Raffles Institution
Year 6 H2 Chemistry 2026
Planning Experiments Tutorial 3
Equilibria, Electrochemistry, Organic Synthesis

Solutions to Discussion Questions

Question 1

(a)

$Cu^{2+}(aq) + 4NH_3(aq) \rightleftharpoons [Cu(NH_3)_4]^{2+}(aq)$ **[1]**

or $[Cu(H_2O)_6]^{2+}(aq) + 4NH_3(aq) \rightleftharpoons [Cu(NH_3)_4]^{2+}(aq) + 6H_2O(l)$

(state symbols are not required by question)

(b) Colour: orange/red/yellow
Explanation:
The colour of the complex is deep blue. Since yellow/red/orange is the complementary colour of blue, it is being absorbed most strongly by the complex ion.

(c)

Pre-calculations for 250.0 cm^3 of 2.00 mol dm^{-3} $CuSO_4$(aq)

Amount of $CuSO_4$ in 250 cm^3 = $\frac{250.0}{1000} \times 2.00 = 0.500$ mol
M_r of $CuSO_4.5H_2O$ = 63.5 + 32.1 + 4(16.0) + 5(18.0) = 249.6
Mass of $CuSO_4$ = 0.500 × 249.6 = 124.8 g

Preparation of 250.0 cm^3 of 2.00 mol dm^{-3} $CuSO_4$(aq)

1. Using an analytical balance, weigh accurately 124.80 g of $CuSO_4.5H_2O$ in a clean and dry weighing bottle.
2. Transfer the $CuSO_4.5H_2O$ to a 250 cm^3 beaker.
3. Rinse the weighing bottle and transfer the washings to the 250 cm^3 beaker.
4. Transfer the solution from the beaker quantitatively into a 250 cm^3 volumetric flask with the aid of a funnel and glass rod. Rinse the beaker a few times with small volumes of deionised water and transfer all washings into the volumetric flask.
5. Top up to the mark with deionised water, stopper the volumetric flask and shake this solution to obtain a homogeneous solution. Label this solution as **FA 1**.

Dilution of 2.00 mol dm^{-3} $CuSO_4$(aq)

1. Using a burette, transfer 75.00 cm^3 of **FA 1** to a 100 cm^3 volumetric flask.
2. Top up to the mark with deionised water, stopper the volumetric flask and shake this solution to obtain a homogeneous solution. Label this solution as **FA 2**.
3. Repeat steps 1 to 2 using the volumes of **FA 1** shown in the table below to prepare **FA 3** to **FA 6**.

Name of solution	Volume of **FA 1** / cm^3	[$CuSO_4$] / mol dm^{-3}
FA 2	75.00	1.50
FA 3	60.00	1.20
FA 4	45.00	0.90
FA 5	30.00	0.60
FA 6	15.00	0.30

Preparation of copper-ammonia complex solutions

1. Pipette 10.0 cm^3 of **FA 1** to a 100 cm^3 volumetric flask.
2. Top up to the mark with 2 mol dm^{-3} NH_3(aq), stopper the bottle and shake this solution to obtain a homogeneous solution.
3. Repeat steps 1 to 2 for **FA 2** to **FA 6** and solution **X**. Label the solution prepared for solution **X** as **XA1**.

Derivation of calibration curve & determination of concentration of copper(II) ions in solution X

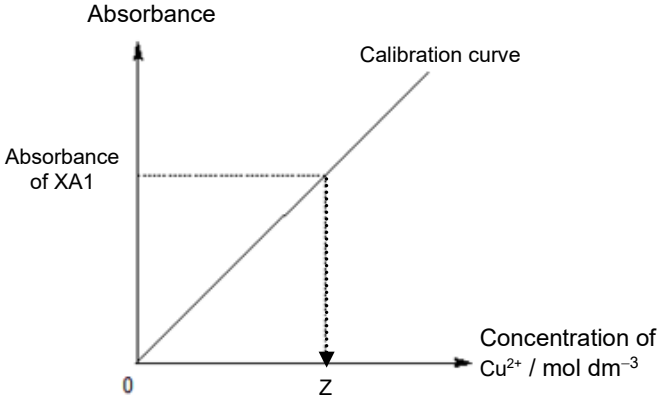
1. Use a UV spectrometer to measure the absorbance of each of the copper-ammonia complex solutions prepared from **FA 1** to **FA 6**.
2. Record the absorbance in the table below.

Original solution used	$[Cu^{2+}]$ in original solution / mol dm^{-3}	Absorbance
FA 1	2.00	
FA 2	1.50	
FA 3	1.20	
FA 4	0.90	
FA 5	0.60	
FA 6	0.30	

3. Using the data from the table above, plot a graph of Absorbance against $[Cu^{2+}]$ in the original FA solutions. This is the calibration curve.

