# ANDERSON JUNIOR COLLEGE

## 2017 JC 1 PROMOTIONAL EXAMINATION

NAME:_____ PDG:____ /17

**CHEMISTRY** **9729/02**

Higher 2 **29 September 2017**

Paper 2 **2 hours**

Candidates answer Section A on the Question Paper.

Additional Materials: Answer Paper
Graph Paper
Data Booklet

**READ THESE INSTRUCTIONS FIRST**

Write your name, PDG and register number on all the work you hand in.
Write in dark blue or black pen.
You may use a pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

**Section A**
Answer **all** questions in the spaces provided on the Question Paper.

**Section B**
Answer **one** question.

The use of an approved scientific calculator is expected, where appropriate.
A Data Booklet is provided.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

| For Examiner's Use | | | | |
|---|---|---|---|---|
| Paper 2 | 1 | / 10 | Paper 1 | / 30 |
| | 2 | / 10 | | |
| | 3 | / 11 | Total for Promo | / 100 |
| | 4 | / 11 | | |
| | 5 | / 8 | | |
| | 6 / 7 * | / 20 | Grade | |
| | Total | / 70 | | |

* circle accordingly

This document consists of **16** printed pages.

## Section A

Answer **all** the questions in this section in the spaces provided.

1 Butanol ($C_4H_{10}O$) can be produced by fermentation of biomass. It is considered as an alternative to ethanol as a biofuel for cars since it provides more energy for a given volume than ethanol.

(a) (i) Write the equation which represents the standard enthalpy change of combustion of $C_4H_{10}O$.

.....[1]

(ii) In a calorimetric experiment, 1.00 g of $C_4H_{10}O$ was burned under a container of water. It was found that 100 g of water was heated from 25.0 °C to 76.7 °C. The process was known to be 60% efficient.

Use these data and values from the *Data Booklet* to calculate the enthalpy change of combustion of $C_4H_{10}O$.

[2]

(iii) Use the bond energies given in the *Data Booklet* to calculate another value for the enthalpy change of combustion of $C_4H_{10}O$.

[2]

(iv) Suggest a reason for the discrepancy between the enthalpy change of combustion of $C_4H_{10}O$ calculated in **(ii)** and that in **(iii)**.

.....

.....[1]

(b) Incomplete combustion of fuel results in the production of carbon monoxide. It can undergo disproportionation into carbon and carbon dioxide.

$$2CO(g) \longrightarrow C(s) + CO_2(g) \qquad \Delta S_r^\ominus = -175.9 \text{ J K}^{-1} \text{ mol}^{-1}$$

The standard free energy change of a reaction, $\Delta G_r^\ominus$, **in J mol$^{-1}$**, can be determined from the equilibrium composition of the reaction mixture, using the following thermodynamic equation.

$$\Delta G_r^\ominus = -RT \ln K_p$$

where $R$ is the molar gas constant in J K$^{-1}$ mol$^{-1}$, $T$ is the temperature in Kelvin and $K_p$ is the equilibrium constant.

**(i)** Calculate the standard free energy change, $\Delta G_r^\ominus$, in J mol$^{-1}$, for the disproportionation of CO given that $K_p = 1.15 \times 10^{21}$ at 298 K.

[1]

**(ii)** Hence calculate the standard enthalpy change, $\Delta H_r^\ominus$, for the disproportionation of CO.

[1]

**(iii)** Predict and explain the effect of decreasing temperature on the feasibility of the disproportionation of CO.

.....

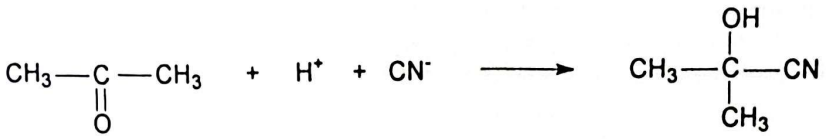
.....

.....

