An Introduction to the Chemistry of the Transition Elements

Question Paper 4

Level	International A Level
Subject	Chemistry
Exam Board	CIE
Topic	An Introduction to the Chemistry of the Transition Elements
Sub-Topic	
Paper Type	Theory
Booklet	Question Paper 4

Time Allowed:	**74 minutes**
Score:	**/61**
Percentage:	**/100**

Grade Boundaries:

A*	A	B	C	D	E	U
>85%	777.5%	70%	62.5%	57.5%	45%	<45%

1 **(a)** Write down what you would see, and write equations for the reactions that occur, when silicon(IV) chloride and phosphorus(V) chloride are separately mixed with water.

silicon(IV) chloride

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.....

phosphorus(V) chloride

.....

.....
[4]

(b) Iron(III) chloride, $FeCl_3$, is used to dissolve unwanted copper from printed circuit boards (PCBs) by the following reaction.

$$2FeCl_3(aq) + Cu(s) \rightarrow 2FeCl_2(aq) + CuCl_2(aq)$$

A solution in which $[Fe^{3+}(aq)]$ was originally equal to $1.50\,mol\,dm^{-3}$ was re-used several times to dissolve copper from the PCBs, and was then titrated as follows.

A $2.50\,cm^3$ sample of the partially-used-up solution was acidified and titrated with $0.0200\,mol\,dm^{-3}$ $KMnO_4$.
This oxidised any $FeCl_2$ in the solution back to $FeCl_3$.
It was found that $15.0\,cm^3$ of $KMnO_4(aq)$ was required to reach the end point.

(i) Construct an ionic equation for the reaction between Fe^{2+} and MnO_4^- in acid solution.

.....

(ii) State here the $Fe^{2+} : MnO_4^-$ ratio from your equation in **(i)**. .....

(iii) Calculate the number of moles of MnO_4^- used in the titration.

(iv) Calculate the number of moles of Fe^{2+} in $2.50\,cm^3$ of the partially-used-up solution.

(v) Calculate the $[Fe^{2+}]$ in the partially-used-up solution.

(vi) Calculate the mass of copper that could still be dissolved by 100 cm^3 of the partially-used-up solution.

mass of copper = ... g
[6]

(c) When $SiCl_4$ vapour is passed over Si at red heat, Si_2Cl_6 is formed. Si_2Cl_6 contains a Si-Si bond.
The reaction of Si_2Cl_6 and Cl_2 re-forms $SiCl_4$.

$$Si_2Cl_6(g) + Cl_2(g) \rightarrow 2SiCl_4(g)$$

Use bond energy data from the *Data Booklet* to calculate $\Delta H^{\ominus}$ for this reaction.

$\Delta H^{\ominus}$ = ... $kJ\,mol^{-1}$
[2]

(d) Calcium forms three calcium silicides, Ca_2Si, CaSi and $CaSi_2$. The first of these reacts with water as follows.

$$.....Ca_2Si + ...H_2O \rightarrow .....Ca(OH)_2 + ...SiO_2 + ...H_2$$

(i) Balance this equation. You may find the use of oxidation numbers helpful.

(ii) During this reaction, state

which element(s) have been oxidised, ...

which element(s) have been reduced. .....
[2]

[Total: 14]

2 (a) Complete the following electronic configurationoftheCu $^{2+}$ ion.

$1s^2\ 2s^2\ 2p^6$ ..... [1]

(b) In a free, gas-phase transition metal ion, the d-orbitals all have the same energy, but when the ion is in a complex the orbitals are split into two energy levels.

(i) Explain why this happens.

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(ii) How does this splitting help to explain why transition metal complexes are often coloured?

.....

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.....

(iii) Why does the colour of a transition metal complex depend on the nature of the ligands surrounding the transition metal ion?

.....

.....
[5]

(c) Draw a fully-labelled diagram of the apparatus you could use to measure the $E^{\ominus}$ of a cell composed of the Fe^{3+}/Fe^{2+} electrode and the Cu^{2+}/Cu electrode.

[5]

(d) The $E^{\ominus}$ for Cu^{2+}/Cu is +0.34 V. When $NH_3(aq)$ is added to the electrode solution, the $E_{electrode}$ changes.

(i) Describe the type of reaction taking place between $Cu^{2+}(aq)$ and $NH_3(aq)$.

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(ii) Write an equation for the reaction.

.....

(iii) Describe the change in the colour of the solution.

.....

(iv) Predict and explain how the $E_{electrode}$ might change on the addition of $NH_3(aq)$.

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.....

[4]

(e) Fehling's reagent is an alkaline solution of Cu^{2+} ions complexed with tartrate ions. It is used in organic chemistry to test for a particular functional group.

(i) **Name** the functional group involved.

.....

(ii) Describe the appearance of a positive result in this test.

.....

(iii) Write an equation for the reaction between Cu^{2+} and OH^- ions and a two-carbon compound containing the functional group you named in **(i)**.

