NAME DATE STARTED TARGET END DATE

GCE A LEVEL — CHEMISTRY UNIT 3 QUESTION PACK

1095-01 (Legacy CH5) · New spec Unit 3 Topic 3 · A2 unit, first sat 2017, 80 marks, 1h 45min paper

REVISE.wales

CHEMISTRY — UNIT 3 · Transition Metals — d-Block Chemistry

Topic 3.4 — d-block transition metals: electron configuration, variable oxidation states, complex ions, ligands, colour and catalysis

Defining transition elements via 3d electron configuration, variable oxidation states, ligand substitution and the shapes of complex ions, the origin of d-d colour and homogeneous / heterogeneous catalysis (Fe, Cu, Cr, Mn).

Legacy 2008 specification

Estimated time for entire question pack: ~1 h 54 min

Derived from the legacy CH5 paper's pace of ~1.3 min/mark, padded for long-prose and calculation answers (71 marks over 4 questions).

*You are advised to **not** attempt to complete all of this in one sitting.*

ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every question from the legacy WJEC CH5 papers (2008 modular spec, Jun 2010 – Jun 2016) that maps onto the new-spec A2 Unit 3 Topic 3.4.

Questions are ordered by source paper date.

INSTRUCTIONS

Use black ink or black ball-point pen. Show all working — quality of written communication will affect marks. A calculator is allowed. You will need the WJEC Periodic Table / Data Booklet.

For Examiner's use only

Q	Source	Max	Mark
1	Jun 11 Q4	20	
2	Jun 12 Q3	15	
3	Jun 15 Q1	16	
4	Jun 16 Q4	20	
Total		**71**	

Transition Metals — d-Block Chemistry — what the new spec asks

WJEC GCE A Level Chemistry (from 2015) · Unit 3: Physical & Inorganic Chemistry · Topic 3.4.

Defining transition elements

- d-block element with an incomplete d-subshell in an ion form.
- Sc (only +3, [Ar]) and Zn (only +2, full $3d^{10}$) excluded.
- Electron filling: 3d before 4s in ions; 4s before 3d in neutral atoms.
- Cr and Cu anomalies: $3d^5 4s^1$, $3d^{10} 4s^1$ (stable half-/full-filled d).

Variable oxidation states

- Mn: +2 to +7 ($KMnO_4$, MnO_2).
- Fe: +2, +3 most common; +6 rare (FeO_4^{2-}).
- Cu: +1 (less stable in aq) and +2 (blue).
- Cr: +2, +3 (green), +6 (orange $Cr_2O_7^{2-}$, yellow CrO_4^{2-}).

Complex ions & ligands

- Ligand: species with a lone pair forming a dative bond to a metal ion.
- Monodentate: H_2O, NH_3, Cl^-, CN^-, OH^-.
- Bidentate: ethane-1,2-diamine (en); ethanedioate.
- Polydentate: $EDTA^{4-}$ (6 sites). Haem: porphyrin + Fe^{2+}.

Shapes of complexes

- Octahedral (6 ligands): $[Cu(H_2O)_6]^{2+}$.
- Tetrahedral (4 ligands): $[CuCl_4]^{2-}$.
- Square planar (4 ligands): cisplatin (Pt).
- Linear (2 ligands): $[Ag(NH_3)_2]^+$.

Colour origin

- d-d transitions: absorb visible light to promote 3d e^- to higher d level.
- Energy gap (ΔE) set by ligand identity (spectrochemical series) and oxidation state.
- Colour observed = complementary to absorbed.
- Change ligand or oxidation state ⇒ colour change.

Ligand substitution & catalysis

- $[Cu(H_2O)_6]^{2+}$ (pale blue) + excess NH_3 → $[Cu(NH_3)_4(H_2O)_2]^{2+}$ (deep blue).
- + Cl^-: $[CuCl_4]^{2-}$ (yellow-green, tetrahedral).
- Heterogeneous: Fe in Haber, V_2O_5 in Contact, Ni for hydrogenation.
- Homogeneous: autocatalysis by Mn^{2+} in MnO_4^- + $C_2O_4^{2-}$.