.....[2]

[Total: 10]

2 (a) Propanone, $(CH_3)_2CO$, reacts with acidified aqueous cyanide ion, $CN^-$, to produce 2–hydroxy–2–methylpropanenitrile, $(CH_3)_2C(OH)CN$.



propanone

2-hydroxy-2-methylpropanenitrile

In a series of experiments, the reaction was carried out with different concentrations of the three reagents, and the following relative initial rates were obtained.

| Expt | $[(CH_3)_2CO]$ / mol $dm^{-3}$ | $[H^+]$ / mol $dm^{-3}$ | $[CN^-]$ / mol $dm^{-3}$ | relative initial rate / mol $dm^{-3}$ $s^{-1}$ |
|---|---|---|---|---|
| 1 | 0.020 | 0.060 | 0.060 | 1.00 |
| 2 | 0.020 | 0.050 | 0.050 | 0.833 |
| 3 | 0.020 | 0.050 | 0.060 | 1.00 |
| 4 | 0.025 | 0.040 | 0.040 | 0.833 |

(i) Use the data in the table to determine the order of reaction with respect to the following species. Show your working clearly in the space provided.

hydrogen ions: .....

cyanide ions: .....

propanone: .....

[3]

(ii) Hence write a rate equation for this reaction.

.....[1]

(b) With the aid of a sketch of the Boltzmann distribution, explain the effect of increasing temperature on the rate of the reaction between propanone and acidified aqueous cyanide ion.

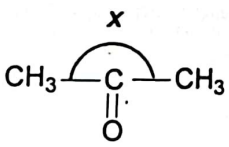
.....

.....

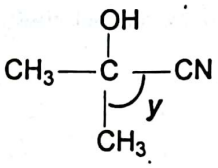
.....

.....[3]

(c) In the reaction in **(a)**, the bond angle about the central carbon atom in the reactant, propanone, differs from that in the product, 2–hydroxy–2–methylpropanenitrile.




propanone




2-hydroxy-2-methylpropanenitrile

(i) Suggest the values of the two bond angles, ***x*** and ***y***. [1]

***x*** .....

***y*** .....

(ii) Explain the difference, if any, in the bond angles by considering the changes in the number, and type, of electron pairs around the central carbon atom.

.....

.....

.....[2]

[Total: 10]

3 *Use of the Data Booklet is relevant to this question.*

Chromium is a hard and brittle metal and its compounds are often used as catalysts or in pigments.

**(a)** **(i)** State the full electronic configuration of chromium.

.....[1]

**(ii)** Draw the shapes of the **types** of electron orbitals found in the **first two** quantum shells of the chromium atom. Label the orbitals.

[1]

**(iii)** $^{50}Cr$ and $^{52}Cr$ are two naturally occurring isotopes of chromium. Deduce the numbers of protons, neutrons and electrons present in $^{50}Cr$ and $^{52}Cr^{3+}$ respectively.

| | number of | | |
|---|---|---|---|
| | **protons** | **neutrons** | **electrons** |
| $^{50}Cr$ | | | |
| $^{52}Cr^{3+}$ | | | |

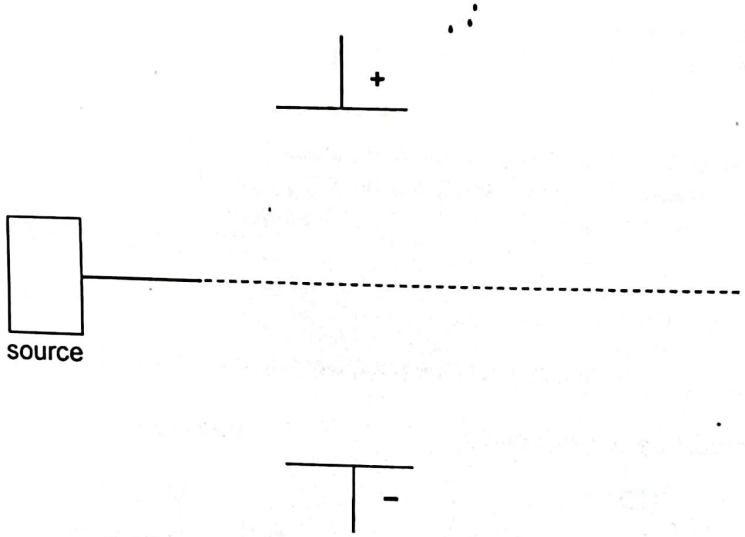
[2]

