Past-paper walk-through

General characteristic chemical properties of the first set of transition ▪ 28.2

eXercise

Questions in this set

- 9701/31 N25 Q3 ▪ 15 marks
- 9701/33 N25 Q3 ▪ 14 marks
- 9701/34 N25 Q3 ▪ 15 marks
- 9701/41 N25 Q5 ▪ 14 marks
- 9701/42 N25 Q5 ▪ 15 marks
- 9701/44 N25 Q1 ▪ 19 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 3

9701/31 N25 ▪ Q3 ▪ 15 marks

3 **(a)** A bottle labelled **FA 5** is thought to contain hydrated zinc sulfate. It would therefore contain zinc ions and sulfate ions as well as water of crystallisation.

(i) Devise and carry out tests to investigate whether zinc ions, sulfate ions and water of crystallisation are present.

Record the tests you carry out and the observations you see in the space provided.

Question 3

[5]

(ii) Use your observations in **(a)(i)** to complete Table 3.1 to show whether each species is present in **FA 5**.

Use a tick (✓) if the species is present.

Use a cross (✗) if the species is **not** present.

Table 3.1

Zn^{2+}	
SO_4^{2-}	
H_2O	

[1]

(b) You are provided with solid **FA 6**.

Question 3

Question 3

(i) Heat a few crystals of **FA 6** in a hard-glass test-tube until no further gas is evolved. Record all your observations.

Leave the test-tube until it is cool.

Keep the cooled residue for use in (b)(ii).

Question 3

(ii) To the cooled residue from **(b)(i)**, add approximately 3 cm depth of distilled water and stir. Filter the solution formed into a test-tube.

Question 3

(c) You are provided with aqueous solutions **FA 7** and **FA 8** and with solid **FA 9**.

FA 7 is an aqueous solution of **FA 6**.
FA 7, **FA 8** and **FA 9** contain compounds which all have one metal that is the same but which may be in different oxidation states.

(i) Carry out the following tests on **FA 7**, **FA 8** and **FA 9** and record your observations in Table 3.2. For each test use a 1 cm depth of a solution or a spatula measure of solid.

Table 3.2

test	*observations*		
	FA 7	**FA 8**	**FA 9**
Test 1 Add hydrogen			

Question 3

peroxide.

Question 3

Test 2 Add aqueous sodium hydroxide, then			
leave to stand.			
Test 3 Add aqueous iron(II) sulfate.			

Question 3

Question 3

[1]

(ii) Suggest the identity of the metal in **FA 6**/**FA 7**, **FA 8** and **FA 9**.

The metal is ..... . [1]

(iii) Complete Table 3.3 to suggest the oxidation state of the metal in **FA 6**/**FA 7** and **FA 8**.

Table 3.3

	FA 6/**FA 7**	**FA 8**
oxidation state		

[1]

[Total: 15]

Qualitative analysis notes

Question 3

Question 3

1 Reactions of cations

cation	reaction with	
	NaOH(aq)	**NH_3(aq)**
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	no ppt. ammonia produced on warming	–
barium, Ba^{2+}(aq)	faint white ppt. is observed unless $[Ba^{2+}(aq)]$ is very low	no ppt.
calcium, Ca^{2+}(aq)	white ppt. unless $[Ca^{2+}(aq)]$ is very low	no ppt.
chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq)	pale blue ppt. insoluble in excess	pale blue ppt. soluble in excess giving dark blue solution

Question 3

giving dark blue solution

Question 3

iron(II), $Fe^{2+}(aq)$	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), $Fe^{3+}(aq)$	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, $Mg^{2+}(aq)$	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), $Mn^{2+}(aq)$	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, $Zn^{2+}(aq)$	white ppt. soluble in excess	white ppt. soluble in excess

2 Reactions of anions

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, $Cl^-(aq)$	gives white ppt. with $Ag^+(aq)$ (soluble in $NH_3(aq)$)

Question 3

chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives cream / off-white ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives pale yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; decolourises acidified aqueous $KMnO_4$
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids); gives white ppt. with high [Ca^{2+}(aq)]
sulfite, SO_3^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (soluble in excess dilute strong acids); decolourises acidified aqueous $KMnO_4$
thiosulfate, $S_2O_3^{2-}$(aq)	gives off-white / pale yellow ppt. slowly with H^+

3 Tests for gases

gas	test and test result

Question 3

ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater
hydrogen, H_2	‘pops’ with a lighted splint
oxygen, O_2	relights a glowing splint