Transition Metals — d-Block Chemistry in one page

Quick-reference notes — revisit before each question.

Defining

d-block with partially-filled d-subshell in a stable ion. Excludes Sc (only Sc^{3+} [Ar]) and Zn (only Zn^{2+}, $3d^{10}$).

Cu^{2+} ligand colour

$[Cu(H_2O)_6]^{2+}$ pale blue → + excess NH_3 → $[Cu(NH_3)_4(H_2O)_2]^{2+}$ deep blue.

+ Cl^- → $[CuCl_4]^{2-}$ yellow-green.

Why coloured

d-d transition: visible light promotes an electron from lower to higher d-orbital. Wavelength absorbed = complementary to observed colour.

Ligand types

Monodentate (1 lone pair): H_2O, NH_3, Cl^-.

Bidentate: en, oxalate (2 sites).

Polydentate: $EDTA^{4-}$ (6 sites).

Catalysis

Heterogeneous: Fe in Haber, V_2O_5 in Contact, Pt/Pd in catalytic converters.

Homogeneous: variable oxidation states permit autocatalysis ($MnO_4^-/C_2O_4^{2-}$ — Mn^{2+} catalyses).

Cr chemistry

Cr(VI) $Cr_2O_7^{2-}$ orange ↔ CrO_4^{2-} yellow (alkali shifts).

Cr(III) $[Cr(H_2O)_6]^{3+}$ green.

Questions begin overleaf.

SECTION B

Answer **both** *questions in the separate answer book provided.*

4. *(a)* (i) State what is meant by the term *transition element*. [1]

(ii) Explain why both iron and copper are classed as transition elements, whilst zinc is not. [1]

(b) Transition elements such as copper frequently form coloured complexes. Copper(II) complexes are usually blue, but the exact colour can vary, with $[Cu(H_2O)_6]^{2+}$ being pale blue and $[Cu(NH_3)_4(H_2O)_2]^{2+}$ being royal blue. Copper(I) complexes are usually colourless.

Explain why transition metal complexes are usually coloured. Your answer should include details of:

- The origin of colour in transition metal complexes;
- Why the copper(II) species above are coloured blue;
- Why the colours seen in different copper(II) complexes are different;
- Why copper(I) complexes do not form coloured compounds. [6]

(QWC) [2]

(c) Iron is usually extracted from iron(III) oxide, Fe_2O_3, in a blast furnace using carbon monoxide, CO, as a reducing agent, releasing metallic iron and the gas carbon dioxide.

(i) Write the overall equation for this reaction. [1]

(ii) Explain in terms of oxidation states why carbon monoxide is considered to be the reducing agent in this reaction. [2]

(iii) Explain why carbon monoxide, CO, can be used as a reducing agent but the corresponding oxide of lead, PbO, cannot. [2]

(d) The iron content of an alloy can be determined by a redox titration using acidified potassium dichromate(VI) solution, $K_2Cr_2O_7$. A piece of alloy of mass 1.870 g was dissolved completely in acid to form Fe^{2+} ions, and the solution made up to 250.0 cm^3. A 25.00 cm^3 sample of this solution was titrated against acidified $K_2Cr_2O_7$. This required 23.80 cm^3 of $K_2Cr_2O_7$ solution of concentration 0.0200 mol dm^{-3} for complete reaction.

