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Chemistry

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Title of the extended essay:

Ascertaining the Concentration of Copper
Ions in water using Quantitative Techniques:
Spectrophotometry and Redox Potential.

Candidate's declaration

If this declaration is not signed by the candidate the extended essay will not be assessed.

I confirm that this work is my own work and is the final version. I have acknowledged each use of the words or ideas of another person, whether written, oral or visual.

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IB EXTENDED ESSAY
CHEMISTRY

ASCERTAINING THE CONCENTRATION OF COPPER IONS

IN WATER

USING QUANTITATIVE TECHNIQUES:

SPECTROPHOTOMETRY

AND

REDOX POTENTIAL

Student :
Candidate no: /
Supervisor :
Word count : 3976

1. Abstract:

Copper is an important element needed for the proper functioning of the human body as well as for soil fertility. However, when large amounts accumulate, it can prove hazardous.

My interest to determine the presence of copper ions in water stems from the fact that in my home country, Bangladesh, the levels of copper ions are rather high in drinking water due to the copper pipes and the extensive garments industry. So I chose to investigate two quantitative techniques to determine the concentration of copper ions in water. This has led me to the research question:

“Which technique is more accurate in determining the concentration of copper ions in solution: Redox potential or Spectrophotometer?”

A colored solution of the Tetraamminecopper(II) ions gave absorbance readings on the Spectrophotometer. Using known concentrations of copper ions, a curve is calibrated applying Beer Lambert's law, which is used to determine the experimental concentrations.

Similarly for Redox Potential, a curve is calibrated using Nernst Equation. To find the voltage for known concentrations of copper, a Galvanic cell is constructed with a zinc half cell and varying the concentration for the copper half cell.

Reliability and precision of the two techniques were determined by comparing the experimental data and actual concentrations and analysing the errors involved.

From my investigation, I concluded that determination of concentration of copper ions in water by Spectrophotometer is a more accurate technique because errors involved in Spectrophotometer is less than Redox Potential. It also showed that readings obtained from Redox potential had a bigger difference from the actual concentrations unlike the Spectrophotometer. Moreover, the Spectrophotometer method proves to be less cumbersome and user-friendly.

My research can be further extended to the study of other ions in water which will prove to be increasingly important as third world countries become more industrialized.

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2.1 (1) Choice of topic:

Copper is essential to the human metabolism but in high amounts, it can be fatal. Some functions of copper are:

1. Copper is essential to the blood and in healing of wounds, and blood clotting.
2. Copper has a role in the production of hormones which come from the thyroid.

(<http://www.vitamins-minerals-for-health.com/Copper.htm>)

While copper is required in significant amounts by the human body, bioaccumulation of copper can be dangerous. Bioaccumulation is the increase in the concentration of a chemical compared to the chemical concentration in the environment

(<http://www.lenntech.com/heavy-metals.htm>).

An overdose of copper can cause anaemia, liver and kidney damage, and stomach and intestinal irritation. People affected from Wilson's disease are at a greater risk from copper exposures. The disease causes the accumulation of copper in the liver rather than being changed into bile. Eventually copper is released into the blood stream where it inhibits the functions of the brain, the kidney and the cornea.

I chose to investigate the concentration of copper ions because of the fact that the majority of the population of Bangladesh where I am native to, are exposed to significant amounts of copper ions in the water. One of the reasons for this is the extensive system of copper pipes used to supply water to houses. The same copper pipes have been in commission for a few decades without being replaced or without any maintenance at all. Due to poor upkeep, corrosion of this pipes causes copper to be released into the water which eventually ends up in the drinking water. Though the recommended general intake is "2 mg per day" (<http://www.lenntech.com/recommended-daily-intake.htm>), the general population is unaware of the copper level in their water which can even be a lethal one.

2.1 (2) Effect of copper on the environment:

Another reason why I chose to investigate to find the concentration of copper ion as it affects agriculture. Copper compounds can have a positive effect on the crops and plants but an increased amount of copper in the soil can disrupt the activities of the microorganisms in the soil and earthworms (<http://www.lenntech.com/Periodic-chart-elements/Cu-en.htm>). Microorganisms and earthworms break down organic substances while microorganisms also take part in nitrogen fixation which makes the soil fertile. Since Bangladesh and other third world countries are highly dependent on agriculture, copper levels in such places should be regulated for better yield.