Solution 3

(a)(i) Mark scheme

- M1 Heat (solid FA 5)
- AND
- observe condensation, droplets, steam, water vapour M2
- Make an aqueous solution of FA 5 / dissolve in water to use for tests M3
- (To portion of the solution) add aqueous NH3
- AND
- white ppt AND insoluble in excess NH3 M4
- (To portion of the solution) add aqueous barium chloride or barium nitrate

Solution 3

- AND
- white precipitate **M5**
- to distinguish sulfate / sulfite
- (white precipitate from M4) insoluble in hydrochloric OR nitric acid
- OR
- KMnO4 is not decolourised / remains purple (added after M4 or directly to FA 5 (aq))
- 5

Solution 3

(a)(ii) Mark scheme

- Zn^{2+}
- X
- SO_4^{2-}
-
- H_2O
-
- 1

Solution 3

(b)(i) Mark scheme

- ▪
- (FA 6) starting colour purple
- ▪
- solid jumps / moves around
- ▪
- black residue
- ▪
- test with glowing splint

Solution 3

- ▪
- splint relights / glows more brightly
- 2

Solution 3

(b)(ii)

Mark scheme

- (dark) Green
- 1
- 9701/31
- October/November 2025

Solution 3

(c)(i) Mark scheme

- 'No change' 2 correct = *, 3 correct = **
- 2* = 1 mark
- Max mark = 4
- test
- observations
- FA 7
- FA 8
- FA 9

Solution 3

- Test 1
- Add
- hydrogen peroxide
- Bubbles/ effervescence *
- Purple / FA 7 (solution) to
- colourless (solution) *
- (Gas / oxygen) relights
- glowing splint *
- No change
- Bubbles / effervescence *

Solution 3

- (Gas/ oxygen) relights
- glowing splint *
- Test 2
- Add
- sodium hydroxide,
- then
- Off-white ppt*
- No change
- leave to stand
- brown ppt on standing*

Solution 3

- Test 3
- Add aqueous
- iron(II) sulfate
- Turns colourless / yellow
- OR colourless / yellow
- solution formed*
- No change
- 4

Solution 3

(c)(ii)

Mark scheme

- manganese / Mn
- 1
- 9701/31
- October/November 2025

Solution 3

(c)(iii) Mark scheme

- FA 6 / FA 7
- FA 8
- oxidation
- state
- (+)7
- (+)2
- 1

Question 3

9701/33 N25 ▪ Q3 ▪ 14 marks

3 Half-fill the 250 cm^3 beaker with water and place it on a tripod and gauze. Heat the water until boiling then switch off your Bunsen burner. This will be your hot water bath for use in **(b)(i)**. Start **(a)(i)** while the water is heating.

(a) **FA 4** is an aqueous solution containing three ions. One ion is **not** listed in the Qualitative analysis notes. **FA 5** is an aqueous solution containing two ions. The cation in **FA 5** is listed in the Qualitative analysis notes. The anions in both **FA 4** and **FA 5** contain sulfur.

(i) Carry out the following tests using a 1 cm depth of either **FA 4** or **FA 5** in a test-tube. Record your observations in Table 3.1.

Table 3.1

test	*observations*	
	FA 4	**FA 5**
Test 1 Add aqueous		

Question 3

Add aqueous sodium hydroxide.		
Test 2 Add aqueous ammonia.		
Test 3 Add aqueous sodium carbonate.		
Test 4 Add aqueous barium chloride or aqueous barium nitrate.		

Question 3

Test 5 Add acidified aqueous potassium manganate(VII).		

[5]

(ii) From your observations in **(a)(i)**, deduce the identities of the ions present in **FA 4** and **FA 5**. Give the formula of each ion in Table 3.2. If you are unable to identify an ion write 'unknown'.

Table 3.2

ions present	**FA 4**	**FA 5**
cations		

Question 3

anions		

[3]

(b) (i) Both **FA 6** and **FA 7** are one of propan-1-ol, propan-2-ol, methanoic acid or ethanoic acid. You will carry out tests to investigate the identities of **FA 6** and **FA 7**. For each test use a 1 cm depth of **FA 6** or **FA 7** in a test-tube. Record your observations in Table 3.3.

Table 3.3

test	*observations*	
	FA 6	**FA 7**
Test 1 Add a few drops of acidified aqueous potassium manganate(VII), then		

Question 3

place the test-tube in the hot

Question 3

place the test-tube in the hot water bath.		
Test 2 Add a 2 cm depth of aqueous iodine followed by drops of aqueous sodium hydroxide until the colour just disappears.		
If no reaction is visible, place the test-tube in the hot water bath.		
Test 3 Add aqueous sodium carbonate.		