**(b)** In a particular experimental set up, a beam of $^{52}Cr^{3+}$ ions was deflected through an angle of magnitude 10° in an electric field.

**(i)** Assuming an identical set of experimental conditions, determine the magnitude of the angle of deflection of a beam of $^{35}Cl^-$ ions.

angle of deflection = .....° [1]

(ii) Hence sketch on the diagram below to show how the paths of separate beams of $^{52}Cr^{3+}$ and $^{35}Cl^{-}$ are affected on passing through an electric field which is at right angles to their direction of travel. You should relate clearly the **magnitude** and the **direction** of deflection of each beam to the other.




[1]

(c) (i) State and explain the trend of the first ionisation energies down a group.

.....

.....

.....[3]

(ii) State and explain the trend of the first ionisation energies across the second period.

.....

.....

.....[2]

[Total: 11]

4 The ideal gas equation is the approximate equation of state of any gas. A gas that obeys the equation under all conditions is called an ideal gas. However, most real gases do not behave like ideal gases.

(a) (i) State **two** assumptions of the kinetic theory of gases.

.....

.....

.....[2]

(ii) Under what conditions of temperature and pressure do real gases behave like ideal gases? Give reasons for your answers.

.....

.....

.....

.....

.....[3]

(b) The van der Waals' equation as shown below is often used to account for the discrepancies between experimental and theoretical behaviour of real gases.

$$(p + \frac{n^2a}{V^2})(V - nb) = nRT$$

$p$ is the actual pressure, $V$ the volume of the container, $T$ the temperature, $n$ the amount of substance (in moles), and $R$ the gas constant. The van der Waals' constants $a$ and $b$ are characteristic of the substance and are independent of temperature.

(i) Given that the van der Waals' constants $a$ and $b$ for carbon dioxide, $CO_2$, are 0.364 Pa $m^6$ $mol^{-2}$ and 4.27 x $10^{-5}$ $m^3$ $mol^{-1}$ respectively, calculate the actual pressure, $p$, exerted by 1 mole of $CO_2$ in a 0.25 $dm^3$ container at 25 °C.

[1]

(ii) Calculate the pressure exerted by $CO_2$ as described in **(b)(i)** if it obeys the ideal gas law.

[1]

(iii) Suggest a reason for the difference between the two values obtained in **(b)(i)** and **(b)(ii)**.

.....

.....[1]

**(c)** A gaseous hydrocarbon **A** contains 85.7% of carbon by mass. When 10.0 $cm^3$ of **A** underwent complete combustion in 80.0 $cm^3$ of oxygen the remaining gases occupied 65.0 $cm^3$. After shaking these gases with aqueous sodium hydroxide the final volume of gas remaining was 35.0 $cm^3$. (All volumes were measured at room temperature and pressure.)

Determine the empirical and molecular formulae of **A**.

[3]

[Total: 11]

5 (a) Washing soda, also known as soda ash, is hydrated sodium carbonate, $Na_2CO_3 \cdot xH_2O$, which can be used to remove stubborn stains from laundry. A student carried out a titration to determine the value of $x$.

5.13 g of washing soda crystals were dissolved in water and the solution was made up to 250 $cm^3$ in a standard flask. 25.0 $cm^3$ of this solution reacted exactly with 35.80 $cm^3$ of 0.100 mol $dm^{-3}$ hydrochloric acid and carbon dioxide was produced.

(i) Write a balanced equation for the reaction between $Na_2CO_3$ and $HCl$.