(i) The half-equations for the processes occurring are:

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \longrightarrow 2Cr^{3+} + 7H_2O$$

$$Fe^{3+} + e^- \longrightarrow Fe^{2+}$$

Write an **ionic** equation for the reaction between Fe^{2+} ions and $Cr_2O_7^{2-}$ ions in acid solution. [1]

(ii) Calculate the number of moles of Fe^{2+} ions present in the 25.00 cm^3 sample used in the titration. [2]

(iii) Calculate the percentage of iron in the original alloy sample. [2]

Total [20]

3. *Read the passage below and then answer the questions (a) to (e) in the spaces provided.*

Copper – an essential element

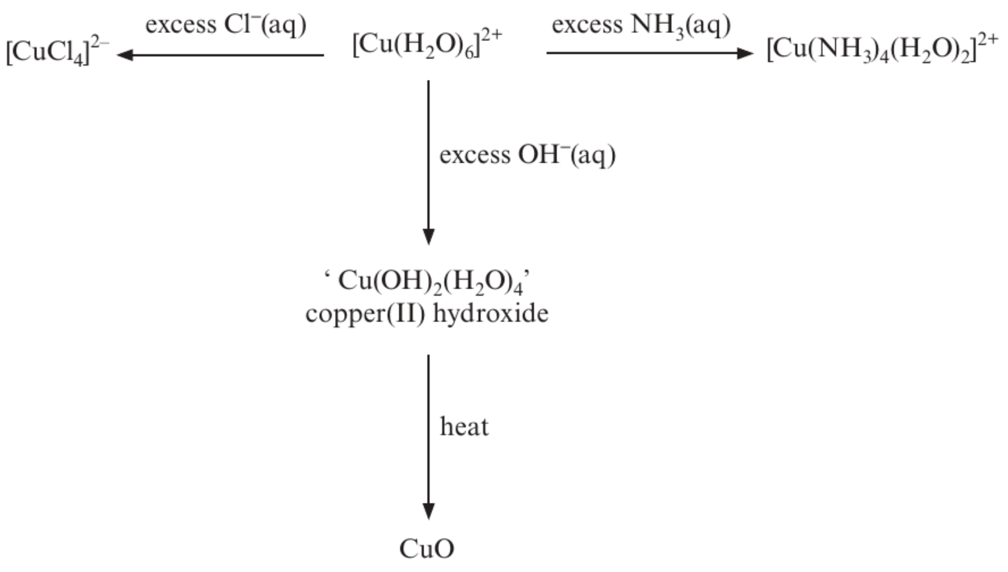
There is an ever-increasing world demand for copper and this has driven its cost upwards. This has led to the extraction of copper from sources once thought to be uneconomic. One such source of copper is the spoil heaps from old mines. The spoil heap material is crushed and then sprayed with acidified water in the presence of the bacterium *Thiobacillus ferrooxidans*. These bacteria convert any iron present to aqueous iron(III) ions, which then oxidise sulfide ions to aqueous sulfate(VI) ions, SO_4^{2-}. A solution containing copper(II) sulfate is produced that is then treated with iron to leave copper.

$$Cu^{2+}(aq) \;+\; Fe(s) \longrightarrow Cu(s) \;+\; Fe^{2+}(aq)$$

The concentration of copper in this copper(II) sulfate solution can be found by a variety of methods, which include

- precipitating the copper and weighing it
- reacting the solution with an excess of iodide ions and titrating the liberated iodine with aqueous sodium thiosulfate
- titrating the copper(II) ions with ethylenediaminetetra-acetic acid (EDTA)
- using instrumental methods such as atomic absorption and X-ray fluorescence spectroscopy

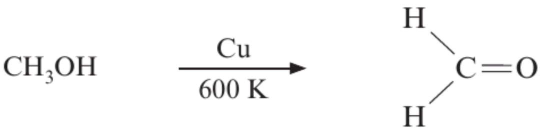
Copper(II) sulfate continues to be a familiar and commonly used substance in schools and colleges and its reactions are typical of many transition metal compounds. For example, in aqueous solution the copper ions are present as the complex cation, $[Cu(H_2O)_6]^{2+}$. The water molecules in this complex ion can be replaced by other ligands.



