Cambridge Assessment International Education

Teaching Pack

Preparation of a transition metal complex

Cambridge International AS & A Level Chemistry 9701

Version 1.0

Cambridge Pathway

Contents

Icons used in this pack:

Briefing lesson

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Introduction

This pack will help you to develop your learners' experimental skills as defined by assessment objective 3 (AO3 Experimental skills and investigations) in the course syllabus.

Important note
Our *Teaching Packs* have been written by **classroom teachers** to help you deliver topics and skills that can be challenging. Use these materials to supplement your teaching and engage your learners. You can also use them to help you create lesson plans for other experiments.

This content is designed to give you and your learners the chance to explore practical skills. It is not intended as specific practice for Paper 3 (Advanced Practical Skills) or Paper 5 (Planning, Analysis and Evaluation).

This is one of a range of *Teaching Packs* and each pack is based on one experiment. The packs can be used in any order to suit your teaching sequence.

The structure is as follows:

Briefing lesson (1 hour*)
This lesson reinforces the key concepts, relevant skills, knowledge and understanding linked to the experiment.

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Planning lesson (1 hour*)
This lesson focuses on planning an experiment.
It ends with a demonstration video of the experiment.

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Lab lesson (1 hour*)
This lesson focuses on carrying out the experiment including the collection and recording of observations, measurements and estimates.

↓

Debriefing lesson (1 hour*)
This lesson focuses on the analysis and interpretation of data.
This includes making conclusions, evaluating methods and the quality of data and how improvements could be made.

** the timings are a guide only; you may need to adapt the lessons to suit your circumstances.*

In this pack you will find lesson plans, worksheets and teacher resource sheets.

Experiment: Preparation of a transition metal complex

This *Teaching Pack* focuses on how to make a transition metal complex.

Transition elements are found in the d block of the Periodic Table, between groups 2 and 13. Some transition elements can form complexes with a variety of ligands.

In this experiment, learners will prepare the cobalt transition metal complex, pentaamminechlorocobalt(III) chloride and calculate its percentage yield.

Note: This experiment requires a lot of time as the preparation of the complex is complicated. The lab and equipment should be set-up before the lab so that learners can set-up quickly. It will also help if learners work in slightly larger groups. It requires gently heating for 20 min after several preparation stages. Time will also be needed for the filtration stage. This could be achieved within an hour lesson, but a 2-hour lesson might provide for a better practical experience.

The syllabus reference for this experiment is:

- 28.1 General characteristic chemical properties of the first set of transition elements, titanium to copper

The experiment covers the following experimental skills, adapted from **AO3: Experimental skills and investigation**:

- plan experiments and investigations, including equipment selection
- evaluate methods and suggest possible improvements.

Prior knowledge

Knowledge from the following syllabus topics is required for this experiment. It is useful to have covered them before carrying out this experiment. If these have not been covered yet, you will need to explain the concepts during the experiment or virtual experiment lesson.

- 28.1 General physical properties of the first set of transition elements, titanium to copper
- 28.2 General characteristic chemical properties of the first set of transition elements, titanium to copper

Briefing lesson: Pre-experiment exercises

Resources	• Worksheets A, B and C
Learning objectives	By the end of the lesson: • ***all*** learners should have completed a risk assessment table for the experiment • ***most*** learners should have completed some research on unfamiliar terms and apparatus to be used in the method • ***some*** learners will have completed extensive research on unfamiliar terms and apparatus to be used in the method.

Timings	Activity
5 min	**Introduction** Group learners into pairs and introduce the pre-experimental exercises that they will do.
	Main lesson Give learners Worksheet A, Worksheet B and Worksheet C.
10 min	*Task 1: Reading the method* Tell learners that they must read the method (Worksheet C) for the preparation of transition metal complex pentaamminechlorocobalt(III) chloride and highlight any unfamiliar words or apparatus in their experimental workbooks. They can use textbooks and the internet to look up these terms and become familiar with them.
30 min	*Task 2: Risk assessment table* Ask each pair to use the method to help complete the risk assessment table for the experiment. Learners should use the internet and/or textbooks to research the chemicals used in the experiment. Provide less able learners with assistance as required (provide web links such as www.sigmaaldrich.com and www.cleapss.org.uk as suitable starting points for recording safety information). If timing is an issue, then all the learners can be given the two suggested web links as a starting point for this activity. Learners can then check their answers against the suggested answers provided.
10 min	Ask learner pairs to peer assess each other's risk assessments and provide guidance where required. The suggested risk assessment table can be used.
5 min	**Plenary** *Task 3: Background knowledge questions* Set learners the homework task of completing the background knowledge questions ahead of the practical lesson.

Planning lesson: Planning the experiment

Resources	• Worksheets C, D and E • Ideal report • Experiment video
Learning objectives	By the end of the lesson: • ***all*** learners should have completed the planning sections of their experimental report • ***most*** learners should have detailed information in the planning sections of their experimental report • ***some*** learners will have compared their experimental set-up to the ideal and have made adjustments.