.....

[3]

(f) A solution containing a mixture of tartaric acid and its sodium salt is used as a buffer in some pre-prepared food dishes.
Calculate the pH of a solution containing 0.50 mol dm^{-3} of tartaric acid and 0.80 mol dm^{-3} sodium tartrate.
[K_a(tartaric acid) = 9.3×10^{-4} mol dm^{-3}]

pH = ...

[2]

[Total: 20]

3 **(a)** Hydrogen fluoride, HF, behaves as a weak acid in water, with $K_a = 5.6 \times 10^{-4}\,\text{mol dm}^{-3}$.

Calculate the pH of a $0.050\,\text{mol dm}^{-3}$ solution of HF.

pH = ...[2]

(b) Gaseous ammonia and hydrogen fluoride react together to give solid ionic ammonium fluoride.

$$NH_3(g) + HF(g) \rightleftharpoons NH_4F(s) \qquad \Delta H = -147\,\text{kJ mol}^{-1}$$

(i) What *type of reaction* is this?

.....

(ii) Draw dot-and-cross diagrams (outer shells only) describing the bonding in the three compounds involved in this reaction.

NH_3	HF	NH_4F

(iii) There are **three** types of bonding in NH_4F.
Give the names of each of the three types, and state where in the compound each type occurs.

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(iv) The reaction between NH_3 and HF is reversible. What conditions of temperature and pressure would favour the **reverse** reaction, i.e. the dissociation of NH_4F? Explain your answer.

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[9]

(c) Many commercial copper and brass polishes contain ammonia. The tarnish that forms on the surface of copper is often copper sulfide, CuS. In the presence of O_2 from the air, NH_3 can combine with this copper sulfide to produce the soluble cuprammonium sulfate, $[Cu(NH_3)_4]SO_4$.

(i) Construct an equation for this reaction.

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(ii) State the colour of cuprammonium sulfate solution.

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(iii) Describe what you would see if a solution of cuprammonium sulfate was diluted with water. Explain your answer.

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[3]

(d) When sulfuric acid is added to $Cu^{2+}(aq)$, no colour change occurs, but when concentrated hydrochloric acid is added to $Cu^{2+}(aq)$, the solution turns yellow-green. The solution reverts to its original colour when it is diluted with water.

Suggest the type of reaction occurring with $HCl(aq)$, suggest what is formed during the reaction, and write an equation for the change.

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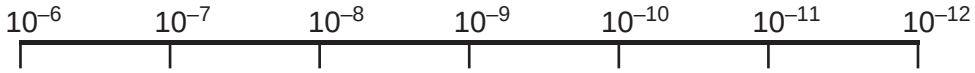
.....[3]

[Total: 17]

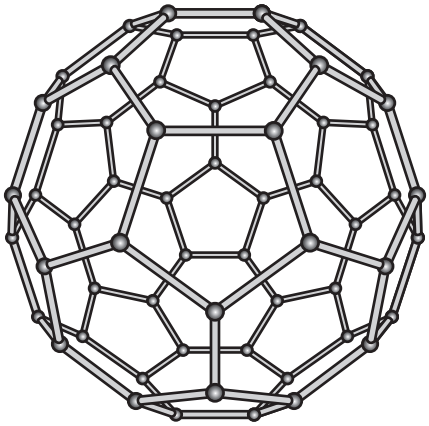
4 Nanotechnology is a fast-developing area of science based on the ability to manipulate materials of very small dimensions.

(a) On the scale shown in metres, mark the upper and lower limits of the range of sizes for nanoparticles.



[2]

(b) One of the most commonly recognised nanoparticles is the 'buckyball', a spherical form of carbon containing 60 carbon atoms. It has been referred to as the third allotrope of carbon.



Diamond and graphite are two other allotropes of carbon. Suggest what is meant by the term *allotrope*.

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.....[2]

(c) Nanoparticles are used to deliver drugs within cells. Suggest what property of nanoparticles enables them to be used in this way. Explain your answer.

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.....[2]

(d) Copper is an important metal that has been used for thousands of years. The problem today is that most of the ores rich in copper compounds have been used up. A century ago ores containing >2% of copper by mass would have been worked; today's mines have to operate at much lower percentages, down to 0.5% of copper by mass.

(i) By what *type of reaction* is the copper present in the ore converted to copper metal?

.....

One of the main ores of copper contains the mineral *chalcopyrite*, $CuFeS_2$.

(ii) Calculate the percentage of copper by mass in *chalcopyrite*.

(iii) If the ore contains 2% of *chalcopyrite* by mass, calculate the mass of copper which can be produced from each tonne of ore.

(iv) Certain bacteria are able to extract copper from the 'spoil' heaps of previously mined copper ore. These bacteria are sprayed onto the spoil heaps in an aqueous solution and the resulting solution containing iron(II) sulfate and copper(II) sulfate is collected in tanks.

Suggest how the copper could be recovered as metal.

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[4]

[Total: 10]