.....[1]

(ii) Calculate the number of moles of $Na_2CO_3$ in the 250 $cm^3$ of solution in the standard flask.

[2]

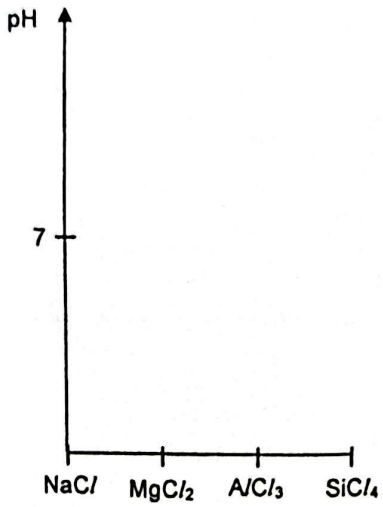
(iii) Calculate the mass of $Na_2CO_3$ present in 5.13 g of washing soda crystals.

[1]

(iv) Hence determine the value of $x$ in $Na_2CO_3 \cdot xH_2O$.

[1]

(b) (i) On the grid below, sketch a graph showing the variation in the pH of the solution obtained when the chlorides of Period 3 elements (sodium to silicon) are added to water.




[1]

(ii) Describe and explain the reaction, if any, when NaCl and $MgCl_2$ are added separately to water, writing a balanced equation for any reaction that takes place.

NaCl:

.....

.....

$MgCl_2$:

.....

.....[2]

[Total: 8]

## Section B

Answer **one** question from this section on separate answer paper.

6 **(a)** Draw a 'dot–and–cross' diagram to illustrate the bonding in sodium chloride. [1]

**(b)** Sodium chloride has a positive enthalpy change of solution, $\Delta H_{sol}$, but is highly soluble in water.

Some enthalpy changes are given in the table below.

| | |
|---|---|
| enthalpy change of formation of solid sodium chloride | –414 kJ mol$^{-1}$ |
| enthalpy change of formation of aqueous sodium chloride | –409 kJ mol$^{-1}$ |
| enthalpy change of hydration of gaseous sodium ions | –390 kJ mol$^{-1}$ |
| enthalpy change of hydration of gaseous chloride ions | –384 kJ mol$^{-1}$ |
| enthalpy change of atomisation of sodium | +107 kJ mol$^{-1}$ |

**(i)** Use the data above to show that the lattice energy of sodium chloride is –779 kJ mol$^{-1}$.

[2]

**(ii)** Using the given data and the value in **(b)(i)**, together with relevant data from the *Data Booklet*, construct a labelled Born–Haber cycle for sodium chloride and use the cycle to calculate the electron affinity of chlorine.

[3]

**(c)** Explain how you would expect the numerical magnitudes of the lattice energies of the Group 1 chlorides to vary down the group.

[2]

**(d)** At 494 °C, 45.0% of nitrogen dioxide in a closed vessel is decomposed into nitrogen monoxide and oxygen.

$$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$$

The numerical value of the equilibrium constant when the partial pressures of the gases are measured in kPa is found to be 36.9.

**(i)** Write an expression for the equilibrium constant, $K_p$, for the reaction. [1]

**(ii)** Based on the information given above, calculate the partial pressure of $NO_2$ at equilibrium.

[2]

**(iii)** Predict, with reasoning, how the position of this equilibrium might change if the volume of the vessel is decreased at 494 °C.

[2]

(iv) Given that the $K_p$ for the reaction increases as the temperature rises, state and explain the sign of $\Delta H$ for the above reaction.

[2]

(e) Describe the reaction, if any, that occurs when separate samples of the following oxides are added to water.

- magnesium oxide, MgO
- aluminium oxide, $Al_2O_3$
- phosphorous(V) oxide, $P_4O_{10}$

Write equations where appropriate and suggest the pH of any aqueous solution formed.