Timings	Activity
5 min	**Introduction** Explain the learning outcomes for the planning lesson. • To read the method and complete the introduction and experimental set-up parts of report. • To watch a video of a similar experiment and adjust their report accordingly.
20 min	**Main lesson** Group learners into pairs and give them the following information: *'To make pentaamminechlorocobalt(III) chloride from cobalt(II) chloride hexahydrate, water molecules need to be replaced by ammonia molecules and chloride ions. You are going to plan an experiment to make the transition metal complex pentaamminechlorocobalt(III) chloride.'* Give learners Worksheet C, Worksheet D and Worksheet E to help scaffold learning. Each group should discuss the variables involved in the experiment and start to write a report in their lab books.
20 min	Then learners should have a discussion with regard to the equipment they would choose and how they would set it up for the experiment. They should use Worksheet D to help with this. Remind them they will not need to use all of the equipment, reagents and the tests that might be needed. They must remember to accurately draw their equipment set-up which should be annotated so that their decisions are explained.
15 min	**Plenary** Show the learners the video of the experiment. Ask learners to compare their experimental illustrations with the video. Show them the section of the ideal report which details the experimental set-up. Get the learners to adjust their experimental set-up in their lab books.

Lab lesson: Running the experiment

Resources	• Teacher notes • *Teacher Walkthrough* video • Worksheets C, D, E and F • Equipment as outlined in the notes
Learning objectives	By the end of the lesson: • ***all*** learners should have prepared a sample of the product • ***most*** learners should be able to calculate the percentage yield • ***some*** learners will be able to start the interpretation and evaluation of their experimental data.

Timings	Activity
5 min	**Introduction** Learners should be put into groups. Hand out Worksheet F to each group (they should already have Worksheet C, Worksheet D and Worksheet E from the briefing and planning lessons).
50 min	**Main lesson** Ensure that the lab and equipment is set-up prior to the learners arriving. This will save time as the preparation of the complex requires gentle heating for 20 min. **(1) Preparation of product and recording results** Learners should follow the appropriate method on Worksheet C. Make sure that the observations are recorded in their lab books. Learners can use Worksheet F to help with any calculations. **Safety** Circulate the classroom at all times during the experiment and make sure that learners are safe and that the data they are collecting is accurate. Whilst the complex is heating on the hot-plate, learners can start to think about the conclusion and evaluation sections in their lab books and also setting up the Büchner funnel. Have to hand the data from the video should any learners have difficulty in preparing the complex or have yet to reach the filtration stage of the process. **(2) Clean-up** Make sure that the learners tidy up after themselves and clean up any bench spills. Finally, they should wash their hands.
5 min	**Plenary** For homework, ask learners to write in their reports, three ways they could improve the experiment. Tell them they need to think about: • the effectiveness of the method • limitations of equipment • possible sources of errors/uncertainties.

Teacher notes

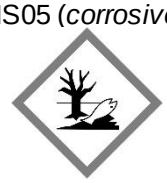
Watch the *Teacher Walkthrough* video for the preparation of the transition metal complex and read these notes.

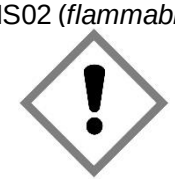
Each group will require:

- ammonium chloride
- concentrated 0.88 ammonia
- 250 cm^3 conical flask
- 10 cm^3 measuring cylinder
- 50 cm^3 measuring cylinder (×2)
- plastic pipette
- magnetic stirrer flea
- cobalt(II) chloride hexahydrate ($CoCl_2 \cdot 6H_2O$)
- 30% v/v hydrogen peroxide
- ice bath, i.e. plastic container containing ice cubes
- a spatula
- weighing boat (×2)
- concentrated hydrochloric acid [12 mol dm^{-3}]
- hot-plate (with stirrer function)
- glass stirring rod
- timer
- thermometer
- watch-glass
- vacuum filtration set-up using a Büchner funnel
- deionised water (cold)
- acetone
- Qualitative grade filter paper
- mass balance (to 3 dps).