[3]

(ii) From your observations in **(b)(i)** deduce the identities of **FA 6** and **FA 7**. Give reasons for

Question 3

your answers

Question 3

your answers.

Question 3

Question 3

Question 3

Question 3

Question 3

Question 3

[2]

(c) A student carrying out a similar set of tests identifies two unknown compounds to be ethanol and propanoic acid.

Write an equation for the reaction between these two compounds.

Question 3

[Total: 14]

Qualitative analysis notes

1 Reactions of cations

cation	reaction with	
	NaOH(aq)	**NH_3(aq)**
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	no ppt. ammonia produced on warming	–
barium, Ba^{2+}(aq)	faint white ppt. is observed unless [Ba^{2+}(aq)] is very low	no ppt.
calcium, Ca^{2+}(aq)	white ppt. unless [Ca^{2+}(aq)] is very low	no ppt.

Question 3

Question 3

chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq)	pale blue ppt. insoluble in excess	pale blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

Question 3

Question 3

2 Reactions of anions

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives cream / off-white ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives pale yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; decolourises acidified aqueous $KMnO_4$
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids); gives white ppt. with high [Ca^{2+}(aq)]
sulfite, SO_3^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (soluble in excess dilute strong acids); decolourises acidified aqueous $KMnO_4$

Question 3

thiosulfate, $S_2O_3^{2-}(aq)$	gives off-white/pale yellow ppt. slowly with H^+

3 Tests for gases

gas	test and test result
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater
hydrogen, H_2	‘pops’ with a lighted splint
oxygen, O_2	relights a glowing splint

Solution 3

(a)(i) Mark scheme

- 2 * = 1 mark (round down). Max 5 marks.
- test
- observations
- FA 4
- FA 5/1 + NaOH(aq)
- red-brown / brown ppt
- AND
- insoluble in excess *

Solution 3

- white ppt *
- soluble in excess *
- 2
- + NH3(aq)
- red-brown / brown ppt
- AND
- insoluble in excess *
- white ppt
- AND
- insoluble in excess *

Solution 3

- 3
- + Na2CO3(aq)
- fizzing *
- gas gives white ppt with
- limewater *
- red-brown ppt *
- white ppt *
- fizzing *
- gas gives white ppt with
- limewater (award if not awarded

Solution 3

- for FA 4)
- 4
- + BaCl 2(aq) /
- Ba(NO3)2(aq)
- white ppt
- AND
- white ppt *
- 5
- + H+ / KMnO4(aq)
- stays purple / no change AND stays purple / no change *

Solution 3

- 5
- 9701/33
- October/November 2025

Solution 3

(a)(ii) Mark scheme

- ions
- FA 4
- FA 5
- cations
- Fe3+; H+
- Al 3+
- anions
- SO42−

Solution 3

- $SO4^{2-}$
- 5 ions correct = 3 marks
- 3 or 4 ions correct = 2 marks
- 2 ions correct = 1 mark
- 3

Solution 3

(b)(i) Mark scheme

- 2 * = 1 mark (round down)
- test
- observations
- FA 6
- FA 7/1 + H+ / KMnO4(aq)
- (turns paler pink)
- (purple fades slightly)
- and warm

Solution 3

- decolourises / turns colourless /
- turns (pale) yellow *
- decolourises / turns colourless /
- turns (pale) yellow *
- 2
- + I2(aq) + NaOH
- (and warm)
- no change *
- ppt * that is (pale) yellow *
- 3

Solution 3

- + Na2CO3(aq)
- fizzing *
- no change *
- 3
- 9701/33
- October/November 2025

Solution 3

(b)(ii)

Mark scheme

- M1 (FA 6 is) methanoic acid because it produces CO2 / reacts with sodium carbonate
- AND it can be oxidised / it reacts with KMnO4 **M2**
- (FA 7 is) propan-2-ol as it gives a ppt in test 2
- OR gives a positive tri-iodomethane/iodoform test
- OR has the $-CH(OH)CH3$ group
- 2

Solution 3

(c)

Mark scheme

- Correct equation
- $CH3CH2COOH + CH3CH2OH \rightarrow CH3CH2COOCH2CH3 + H2O$
- OR
- $C2H5COOH + C2H5OH \rightarrow C2H5COOC2H5 + H2O$
- 1

Question 3

9701/34 N25 ▪ Q3 ▪ 15 marks

3 **(a)** **(i)** To a 1 cm depth of **FB 4** in a boiling tube, slowly add a 1 cm depth of dilute nitric acid. Stir gently until the reaction is complete. Use this solution for your tests.
Select reagents to identify which sodium halide is present.
Record details of the reagents used and your observations.
Identify the sodium halide that is present as an impurity in **FB 4**.