Copper is a relatively unreactive metal and is easy to obtain by the smelting of its ores, as was carried out in the Bronze Age. Small quantities of many transition metals can be produced by strongly heating the oxide with aluminium or magnesium. One application of this is the reaction of aluminium with iron(III) oxide to give molten iron that can be used to weld together lengths of railway track. A similar reaction occurs when magnesium is strongly heated with copper(II) oxide.

$$\text{Mg(s)} + \text{CuO(s)} \longrightarrow \text{Cu(l)} + \text{MgO(s)} \qquad \Delta H = -431\,\text{kJ mol}^{-1}$$

Transition metals also have important uses as catalysts and copper can be used as an economical catalyst in a number of organic processes, for example in the production of methanal.



- End of passage -

(a) The percentage of copper in a sample from a spoil heap was found by a titration using ethylenediaminetetra-acetic acid (EDTA).
19.20 cm^3 of an EDTA solution of concentration 0.010 mol dm^{-3} reacted with 50.00 cm^3 of a solution containing copper(II) ions.
EDTA reacts with copper(II) ions in a 1:1 mole ratio.

(i) Calculate the number of moles of EDTA solution used in the titration. [1]

(ii) State the number of moles of copper(II) ions present in 50.00 cm^3 of the copper-containing solution. [1]

(iii) Calculate the concentration of copper in the solution in **g dm^{-3}**. [2]

(iv) The mass of the copper-containing sample was 11.56 g. All the copper in this sample was present in a solution of volume 1.00 dm^3.
Calculate the percentage of copper in the sample. [1]

(b) Both copper and zinc are d-block elements. Explain, using electron configurations, why copper is described as a transition metal and zinc (whose compounds contain Zn^{2+} ions) is not. [2]
(QWC) [1]

(c) The passage shows the formulae of some copper-containing species formed by ligand exchange *(line 20)*.
Complete the table below, stating the approximate shape and colour of the complex ions shown. [2]

Complex ion	Shape	Colour
$[CuCl_4]^{2-}$		
$[Cu(NH_3)_4(H_2O)_2]^{2+}$		

(d) Standard enthalpy of formation values, $\Delta H_f^{\ominus}$, can be used to calculate enthalpy changes, such as the reduction of copper(II) oxide by magnesium, described in the article *(line 27)*.
Some $\Delta H_f^{\ominus}$ values are given in the table below.

Metal oxide	$\Delta H_f^{\ominus}$/ kJ mol^{-1}
CuO	–157
PbO	–217

State and explain how the $\Delta H_f^{\ominus}$ values for these two oxides give an indication of their relative stability. [2]

(e) Many transition metals and their compounds act as catalysts. The article describes copper acting as a catalyst in the oxidation of methanol *(line 30)*.

(i) Give **two** reasons why transition metals and their compounds can act as catalysts. [2]

....

....

(ii) Give a reason, in terms of Green Chemistry, why scientists often seek new catalysts for established chemical processes. [1]

....

....

Total [15]

Total Section A [40]

SECTION A

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

1. *(a)* Copper ions combine with a range of ligands to form complex ions, including $[CuCl_4]^{2-}$ and $[Cu(H_2O)_6]^{2+}$.

(i) State what is meant by a *ligand*. [1]

(ii) Draw the structures of $[CuCl_4]^{2-}$ and $[Cu(H_2O)_6]^{2+}$ ions. [2]

(iii) A solution containing $[Cu(H_2O)_6]^{2+}$ ions is blue. Explain the origin of this colour. [3]

(iv) When excess ammonia is added to a solution containing $[Cu(H_2O)_6]^{2+}$ ions, the colour of the solution changes as a new complex ion is formed. Give the formula of the new complex ion and the colour of the solution formed. [2]

(b) Phosphorus forms two chlorides, PCl_3 and PCl_5, and there is a dynamic equilibrium between these compounds in the gas phase. This is represented by the equation below.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

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

(ii) A sealed vessel is filled with PCl_5 at a pressure of 3.0×10^5 Pa. Upon heating, the system comes to equilibrium to form a mixture that contains PCl_3 at a partial pressure of 1.3×10^5 Pa.

I. State the partial pressure of Cl_2 at equilibrium. [1]

....

II. Calculate the value of the equilibrium constant, K_p, giving its units. [3]

K_p = ...