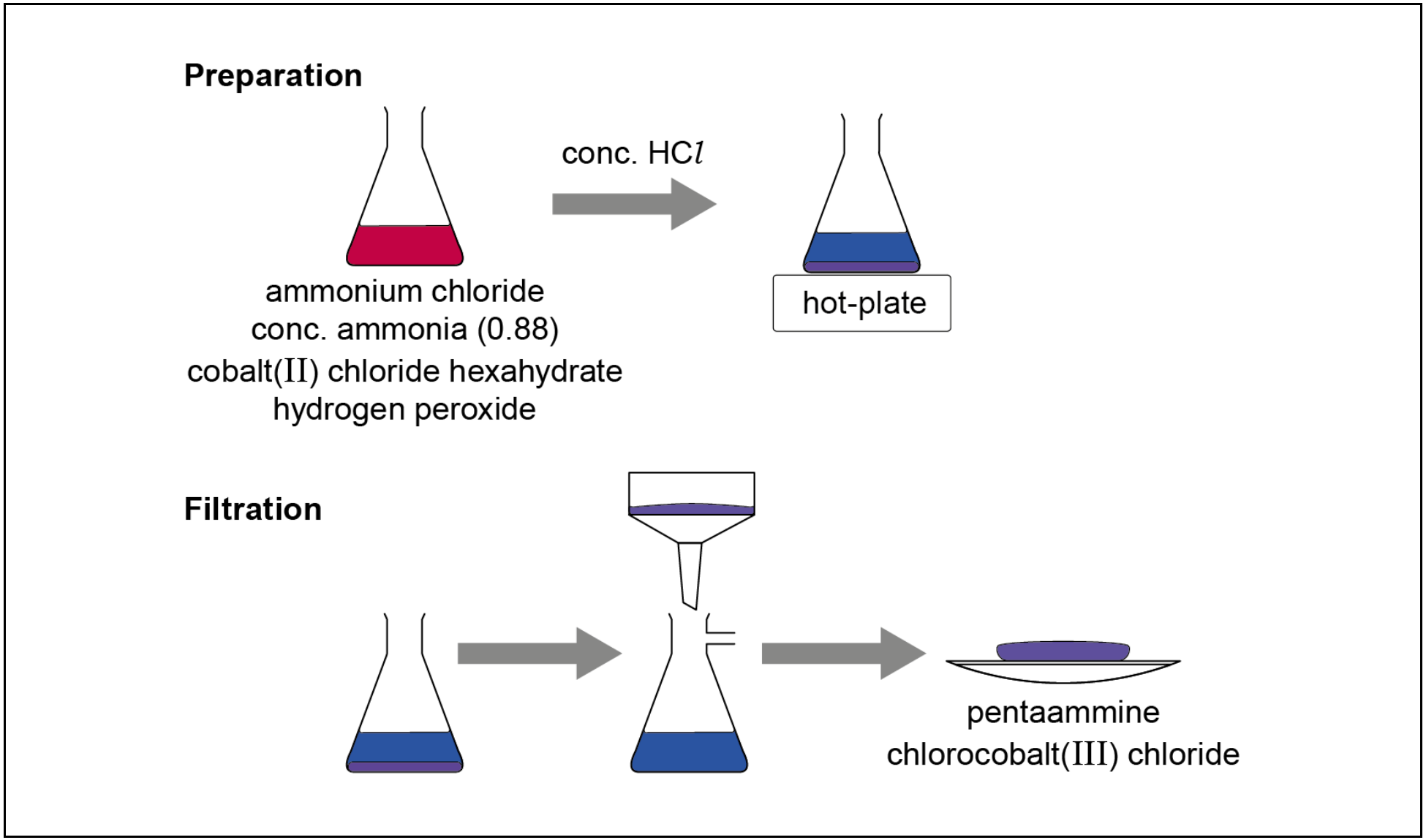
Safety

The information in the table below is a summary of the key points you should consider before undertaking this experiment with your learners.
It is your responsibility to carry out an appropriate risk assessment for this experiment.

Substance	Hazard	First aid measures
Ammonium chloride [solid]	 GHS07 (*moderate hazard* **MH**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Concentrated 0.88 ammonia solution	 GHS07 (*moderate hazard* **MH**)  GHS05 (*corrosive* **C**)  GHS09 (*hazardous to the aquatic environment* **N**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Cobalt(II) chloride hexahydrate [solid]	 GHS07 (*moderate hazard* **MH**)  GHS08 (*health hazard* **HH**)  GHS09 (*hazardous to the aquatic environment* **N**)	**In the eye:** flush eyes with water as a precaution. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.

Substance	Hazard	First aid measures
Hydrogen peroxide solution 30% v/v	 GHS05 (*corrosive* **C**)  GHS07 (*moderate hazard* **MH**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Concentrated hydrochloric acid solution [12 mol dm^{-3}]	 GHS05 (*corrosive* **C**)  GHS07 (*moderate hazard* **MH**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Acetone	 GHS02 (*flammable* **F**)  GHS07 (*moderate hazard* **MH**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Pentaamminechlorocobalt(III) chloride solid	 GHS07 (*moderate hazard* **MH**)  GHS08 (*health hazard* **HH**)  GHS09 (*hazardous to the aquatic environment* **N**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.

Experiment set-up



Teacher method

This is your version of the method for this experiment that accompanies the teacher video.

Do not share this method with learners. Give them Worksheet C.

Before you begin
Plan how you will group your learners during the experiment.

Think about:

- the number of pairs you will need and whether or not you or the learners should add the concentrated hydrochloric acid
- the amount of equipment/chemicals required.

Experiment
Circulate during the experiment in case learners encounter any difficulties.