Question 3

[2]

(ii) Suggest why it is necessary to add the nitric acid to **FB 4** before carrying out your tests in **(a)(i)**.

Question 3

(b) **FB 7** contains a metal cation which is listed in the Qualitative analysis notes.

(i) Place half the sample of **FB 7** in a hard-glass test-tube. Heat gently at first and then more strongly.
Record your observations.

Question 3

(ii) Use the 25 cm^3 measuring cylinder to measure 20 cm^3 of **FB 1**.
Place the remaining sample of **FB 7** in a boiling tube and add portions of **FB 1** from the measuring cylinder until all the **FB 7** has reacted. Stir until the reaction is complete.
Record your observations.

Keep this solution for use in (b)(iii).

Question 3

(iii) Carry out the following tests. For each test use a 1 cm depth of the solution from **(b)(ii)** in a test-tube.
Record your observations in Table 3.1.
Identify the metal ion present in **FB 7**.

Table 3.1

test	*observations*
Test 1 Add aqueous sodium hydroxide.	
Test 2 Add aqueous ammonia.	

Question 3

Question 3

Test 3 Add a piece of aluminium foil.	

Question 3

[4]

(c) **FB 8** is an acidified aqueous solution containing a metal cation which is listed in the Qualitative analysis notes.

(i) Carry out the following tests. For each test use a 1 cm depth of **FB 8** in a test-tube.
Record your observations in Table 3.2.
Identify the metal ion present in **FB 8**.

Table 3.2

test	*observations*
Test 1 Add aqueous sodium hydroxide.	
Test 2	

Question 3

Test 2

Question 3

Add a 1 cm depth of acidified aqueous potassium manganate(VII).	

Question 3

[3]

(ii) State the type of reaction between the metal ion in **FB 8** and acidified aqueous potassium manganate(VII).
Explain how your observations support your answer.

Question 3

[Total: 15]

Qualitative analysis notes

1 Reactions of cations

cation	reaction with	
	NaOH(aq)	**NH_3(aq)**
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	no ppt. ammonia produced on warming	–
barium, Ba^{2+}(aq)	faint white ppt. is observed unless [Ba^{2+}(aq)] is very low	no ppt.
calcium, Ca^{2+}(aq)	white ppt. unless [Ca^{2+}(aq)] is very low	no ppt.

Question 3

chromium(III), $Cr^{3+}(aq)$	grey-green ppt. soluble in excess	grey-green ppt. insoluble in excess

Question 3

	giving dark green solution	
copper(II), Cu^{2+}(aq)	pale blue ppt. insoluble in excess	pale blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

2 Reactions of anions

Question 3

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives cream / off-white ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives pale yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; decolourises acidified aqueous $KMnO_4$
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids); gives white ppt. with high [Ca^{2+}(aq)]
sulfite, SO_3^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (soluble in excess dilute strong acids); decolourises acidified aqueous $KMnO_4$
thiosulfate, $S_2O_3^{2-}$(aq)	gives off-white / pale yellow ppt. slowly with H^+

Question 3

3 Tests for gases

gas	test and test result
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater
hydrogen, H_2	‘pops’ with a lighted splint
oxygen, O_2	relights a glowing splint

Solution 3

(a)(i) Mark scheme

- ▪
- selects (aqueous) silver nitrate and (aqueous) ammonia *
- ▪
- white ppt *
- ▪
- soluble in (aqueous) ammonia *
- ▪
- NaCl *

Solution 3

- 2 * = 1 mark
- 2

Solution 3

(a)(ii)

Mark scheme

- (The acid) removes / reacts with the hydrogencarbonate ions OR silver ions react with hydrogencarbonate ions
- 1

Solution 3

(b)(i) Mark scheme

- ▪
- green (at start) *
- ▪
- turns to a black powder / solid *
- ▪
- powder very fluid / moves around the test-tube *
- ▪
- condensation (on walls of test-tube) *