4. Use a UV spectrometer to measure the absorbance of copper-ammonia complex ions in solution **XA1**.

5. Use the calibration curve to determine Z, the concentration of Cu^{2+} in the original solution **X**.



[1] Pre-calculations for 250.0 cm^3 of 2.00 mol dm^{-3} $CuSO_4(aq)$
[1] Procedure for preparation of 250.0 cm^3 of 2.00 mol dm^{-3} $CuSO_4(aq)$

[1] Procedure for dilution of 2.00 mol dm^{-3} $CuSO_4(aq)$

[1] Appropriate apparatus and capacity

[1] Suitable range (FA 1 and at least 4 other diluted solutions) +

(note: at least 5 points required for the calibration straight line graph)

[1] Computation of correct corresponding diluted concentrations of Cu^{2+}

[1] Procedure for preparation of copper-ammonia complex solutions & XA1

[1] Measurement of absorbance of the copper-ammonia complex solutions & XA1

[1] Sketch of calibration line

[1] Use of calibration line to determine $[Cu^{2+}]$ in solution X

Question 2

(a) Theoretical yield = 10.0 / (0.70) = 14.29 g
Amount of nitrobenzene = 14.29 / 123 = 0.1161 mol
Since mole ratio of benzene and nitrobenzene is 1 : 1,
Amount of benzene required = 0.1161 mol
Mass of benzene required = 0.1161 x 78 = 9.059 = 9.06 g.

(b) Estimation of quantity of acids to be used
Volume of benzene required = 9.059 / 0.8765 = 10.34 = 10.3 cm^3

Since the teacher used 8.0 cm^3 of concentrated HNO_3 and 8.0 cm^3 of concentrated H_2SO_4 to react with 8.0 cm^3 of benzene (i.e. 1:1:1 by volume), the volume of concentrated HNO_3 and concentrated H_2SO_4 used will be 10.3 cm^3 each.

	Remarks
1. Using separate burettes, transfer 10.3 cm^3 of concentrated nitric acid and 10.3 cm^3 of concentrated sulfuric acid into the same 100 cm^3 round bottom flask.	
2. Cool the mixture of acids by placing the round bottom flask in an ice bath.	Step 3 ensures that a controlled amount of heat is released by allowing only a small amount of benzene to be added and reacted at a time.
3. Using another burette, transfer approximately 2 cm^3 of benzene into the round bottom flask, stirring with a thermometer and checking the temperature. The temperature of the mixture should not rise above 50 °C. If the temperature of the mixture rises above 50 °C, cool the flask in the ice bath until the temperature drops below room temperature.	Steps 2 – 4 ensure that the exothermic reaction does not rise above 50 °C.
4. Repeat step 3 until a total of 10.3 cm^3 of benzene has been added.	
5. A reflux condenser was attached to the round bottom flask and the flask was heated in a thermostatically controlled water bath set at 50 °C for 30 minutes.	The reaction temperature is close to boiling point of benzene. The use of a reflux setup reduces the loss of benzene due to evaporation.
6. After 30 minutes, the reaction mixture was allowed to cool .	
7. Transfer the contents into a 250 cm^3 separating funnel containing 100 cm^3 of water.	100 cm^3 of water was used instead of 75 cm^3 as we used more reactants than the teacher.
8. Stopper and shake the separating funnel to mix the organic and aqueous layers, occasionally releasing the pressure by opening the tap.	
9. Allow the organic and aqueous layers to separate before opening the tap to allow the bottom organic layer to flow out into a 50 cm^3 conical flask. Pour out and discard the upper aqueous layer.	Both benzene and nitrobenzene are insoluble in water while the residual acids are soluble in water. Use a separating funnel to separate them since they have different solubilities in different layers.
10. Transfer the organic layer back into the separating funnel and repeat steps 7 to 9 using 100 cm^3 of aqueous sodium carbonate instead of water.	
11. Transfer the organic layer back into the separating funnel and repeat steps 7 to 9 using 100 cm^3 of deionised water.	Most of the acid would have dissolved in the 100 cm^3 of water and has been

12. Using a spatula, add anhydrous calcium chloride to the conical flask containing the organic layer to remove any residual water. 13. Filter the mixture through a filter funnel lined with filter paper into a 50 cm^3 round bottom flask and connect the round bottom flask to a distillation set-up. 14. Heat the round bottom flask using a heating mantle. At approximately 80 °C, collect the liquid benzene that condenses from the distillation setup and discard it. 15. At approximately 211 °C, collect the pure liquid nitrobenzene that condenses from the distillation setup.	discarded. The sodium carbonate reacts with any residual acids that may still be present. At this point, the mixture contains mainly benzene and nitrobenzene. Since both of them are liquids and have different boiling points, we will separate them by distillation.

(c) Aqueous sodium carbonate was added to react with and remove any residual nitric acid or sulfuric acid which may still be present.

Note: the sodium carbonate does not quench the reaction. The reaction was quenched when the mixture was transferred into water. The acids dissolved in the water, separating them from the organic substances which are not soluble in water.

(d) safety issue 1 Both benzene and nitrobenzene are flammable.

precaution Keep benzene and nitrobenzene away from naked flames. In this experiment, no naked flames were used as heating sources.

safety issue 2 Nitrobenzene is toxic and causes respiratory problems.

precaution The entire procedure, especially distillation, should be carried out in the fumehood to avoid inhaling any fumes when the mixture is heated at high temperatures.