Steps	Notes
1. Learners should collect all the equipment they need from the front of the class.	*Remind learners they need to wear gloves throughout this experiment and work in the fume cupboard.*
2. Learners should use the balance to weigh out approximately 5.0 g of ammonium chloride and leave aside.	
3. Learners should then use a measuring cylinder to add 30 cm^3 concentrated 0.88 ammonia to the conical flask.	
4. Learners should transfer the ammonium chloride to conical flask and dissolve using the stirring rod.	
5. Learners should then weigh out approximately 10.0 g of cobalt(II) chloride hexahydrate.	*Remind learners to record this mass in their results table as it will be used to calculate the percentage yield.*
6. Learners should use a spatula to transfer about a quarter of the cobalt(II) chloride hexahydrate to the flask and continually agitate this solution by gently swirling the flask at its neck.	

7. Learners should repeat the same process with the other three portions of cobalt(II) chloride hexahydrate until a warm slurry/solution has formed.

Remind learners to make sure that each portion reacts before the next portion is added.

This slurry/solution contains a precipitate of $[Co(NH_3)_6]Cl_2$.

8. Learners should then use a measuring cylinder to measure out 20 cm^3 of 30% v/v hydrogen peroxide.

9. Learners should use a plastic pipette to carefully add 1 cm^3 of hydrogen peroxide at a time to the warm slurry/solution in the conical flask, whilst continually stirring the reaction mixture.

Remind learners that addition of the hydrogen peroxide results in a vigorous exothermic reaction with effervescence.

They can adjust the amount of hydrogen peroxide added if the reaction is too vigorous.

10. Learners should add a thermometer to the flask and allow the contents to slowly cool down to room temperature.

Learners should see a deep red solution ($[Co(NH_3)_5(OH_2)]^{3+}$) appearing (sometimes this may look brown, which is not a problem).

11. Learners should wait until the flask contents have cooled down, measure out 30 cm^3 of concentrated hydrochloric acid and slowly add to the cooled conical flask.

12. Learners should then add a magnetic stirrer flea to the cooled flask, place it on a hot-plate and gently heat the reaction mixture (50 °C) with stirring, until a purple product precipitates out from a blue-green supernatant liquid. Do not allow the solution to boil.

Remind learners that they will need to gently heat the flask contents for about 20 min before they will see a purple precipitate coming out of a blue-green supernatant liquid.

Remind them not to allow the solution to boil!

For learners that don't reach this stage in the time allotted, give them the sample data from the video.

13. Learners should allow the reaction mixture to cool down to room temperature.

Remind learners that they may see a distinct blue supernatant and a purple precipitate.

14. Whilst waiting for the flask to cool, learners should set up the equipment for a vacuum filtration. In addition, they can tare the balance and record the mass of a watch-glass. Learners should record the mass in their results table.

Remind learners to use two filter papers.

Remind learners to record the mass in the 'Results' table section of their report.

15. Learners should filter the cooled contents of the flask, then wash through with several portions of ice-cold water and with 10 cm^3 of acetone, before drying in the air. The product should be a dry powder. Learners should not proceed with a wet solid.

Remind learners that the product should be a dry powder. If it is still wet, they should re-wash the sample with acetone, until free from water.

16. Learners should carefully transfer the product from the filter paper to the watch-glass and use the balance to record the mass.

Remind learners that they should record the mass in the 'Results' table section of their report.

17. Learners should use the mass reading to work out the mass of pentaamminechlorocobalt(III) chloride obtained and the percentage yield.

Clean-up

After the experiment learners should:

- clean all glassware, tidy up their work space and ensure any spillages are mopped up
- empty their chemical waste into the main chemical waste bottle in a central location
- return all equipment and any unused chemicals to you
- wash their hands with soap and water.

Alternative method

If you do not have access to the required equipment or the suggested method would not work for your class, here is a possible alternative that you could use.

Preparation of tetraamminecopper(II) sulfate monohydrate $[Cu(NH_3)_4]SO_4 \cdot H_2O$

1. Add a weighing boat to the balance and tare. Weigh out approximately 10.0 g of copper(II) sulfate pentahydrate and record the actual mass.

2. Place the copper(II) sulfate pentahydrate solid into a 250 cm^3 beaker and, using a measuring cylinder, add about 15 cm^3 of water to the solid in the beaker.

3. Place the beaker into a fume hood and add, using a measuring cylinder, 20 cm^3 of concentrated ammonia solution (15 mol dm^{-3}). Use a stirring rod to help dissolve the mixture in the beaker.

4. After the crystals have dissolved, slowly add 20 cm^3 of 95% ethanol to the reaction solution in the beaker.

5. Leave the reaction beaker and use separate measuring cylinders to add 15 cm^3 of concentrated ammonia and 15 cm^3 of 95% ethanol into a 50 cm^3 beaker. This mixture will be used during the filtration phase of the experiment.

6. Set up the equipment for a vacuum filtration (using Büchner funnel).
   In addition, tare the balance and record the mass of the filter paper that will be used in the vacuum filtration. Record the mass in your results table.

7. Filter the contents of the 250 cm^3 beaker by vacuum filtration using a Büchner funnel.

8. Turn off the vacuum and add 10 cm^3 of the concentrated ammonia–ethanol mixture prepared in step 5. Use the flat end of the stirring rod to carefully mix the solid in with the liquid. Be careful not to tear the filter paper.