Solution 3

- 2 * = 1 mark
- 2

Solution 3

(b)(ii) Mark scheme

- ▪
- forms green-blue solution *
- ▪
- effervescence *
- ▪
- vigorous reaction *
- ▪
- attempts to test with limewater *

Solution 3

- ▪
- gas / carbon dioxide gives white precipitate / solid with limewater *
- 2 * = 1 mark
- 2
- 9701/34
- October/November 2025
- Question Answer

Solution 3

(b)(iii) Mark scheme

- Test 1
- Add NaOH(aq)
- (pale) blue precipitate insoluble in excess *
- Test 2
- Add NH3(aq)
- (pale) blue precipitate *
- (precipitate dissolves forming) dark / deep blue solution in excess *
- Test 3

Solution 3

- Add aluminium
- foil
- effervescence / fizzing*
- (gas) pops with a lighted splint *
- pink-brown solid *
- turns colourless / pale blue solution formed *
- gets hotter *
- Metal ion in FB 7: Cu2+ *
- 2 * = 1 mark
- 4

Solution 3

(c)(i) Mark scheme

- Test 1
- Add NaOH(aq)
- green precipitate *
- insoluble in excess *
- (precipitate) turns brown (on surface) *
- Test 2
- Add acidified
- KMnO4

Solution 3

- purple to colourless / (pale) yellow solution
- OR KMnO4 decolourised*
- 2 * = 1 mark
- 2
- Metal ion in FB 8: Fe2+
- 1

Solution 3

(c)(ii)

Mark scheme

- Redox reaction
- AND change to colourless linked to reduction of manganate(VII) ions OR change to yellow colour linked to oxidation of
- Fe2+ or production of Fe3+.
- 1

Question 5

9701/41 N25 ▪ Q5 ▪ 14 marks

5 **(a)** Copper shows typical properties of transition elements, including its behaviour as a catalyst.

Complete Table 5.1 to show the total number of **unpaired** electrons in the 3d and 4s orbitals of an isolated gaseous Cu atom and a Cu^{2+} ion.

Table 5.1

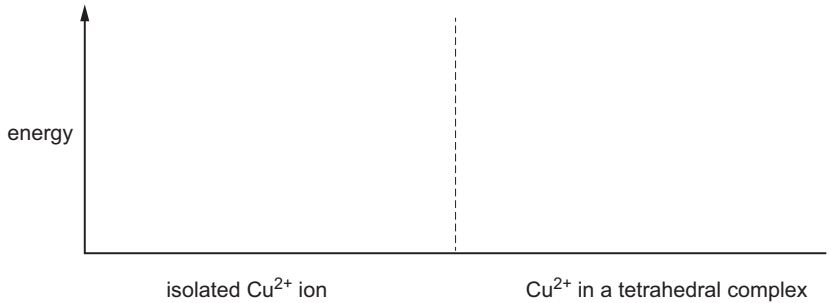
species	number of **unpaired** electrons	
	3d	4s
Cu		
Cu^{2+}		

[1]

(b) The 3d orbitals in an isolated Cu^{2+} ion are degenerate.

Question 5

Complete the diagram to show the relative energies of the 3d orbitals in an isolated Cu^{2+} ion and in Cu^{2+} in a tetrahedral complex.



[2]

(c) Explain why transition elements behave as catalysts.

(d) CN^- is a monodentate ligand.

Table 5.2 shows information about two complex ions that contain only CN^- ions as ligands.

Complete Table 5.2.

Table 5.2

metal ion	coordination number	formula of complex ion	charge of complex ion
Ag^+	2		
Fe^{2+}			4–

[2]

(e) The complex ion $[Au(CN)_2Br_2]^-$ displays geometrical (cis/trans) isomerism.

Draw the structure of *trans*-$[Au(CN)_2Br_2]^-$. State its shape and the Br-Au-Br bond angle.

Question 5

Draw the structure of *trans*-$[Au(CN)_2Br_2]^-$. State its shape and the Br–Au–Br bond angle.

Question 5

Question 5

[2]

(f) An impure sample of a vanadium(V) compound of mass 0.250 g is dissolved in aqueous acid. This solution contains VO_3^- ions.

An excess of zinc is added to this solution. All the VO_3^- ions are reduced to V^{2+} ions and Zn atoms are oxidised to Zn^{2+} ions.

The unreacted zinc is removed and the resulting solution is titrated with acidified MnO_4^-.

The end-point is reached when 22.5 cm^3 of 0.0750 mol dm^{-3} MnO_4^- is added.