[5]

[Total: 20]

7 (a) Bromine reacts with methanoic acid according to the following equation.

$$Br_2(aq) + HCO_2H(aq) \longrightarrow 2Br^-(aq) + 2H^+(aq) + CO_2(g)$$

In an experiment using 0.10 mol $dm^{-3}$ methanoic acid, the rate of the reaction was monitored at regular time intervals by measuring the absorbance of the remaining bromine in the reaction mixture using a colorimeter. From the measured absorbance, the following values of concentrations of bromine at the different times were obtained.

| Time / min | $[Br_2(aq)] \times 10^{-3}$ / mol $dm^{-3}$ |
|---|---|
| 0 | 10.0 |
| 2 | 6.50 |
| 4 | 4.40 |
| 6 | 2.85 |
| 8 | 1.90 |
| 10 | 1.25 |

(i) By plotting an appropriate graph, confirm that the reaction is first order with respect to bromine.

[3]

(ii) Further studies show that the reaction is also first order with respect to methanoic acid.

Using this data, derive the units for the rate constant, *k*.

[1]

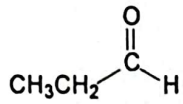
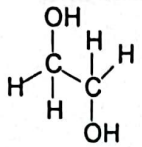
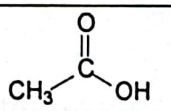
(iii) The experiment in (i) was repeated using aqueous bromine of the same concentration and another methanoic acid sample of concentration 0.20 mol $dm^{-3}$.

Deduce the time taken for the concentration of bromine to reduce to $5.00 \times 10^{-3}$ mol $dm^{-3}$.

[2]

(b) (i) The standard enthalpy change of vaporisation, $\Delta H^{\ominus}_{vap}$, is the enthalpy change when one mole of a liquid vaporises at its boiling point and a pressure of 1 bar.

The following table lists the standard enthalpy change of vaporisation of some organic compounds.

| Formula | Structural formula | $M_r$ | $\Delta H^{\ominus}_{vap}$ / kJ mol$^{-1}$ |
|---|---|---|---|
| $CH_3CH_2CHO$ |  | 58.0 | +29.7 |
| $CH_2(OH)CH_2OH$ |  | 62.0 | +65.6 |
| $CH_3COOH$ |  | 60.0 | +41.6 |

By reference to the type and extent of relevant intermolecular forces, explain as fully as you can the differences in $\Delta H^{\ominus}_{vap}$ between

I. $CH_3CH_2CHO$ and $CH_2(OH)CH_2OH$

II. $CH_2(OH)CH_2OH$ and $CH_3COOH$

[3]

(ii) Aqueous $CH_3COOH$ undergoes an acid–base reaction with aqueous NaOH to form a salt and water.

$$CH_3COOH + NaOH \longrightarrow CH_3COO^-Na^+ + H_2O$$

The melting point of $CH_3COOH$ is 16 °C. Predict if the melting point of $CH_3COO^-Na^+$ is higher or lower than that of $CH_3COOH$. Explain your answer in terms of structure and bonding.

[2]

(c) Some hydrogen halides are unstable to heat.

(i) Write an equation for the reaction undergone on heating a hydrogen halide. [1]

(ii) Describe and explain how the thermal stability of the hydrogen halides varies down Group 17 from HCl to HI.

[2]

(d) The key stage in the manufacture of sulfuric acid is the reaction between sulfur dioxide and oxygen.

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

The reaction is carried out at 500 °C in a 10.0 $dm^3$ vessel. At the start of the reaction, 4 moles of $SO_2$ and 2 moles of $O_2$ are introduced into the vessel. When equilibrium is established, it is found that 2% of $SO_2$ remains unconverted.

(i) Calculate the equilibrium concentrations of the three gases. [3]

(ii) Hence determine the value of the equilibrium constant, $K_c$, for this reaction at 500 °C. [1]

(iii) Predict, with reasoning, how the percentage of unconverted $SO_2$ at equilibrium would change if

I. an excess of oxygen,

II. a catalyst

is added separately to the initial gas mixture.

[2]

[Total: 20]