9. Turn on the vacuum and remove the liquid. Repeat the same procedure twice more using the remaining concentrated ammonia–ethanol mixture.

10. Then wash the solid crystals, twice, with 10 cm^3 of 95% ethanol.

11. Finally, wash the solid crystals with two portions of 10 cm^3 of acetone.

12. The product should be a dry powder. If it is still wet, re-wash the sample with acetone on the Büchner funnel until dry. Do not proceed with a wet solid.

13. Tare the balance and record the mass of product + filter paper in your results table.

14. Work out the mass of the obtained tetraamminecopper(II) sulfate monohydrate and use this to calculate the percentage yield.

Debriefing lesson: Evaluating the experiment

Resources	• Worksheet G • Ideal report
Learning objectives	By the end of the lesson: • ***all*** learners should be able to write a conclusion based on their findings • ***most*** learners should be able to evaluate the experiment • ***some*** learners will be able to review their finished report in line with success criteria and offer improvements.

Timings	Activity
10 min	**Introduction** Ask learners to complete and review their findings from the experiment. Encourage them to share their findings with other learners.
20 min	**Main lesson** Ask learners to discuss the characteristics of a good scientific report. Get them to write out suggestions and ask them to stick these on the board. Use this as the focal point of a classroom discussion. They are likely to suggest things like: explains processes, uses clear language, writing is concise, uses technical language or presents data clearly.
20 min	Share with learners the ideal report. Leaners should then swap their report with a member of another group they haven't worked with. Using the success criteria in Worksheet G, they should assess the report they have been given. You can guide their progress using the ideal report if required.
10 min	**Plenary** Learners should return the work they have assessed. Each learner should read the feedback given by their partners and act on it by rewriting a section of their work, incorporating the improvements that have been suggested.

Worksheets and answers

	Worksheets	Answers
For use in *Briefing lesson*:		
A: Pre-experiment exercises	**19**	**26**
B: Example risk assessment table	**20**	**27**
C: Method	**21**	**n/a**
For use in *Planning lesson*:		
C: Method	**21**	**n/a**
D: Choosing the correct equipment	**22**	**n/a**
E: Experimental report guidelines	**23**	**n/a**
For use in *Lab lesson*:		
C: Method	**21**	**n/a**
D: Choosing the correct equipment	**22**	**n/a**
E: Experimental report guidelines	**23**	**n/a**
F: Calculation guidance	**24**	**n/a**
For use in *Debriefing lesson*:		
G: Assessing a scientific report	**25**	**n/a**
Ideal report	**n/a**	**29**

Worksheet A: Pre-experiment exercises

In this experiment, the transition metal complex pentaamminechlorocobalt(III) chloride will be prepared and its percentage yield calculated.

The reaction sequence that will be used in the experiment is as follows:

$$CoCl_2 \cdot 6H_2O \xrightarrow[H_2O]{NH_3 \,/\, NH_4Cl} [Co(NH_3)_6]Cl_2 \xrightarrow{H_2O_2} [Co(NH_3)_5(H_2O)]Cl_3 \xrightarrow{\text{conc. } HCl} [Co(NH_3)_5Cl]Cl_2$$

Complete the following exercises before you carry out the experiment, writing all your responses in your lab book.

Exercise 1

Read the method that will be used for the experiment and carefully highlight unfamiliar words or equipment. Use your course notes, textbooks or the internet to look up these terms.

Exercise 2

Prepare a risk assessment table for the experiment. It should list the hazards associated with all the chemicals in the experiment (solvents, starting chemicals and any products), as well as safety precautions and first aid measures. You can use textbooks and/or the internet to help with this exercise.

Exercise 3

Homework task

Answer the following questions related to the experiment.

1. Concentrated ammonia and hydrogen peroxide are to be used in experiment.

   Write a balanced equation to show what happens when ammonia dissolves in water including state symbols.