A redox reaction takes place and all the V^{2+} reacts forming VO_3^-.

$$3MnO_4^- + 5V^{2+} + 3H_2O \rightarrow 3Mn^{2+} + 5VO_3^- + 6H^+$$

(i) Calculate the percentage by mass of vanadium in the 0.250 g of impure sample.

Assume the impurities do not contain any vanadium ions.

Question 5

Question 5

Show your working.

Question 5

(ii) Complete the equation for the reaction between acidified VO_3^- ions and Zn metal.

Question 5

[2]

[Total: 14]

Solution 5

(a)

Mark scheme

- 1

Solution 5

(b) Mark scheme

- ▪
- five 3d orbitals (lines, boxes) in the isolated Cu2+ ion of the same energy
- ▪
- splitting: three higher and two lower d orbitals
- ▪
- energy of all five d orbitals in complex higher than all d orbitals in isolated ion
- any two [1], all three [2]
- 2

Solution 5

(c)

Mark scheme

- M1: more than one (stable) oxidation state / exist in variable oxidation states
- M2: vacant / empty (d) orbitals are energetically accessible
- OR vacant / empty (d) orbitals can form dative bonds with ligands
- 2

Solution 5

(d)

Mark scheme

- each row [1]
- 2
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Solution 5

(e)

Mark scheme

- M1:
- M2: (shape) square planar AND (bond angle) 180o
- 2

Solution 5

(f)(i)

Mark scheme

- M1: moles $MnO4- = 0.075 \times 0.0225 = 1.6875 \times 10–3$
- M2: moles $V2+ = 5 / 3 \times 1.6875 \times 10–3 = 2.8125 \times 10–3$
- M3: mass $V = 50.9 \times 2.8125 \times 10–3 = 0.143\,g$
- % of $V = 0.143 / 0.250 \times 100 = 57.3$ min 2sf
- 3

Solution 5

(f)(ii)

Mark scheme

- $2VO3- + 3Zn + 12H+ \rightarrow 2V2+ + 3Zn2+ + 6H2O$
- M1: 2 : 3 ratio on both sides
- M2: rest of the equation correct
- 2

Question 5

9701/42 N25 ▪ Q5 ▪ 15 marks

5 Cobalt is a transition element which forms compounds containing Co^{2+} and Co^{3+} ions. Cobalt(II) sulfate dissolves in water to form a solution containing the $[Co(H_2O)_6]^{2+}$ complex ion.

(a) (i) Complete the electronic configurations of a Co^{2+} ion and a Co^{3+} ion.

Question 5

Question 5

[1]

(ii) Explain why transition elements can form complex ions.

Question 5

(iii) An excess of concentrated HC*l* is added to a solution containing $[Co(H_2O)_6]^{2+}$.

Describe the colour change observed and the state of the cobalt-containing product.

Question 5

Question 5

[2]

(iv) Write an equation for the reaction occurring in **(a)(iii)**.

Question 5

(v) Name the type of reaction occurring in **(a)(iii)**.

Question 5

(vi) Write an equation for the reaction that occurs when an excess of NaOH(aq) is added to a solution containing $[Co(H_2O)_6]^{2+}$.

Question 5

(b) Cobalt metal can be oxidised by acidified $K_2Cr_2O_7$. The relevant half-equations, and their $E^\ominus$ values, are shown.

$$Co^{2+} + 2e^- \rightleftharpoons Co \qquad E^\ominus = -0.28\,V$$
$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O \qquad E^\ominus = +1.33\,V$$

(i) A Co^{2+}/Co electrode is constructed in which $[Co^{2+}]$ is $0.020\,mol\,dm^{-3}$ at 298 K.

Use the Nernst equation to show that the E value for this Co^{2+}/Co electrode is –0.33 V.

Question 5

[2]

(ii) An electrochemical cell is constructed using the Co^{2+}/Co electrode described in **(b)(i)** and a $Cr_2O_7^{2-}/Cr^{3+}$ electrode in which all conditions are standard.

Calculate the value of E_{cell}.

Question 5

(iii) A current is drawn from the electrochemical cell described in **(b)(ii)**.

Write an equation for the reaction taking place in the cell.

Question 5

(iv) Complete the sentences to identify the negative electrode and the direction of electron flow when a current is drawn from the cell described in **(b)(ii)**.

Question 5

[1]

(c) A molten Co^{2+} salt is electrolysed using a current of 0.500 A.

0.547 g of cobalt metal forms at the cathode. Under the conditions used no other reduction reaction occurs at the cathode.

Calculate the time in minutes for which the current flows to produce this mass of cobalt.