Units ....

III. As the temperature is increased the value of K_p increases. State what information this provides about the enthalpy change of this reaction, giving a reason for your answer. [1]

....

....

(c) Silicon(IV) chloride reacts with water whilst CCl_4 does not. Give the equation for the reaction of $SiCl_4$ with water and explain why the behaviour of CCl_4 and $SiCl_4$ with water is so different. [2]

....

....

....

Total [16]

16

SECTION B

Answer **both** *questions in the separate answer book provided.*

4. *(a)* Copper is a typical transition metal.

Characteristics of these metals include an ability to:

- form coloured ions
- show variable oxidation states
- form complex ions

(i) State **one** *other* chemical property of transition metals. [1]

(ii) Explain why copper(I) compounds are generally white. [2]

(b) Copper compounds take part in several different types of reaction including ligand substitution and precipitation. Using copper compounds, give an example for both types of reaction, stating any observations. Give the formula for the copper-containing product for each example. [6]
QWC [1]

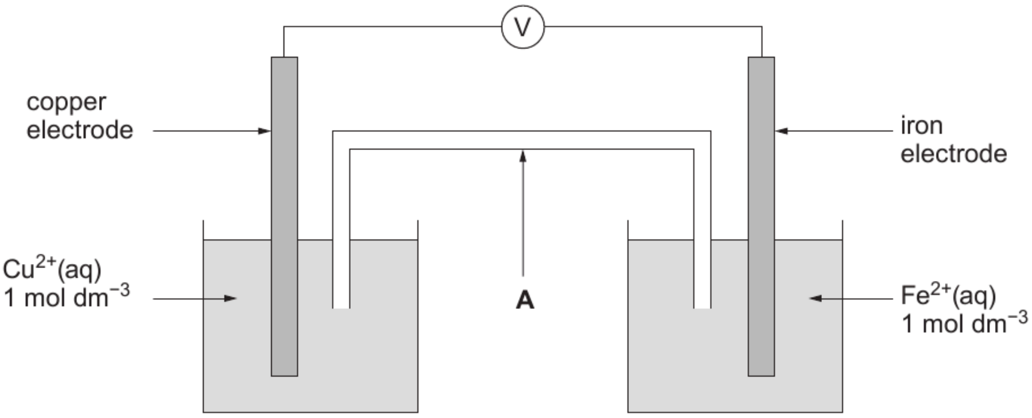
(c) Brass is an alloy of copper and zinc.

A 2.05 g brass screw was dissolved in nitric acid and the solution formed was diluted to 100 cm^3 in a volumetric flask. An excess of potassium iodide solution was added to 25.0 cm^3 of this solution and the iodine produced was titrated against a 0.200 mol dm^{-3} solution of sodium thiosulfate. The iodine required 24.00 cm^3 of the sodium thiosulfate solution for complete reaction.

(i) Name a suitable indicator for this titration. [1]

(ii) Calculate the percentage by mass of copper in the brass. Give your answer to **three** significant figures. [4]
(The ratio of $Cu^{2+} : S_2O_3^{2-}$ is 1 : 1)

(d) The diagram below shows the apparatus that was used to measure the emf of a Cu^{2+}/Cu, Fe^{2+}/Fe electrochemical cell.



Some standard electrode potentials, E^{θ}, are given below.

System	E^{θ}/V
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.44
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	−0.25

(i) Name the part of the cell labelled **A** and state its purpose. [2]

(ii) State, giving a reason, which of the electrodes will be positively charged in the above cell. [1]

(iii) Calculate the standard emf, in volts, for the above cell. [1]

(iv) State whether or not you would expect nickel to react with iron(II) ions. Give a reason for your answer. [1]

Total [20]

END OF QUESTION PACK

4 questions · 71 marks · ~1 h 54 min
Source: WJEC CH5 (2008 modular spec, Jun 2010 – Jun 2016)
Curated for WJEC Chemistry 2015 spec A2 Unit 3 — Topic 3 (3.4)