2. Name each of the transition metal complexes involved in the experiment.

Worksheet B: Incomplete risk assessment table

Substance	Hazard symbols	Precautionary statement(s)	First aid measures

Worksheet C: Method

Preparation of pentaamminechlorocobalt(III) chloride $[Co(NH_3)_5Cl]Cl_2$

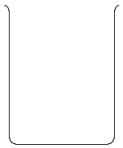
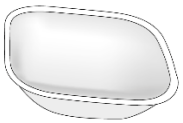
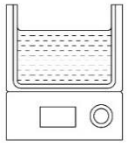
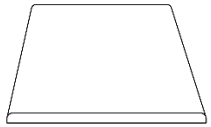
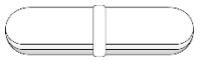
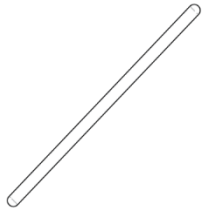
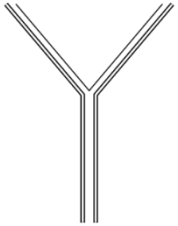
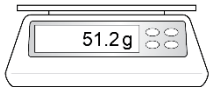
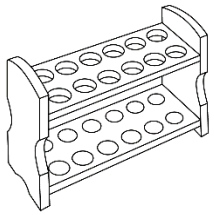
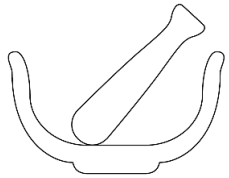
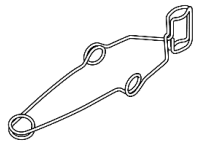
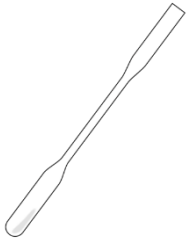
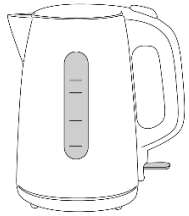
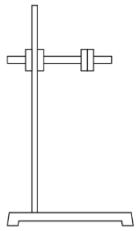
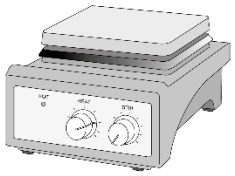
1. Place a weighing boat on the balance and tare. Then weigh out approximately 5.0 g of ammonium chloride.
2. Use a measuring cylinder to add 30 cm^3 of the concentrated 0.88 ammonia to the conical flask.
3. Carefully transfer the ammonium chloride to the conical flask and dissolve by swirling the contents or by using a stirring rod.
4. Place a second weighing boat on the balance and tare. Then weigh out approximately 10.0 g of cobalt(II) chloride hexahydrate. Record the actual mass in your results table.
5. Using a spatula, transfer about a quarter of the cobalt(II) chloride hexahydrate ($CoCl_2 \cdot 6H_2O$) to the contents of the flask. Continually agitate this solution by gently swirling the flask at its neck.
6. Repeat the same process with the other three portions of cobalt(II) chloride hexahydrate. Make sure that each portion reacts before the next portion is added. Stop the agitation once a warm slurry solution forms. This slurry solution contains a precipitate of $[Co(NH_3)_6]Cl_2$.
7. Use a measuring cylinder to measure out 20 cm^3 of 30% v/v hydrogen peroxide.
8. Using the plastic pipette, carefully add the hydrogen peroxide to the warm slurry solution in the flask, one cm^3 at a time, whilst continually stirring the reaction mixture. Addition of the hydrogen peroxide results in a vigorous exothermic reaction with effervescence. You can adjust the amount of hydrogen peroxide added if the reaction is too vigorous.
9. Repeat the same process until all of the hydrogen peroxide has been added. A deep red solution ($[Co(NH_3)_5(OH_2)]^{3+}$) should appear.

Note: sometimes this may look brown, which is not a problem.

10. Add a thermometer to the flask and allow the contents to slowly cool down to room temperature.
11. When the flask contents have cooled down enough, measure out 30 cm^3 of concentrated hydrochloric acid and slowly add to the cooled conical flask.
12. Add a magnetic stirrer flea to the cooled flask, place on the hot-plate and gently heat the reaction mixture (50 °C) with stirring until a purple product precipitates out (typically after 20–30 min) from a blue-green supernatant liquid. Do not allow the solution to boil.
13. When the reaction is complete the supernatant liquid should be deep blue (to see this, let the mixture settle for a few seconds).
14. Allow the reaction mixture to cool down to room temperature.
15. Whilst you are waiting for the reaction to cool, set up the equipment for a vacuum filtration (using a Büchner funnel containing two filter papers). In addition, tare the balance and record the mass of a watch-glass. Record its mass in your results table.
16. Once the reaction mixture has reached room temperature, filter the cooled contents of the flask by vacuum filtration. Wash with several portions of ice-cold water, then with 10 cm^3 of acetone before drying in the air. The product should be a dry powder. If it is still wet, re-wash the sample with acetone on the Büchner filter until free from water. Do not proceed with a wet solid.
17. Carefully transfer the product to the watch-glass and reweigh using the balance. Record the mass.
18. Use the two readings to work out the mass of pentaamminechlorocobalt(III) chloride ($[Co(NH_3)_5Cl]Cl_2$) obtained and use this to calculate the percentage yield.

Worksheet D: Choosing the correct equipment

Here is a range of some common lab equipment. Select what you would use in this experiment.

					
Büchner funnel	**beaker**	**weighing boat**	**filter paper**	**water bath**	**watch glass**
					
conical flask	**white tile**	**measuring cylinder**	**test-tubes**	**magnetic flea**	**glass rod**
					
filter funnel	**balance**	**rack**	**pipette**	**pestle and mortar**	**test-tube holder**
					
thermometer	**spatula**	**kettle**	**clamp and stand**	**hot-plate**	**timer**

Worksheet E: Experiment report guidelines

Use the following guidelines to help you prepare your experiment report in your lab book.

Introduction

- Provide a suitable title for your report.
- To give your report some context, write a brief background information section.
- Detail the aims of the experiment.
- Describe the variables for your experiment (independent, dependent and fixed).