Give your answer to **three** significant figures.

Question 5

[Total: 15]

Solution 5

(a)(i)

Mark scheme

- Co2+ = [Ar] 3d7 AND Co3+ = [Ar] 3d6
- 1

(a)(ii)

Mark scheme

- has vacant d orbitals that are energetically accessible
- 1

Solution 5

(a)(iii) Mark scheme

- ▪
- pink
- ▪
- blue
- ▪
- aqueous
- Any two [1], all three [2]
- 2

Solution 5

(a)(iv)

Mark scheme

Co(H2O)6 2+ + 4HCl → [CoCl4]2– + 6H2O + 4H+ OR [Co(H2O)6]2+ + 4Cl– → [CoCl4]2– + 6H2O

- 1
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Solution 5

(a)(v)

Mark scheme

- ligand exchange
- 1

Solution 5

(a)(vi)

Mark scheme

$Co(H_2O)_6^{2+} + 2OH^- \rightarrow Co(OH)_2(H_2O)_4 + 2H_2O$ OR

$Co(H_2O)_6^{2+} + 2OH^- \rightarrow Co(OH)_2 + 6H_2O$

- 1

Solution 5

(b)(i)

Mark scheme

- M1: Nernst equation $E = Eo + (0.059 / z) \times \log(\frac{[\text{oxidised}]}{[\text{reduced}]})$
- M2: $E = -0.28 + (0.059 / 2) \times \log(0.02)$
- 2

Solution 5

(b)(ii)

Mark scheme

- 1.66 V
- 1

(b)(iii)

Mark scheme

- $3Co + Cr2O72- + 14H+ \rightarrow 3Co2+ + 2Cr3+ + 7H2O$
- 1

Solution 5

(b)(iv)

Mark scheme

- Co^{2+} / Co, Co^{2+} / Co, $Cr_2O_7^{2-}$ / Cr^{3+}
- 1

Solution 5

(c)

Mark scheme

- M1: moles of cobalt $= 0.547 / 58.9 = 0.00929$
- M2: coulombs required $= 0.00929 \times 96500 \times 2 = 1792$
- M3: time required $= 1792 / 0.50 = 3584.8\,\text{s} = 59.7$ minutes 3sf
- 3

Question 1

9701/44 N25 ▪ Q1 ▪ 19 marks

1 **(a)** Define a transition element.

Question 1

(b) The 3d orbitals in an isolated gaseous Cu^{2+} ion are degenerate.

(i) Define the term degenerate.

Question 1

(ii) Complete the electronic configuration of Cu^{2+}.

Question 1

(c) **(i)** State the colours of the aqueous solutions for the **two** copper(II) complex ions shown.

Question 1

Question 1

[1]

(ii) Explain why aqueous complex ions of transition elements are usually coloured.

Question 1

(d) **(i)** When an excess of $NH_3(aq)$ is added to a solution of $[CuCl_4]^{2-}(aq)$, $[Cu(NH_3)_4(H_2O)_2]^{2+}(aq)$ is formed.

State the type of reaction.
Complete the equation for this reaction. State symbols are **not** required.

Question 1

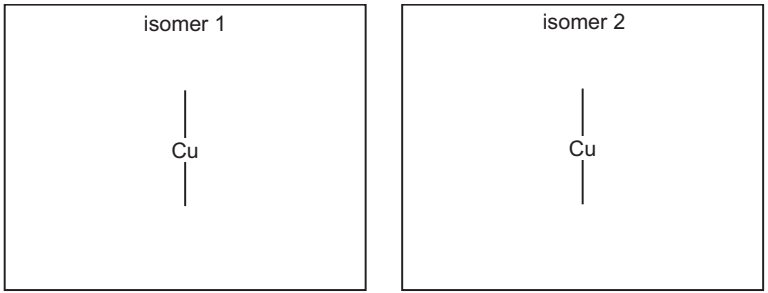
equation

Question 1

[2]

(ii) The $[Cu(NH_3)_4(H_2O)_2]^{2+}$ complex ion shows stereoisomerism.

Complete the three-dimensional diagrams in Fig. 1.1 to show the **two** different stereoisomers of $[Cu(NH_3)_4(H_2O)_2]^{2+}$.



Question 1

Fig. 1.1

Question 1

Fig. 1.1

[2]

(iii) Deduce which stereoisomer in **(d)(ii)** is polar.

