can be obtained by concentrating the weak nitric acid using extractive distillation. Normal distillation cannot be used due to strong intermolecular attractions between Nitric Acid and Water. The distillation must be carried out in the presence of a dehydrating agent. Concentrated sulfuric acid is most commonly used for this purpose. Concentrated nitric acid leaves the top of the column as 99% vapour which is then condensed.

Explain the Chemistry behind the design of the process at each stage. You can use the concepts of Stoichiometry, Rate of Reaction, Dynamic Equilibrium and Intermolecular Bonding. Include how the process maximises the final yield of Nitric Acid.

END OF QUESTIONS

END OF EXAMINATION