Experimental set-up and materials

- Draw a labelled diagram for your experiment.
- List the materials and equipment used.

Method

- Include your method in the report.
- Make note of any changes to the method given to you by the teacher.

Results and analysis

- Record all the masses used in this experiment
- Write down any observations you make during the preparation of the complex
- Calculate the percentage yield of the product collected.

Conclusion

- Provide conclusions for your results remembering to link them back to the aims of the experiment.

Evaluation

- Assess whether the experiment you carried out was fair and whether the conclusions you have made are reliable based upon the data collection.
- Think about:
    - the overall fairness of the experiment
    - the accuracy of and reliability of the results
    - sources of uncertainty
    - any improvements you would like to make.

Worksheet F: Calculation guidance

The percentage yield of a compound is worked out using the following equation:

$$\text{percentage yield (\%)} = \frac{\text{actual yield}}{\text{theoretical yield}}$$

Example

$2CoCl_2 \cdot 6H_2O(s)$ + $2NH_4Cl(s) + 8NH_3(aq) + H_2O_2(aq) + 3H_2O(l) \rightarrow$ **$2[Co(NH_3)_5Cl]Cl_2(s)$** + $\frac{1}{2}O_2(g)$

Cobalt(II) chloride hexahydrate 2 moles 1 mole M_r = 237.93 g	Pentaamminechlorocobalt(III) chloride 2 moles 1 mole M_r = 250.44 g

Actual yield from the experiment = 8.99 g

The theoretical yield (from the balanced equation) is that **237.93 g** of cobalt(II) chloride hexahydrate should give **250.44 g** of pentaamminechlorocobalt(III) chloride.

1 g should give 250.44 / 237.93 = 1.053 g

10 g should give 1.053 × 10 = 10.53 g

Therefore, the percentage yield = $\frac{8.99}{10.53} \times 100 = 85.38\%$

Worksheet G: Assessing a scientific report

Report section	Success criteria
Title	Does the report contain a simple and informative title?
Background	Is there a brief explanation of a theory or concept linked to the experiment?
Aim(s)	Does this section say what will be investigated?
Variables	Does the report state what variables were changed, what variables were measured and what were fixed?
Materials and Method(s)	• Is there a list of equipment and chemicals used? • Does this section have a sequence of steps or commands that show how a task should be carried out? • Is it written using impersonal language? • Is there a clear labelled diagram of the experiment? • Is the language clear so that someone could repeat the experiment without mistakes?
Results	This section should be made up of what can be measured or observed, not guessed. For example, if bubbles were observed, then this is all that can be stated in this section (unless the gas produced was tested). • Is this section well-presented and clear? • Have observations been made as accurately as possible? • Is the data in the form of a table and/or graph? • Have correct headings and units been used? • Has an average (mean) been worked out from repeat readings?
Conclusion(s)	• Have the results been described? • Are any conclusions related to the aims? • Are there any comments on whether the results agree with the hypothesis?
Evaluation	The evaluation is an opportunity to discuss both the strengths and weaknesses of an experiment. It should be specific and explain why the experiment did or did not work well and how it could be improved. • Has the fairness of the experimental design been evaluated? • Is there any mention about the accuracy and reliability of the results? • Does the report mention possible sources of error/uncertainty? • Does the report contain **three** possible improvements?
Overall quality of the report	Look at the whole of the report and decide on its quality. • Does the report follow clearly from start to finish? • Is the vocabulary used in the report precise? • Has technical language been used throughout? • Has impersonal language (no 'I' or 'we') been used?

Worksheet A: Suggested answers

1. $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

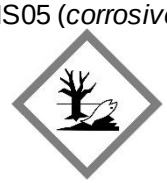
2. $CoCl_2 \cdot 6H_2O$ Cobalt(II) chloride hexahydrate

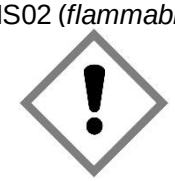
   $[Co(NH_3)_6]Cl_2$ Hexaamminecobalt(II) chloride

   $[Co(NH_3)_5(H_2O)]Cl_3$ Pentaammineaquacobalt(III) chloride

   $[Co(NH_3)_5Cl]Cl_2$ Pentaamminechlorocobalt(III) chloride

Worksheet B: Suggested answers

Substance	Hazard	First aid measures
Ammonium chloride [solid]	 GHS07 (*moderate hazard* **MH**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Concentrated 0.88 ammonia solution	 GHS07 (*moderate hazard* **MH**)  GHS05 (*corrosive* **C**)  GHS09 (*hazardous to the aquatic environment* **N**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Cobalt(II) chloride hexahydrate [solid]	 GHS07 (*moderate hazard* **MH**)  GHS08 (*health hazard* **HH**)  GHS09 (*hazardous to the aquatic environment* **N**)	**In the eye:** flush eyes with water as a precaution. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Hydrogen peroxide solution 30% v/v		**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything