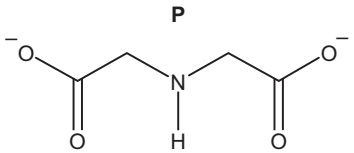
Explain your answer.

Question 1

[1]

(e) The dianion **P** can act as a tridentate ligand.

P



(i) Suggest how **P** can form **three** dative covalent bonds.

Question 1

(ii) 2 moles of dianion **P**, $C_4H_5NO_4^{2-}$, react with 1 mole of aqueous cobalt(III) ions, $[Co(H_2O)_6]^{3+}$ to form 1 mole of complex ion **Q**.

Deduce the formula and charge of **Q**.

Question 1

(f) Table 1.1 shows values for the stability constants, K_{stab}, of some silver(I) complexes.

Table 1.1

complex	value of K_{stab}
$[Ag(CN)_2]^-(aq)$	1.1×10^{18}
$[Ag(NH_3)_2]^+(aq)$	1.2×10^{7}
$[Ag(S_2O_3)_2]^{3-}(aq)$	2.9×10^{13}

(i) Define the stability constant of a complex.

Question 1

(ii) Use the information in Table 1.1 to identify the most stable silver(I) complex.

Explain your answer.

Question 1

Question 1

Question 1

[1]

(g) Sodium sulfite, Na_2SO_3, is used as a food preservative.

A 3.75 g sample of impure Na_2SO_3 is dissolved in distilled water and made up to 250 cm^3 in a volumetric flask.

10.0 cm^3 of this solution requires 18.70 cm^3 of acidified 0.0150 mol dm^{-3} MnO_4^-(aq) to reach the end-point.

The equation for the reaction is shown.

$$2MnO_4^- + 5SO_3^{2-} + 6H^+ \rightarrow 2Mn^{2+} + 5SO_4^{2-} + 3H_2O$$

Calculate the percentage by mass of Na_2SO_3 in the sample.

Question 1

Question 1

[Total: 19]

Solution 1

(a)

Mark scheme

- forms (one or more) stable ions / compounds / oxidation states
- with incomplete / partially filled (3)d orbital(s) / d shell / d sub-shell
- 1

Solution 1

(b)(i)

Mark scheme

- (orbitals) are at the same energy
- 1

(b)(ii)

Mark scheme

- (1s2) 2s2 2p6 3s2 3p6 3d9
- 1

Solution 1

(c)(i)

Mark scheme

H3)4(H2O)2 2+(aq) deep / dark / royal blue

- AND

CuCl4 2–(aq)

- yellow
- 1

Solution 1

(c)(ii) Mark scheme

- M1:
- d orbital(s) of different energy / d-d splitting occurs / d sub-shell splits
- M2:
- electron(s) promoted / excited
- M3:
- light / wavelength / frequency / photon absorbed AND complementary colour seen
- 3

Solution 1

(d)(i)

Mark scheme

- M1: ligand exchange / replacement / substitution / displacement
- M2: $[CuCl_4]^{2-} + 4NH_3 + 2H_2O \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4Cl^-$
- 2

Solution 1

(d)(ii)

Mark scheme

- M1: one correct 3D structure of [Cu(H2O)2(NH3)4]2+
- M2: correct 3D stereoisomer structure of isomer 1/2

(d)(iii)

Mark scheme

- cis isomer AND dipoles do not cancel
- 1

Solution 1

(e)(i)

Mark scheme

- (two) oxygen and (one) nitrogen (can donate) three lone pair(s) of electrons (to the metal ion)
- 1
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Solution 1

(e)(ii)

Mark scheme

C4H5NO4)2 –

- 1

Solution 1

(f)(i)

Mark scheme

- equilibrium constant for the formation of the complex (ion)
- in a solvent / water / solution OR from its constituent ions or molecules
- 1

Solution 1

(f)(ii)

Mark scheme

$Ag(CN)_2^-$(aq) AND largest (value of) Kstab

- 1

Solution 1

(g) Mark scheme

- M1 M2: any two [1], all four [2]
- ▪
- moles MnO4– = 0.015 ×18.70/1000 = 2.805 × 10–4
- ▪
- moles SO32– = 2.805 × 10–4 × 5/2 = 7.0125 × 10–4 (in 10 cm3)
- ▪
- moles SO32– = 1.753 × 10–2 (in 250 cm3)
- ▪

Solution 1

- mass Na2SO3 = 1.753 × 10–2 × 126.1 = 2.21 g
- M3: % purity = 100 × 2.21 / 3.75 = 58.9 – 59.0 % min 2sf
- 3