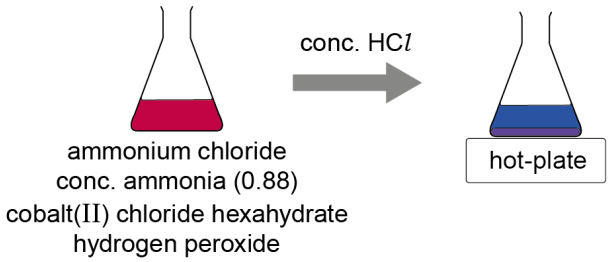
Substance	Hazard	First aid measures
	GHS05 (*corrosive* **C**)  GHS07 (*moderate hazard* **MH**)	by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Concentrated hydrochloric acid solution [12 mol dm^{-3}]	 GHS05 (*corrosive* **C**)  GHS07 (*moderate hazard* **MH**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Acetone	 GHS02 (*flammable* **F**)  GHS07 (*moderate hazard* **MH**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Pentaamminechlorocobalt(III) chloride [solid]	 GHS07 (*moderate hazard* **MH**)  GHS08 (*health hazard* **HH**)  GHS09 (*hazardous to the aquatic environment* **N**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.

Ideal report

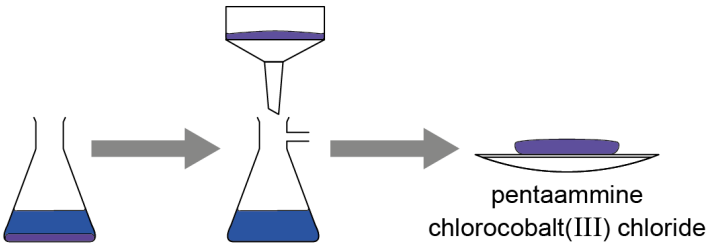
Title	Transition metal complex
Background information	Transition elements are found in the d block of the Periodic Table and form complexes when they join with ligands. These complexes can be man-made or are found in nature.
Aims	To prepare the transition metal–ligand complex pentaamminechlorocobalt(III) chloride and calculate its percentage yield.
Experimental variables	**Changed (independent) variables** Mass of cobalt(II) chloride hexahydrate used.
	Measured (dependent) variables Colour of product Mass of pentaamminechlorocobalt(III) chloride formed.
	Fixed variables Volumes and masses of reagents used. Temperature of reaction.

Ideal report, continued

Preparation



Filtration



Materials (list of chemicals and equipment)

- ammonium chloride
- concentrated 0.88 ammonia
- 250 cm^3 conical flask
- 10 cm^3 measuring cylinder
- 50 cm^3 measuring cylinder (×2)
- plastic pipette
- magnetic stirrer flea
- cobalt(II) chloride hexahydrate ($CoCl_2.6H_2O$)
- 30% v/v hydrogen peroxide
- ice bath, i.e. plastic container containing ice cubes
- a spatula
- weighing boat (×2)
- concentrated hydrochloric acid [12 mol dm^{-3}]
- hot-plate (with stirrer function)
- glass stirring rod
- timer
- thermometer
- watch-glass
- vacuum filtration set-up using a Büchner funnel
- deionised water (cold)
- acetone
- Qualitative grade filter paper
- mass balance (to 3 dps).

Ideal report, continued

Results

Item	Mass / g
cobalt(II) chloride hexahydrate	10.09
watch-glass	12.00
watch-glass + product	20.99
product	8.99

Observation

A purple product was formed.

Percentage yield calculation

$2CoCl_2 \cdot 6H_2O(s) + 2NH_4Cl(s) + 8NH_3(aq) + H_2O_2(aq) + 3H_2O(l) \rightarrow 2[Co(NH_3)_5Cl]Cl_2(s) + \frac{1}{2}O_2(g)$

Cobalt(II) chloride hexahydrate 2 moles 1 mole M_r = 237.93 g	Pentaamminechlorocobalt(III) chloride 2 moles 1 mole M_r = 250.44 g

Actual yield from the experiment = 8.99 g

The theoretical yield (from the balanced equation) is that **237.93 g** of cobalt(II) chloride hexahydrate should give **250.44 g** of pentaamminechlorocobalt(III) chloride.

1 g should give 250.44 / 237.93 = 1.053 g

10.09 g should give 1.053 × 10.09 = 10.62 g

Therefore, the percentage yield = $\frac{8.99}{10.62} \times 100 = 84.65\%$

Conclusion(s)

Purple pentaamminechlorocobalt(III) chloride solid was prepared and its percentage yield was calculated as being 84.65%.

Ideal report, continued

Evaluation

Overall fairness of experiment	• *Only one variable changed, so experimental results are valid.*
Accuracy and reliability of results	• ***Accuracy:*** *Results were obtained through correct and careful measurement of volumes and identification of colours.* • ***Reliable:*** *Results were reliable as several other groups in the class got the same type of results.*
Sources of error/uncertainties	• *Some of the products from each part of the preparation may have been lost during transfer.* • *Side reactions.* • *Apparatus.*
Improvements	• *Weigh the filter papers before and after filtration–decreases losses that occur during transfer to the watch-glass.*

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