In Bangladesh, the growing garments industry is contributing the most to the alarming rise of copper compounds in water sources. Garment industries mostly inhabit the rural part of the country and dump vast amounts of unused dyes and color wastes in various water sources which the farmers use in their crops. Colored compounds often

contain huge amounts of copper and water used in irrigation containing high amount of copper mixes with the soil causing damage.

In order to find the concentration of copper in water, my investigation has led me to the following research question:

“Which technique is more accurate in determining the concentration of copper ions in solution: Redox potential or Spectrophotometer?”

Verifying which of the two techniques stated in the research question is more viable would give agricultural officers an opportunity to check the water for copper contamination.

2.2 (1) Tetraamminecopper(II)ion

Since most naturally occurring copper compounds are not colored, determination of copper in the sample water cannot be done by spectrophotometry. In order to do so, a solution of tetraamminecopper(II) ion of the sample, which is a complex compound of copper with the general formula $[\text{Cu}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$ and having a deep blue color.

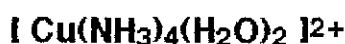
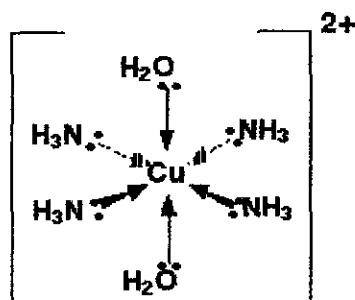
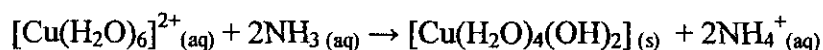


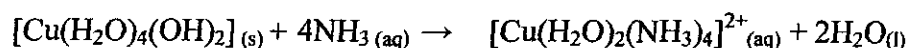
Figure 1: Structure of Tetraamminecopper(II) ion

2.2 (2) Formation of $[\text{Cu}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$

Tetraamminecopper(II) ion forms in the presence of excess ammonia in copper solution. When excess ammonia is added to a copper compound solution, initially the hydrated copper ion is converted into a precipitation of copper (II) oxide.



This precipitate of copper later dissolves in the excess ammonia to form tetraamminecopper(II) ion having a deep blue color.



2.3 Spectrophotometer

The U.V Visible spectrophotometer is an instrument used for the quantitative measurement of concentrations of colored solutions. The instrument measures the intensity of light of a particular wavelength being absorbed by a sample and compares it to the intensity of a reference beam of light. The method relies on the fact that some of the light emitted on the solution is absorbed by the ions present in the solution. Since the method relies on the absorption of light, the solution must be colored. The instrument constitutes of a light source, a monochromator which diffracts the light producing light of different wavelengths and a photodiode which filters different wavelengths of light so that light of a particular wavelength reaches the detector. A spectrophotometer can be either single beam or double beam. In a double beam spectrophotometer, two rays of light reach the detector. One ray of light passes through the sample solution and reaches the detector while the other directly reaches the detector which is used as a reference and the intensities are compared. The wavelength chosen for the transmitted light is for the complimentary color of the sample solution so that maximum absorption by the solution takes place.

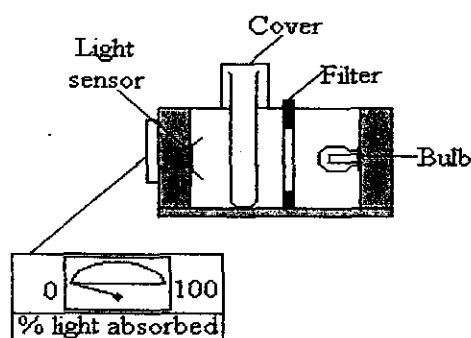
The spectrophotometry method is designed on the basis that when light falls on a substance, some of the light is absorbed by the substance, part of it is reflected out and a portion of it is transmitted out. The equipment uses this relationship to measure the concentration of ions in the solution by verifying the difference between the intensity of the light emitted on the solution and the amount of light absorbed by it.

$$I_0 = I_a + I_t + I_r$$

Where,

- I_0 : the intensity of the incident light
- I_a : the intensity of the absorbed light
- I_t : the intensity of the light transmitted
- I_r : the intensity of the light reflected.

(Vogels textbook of quantitative inorganic analysis 1978, pg 695)



http://www.scijournal.org/index.php?template_type=report&id=&htm=reports/a3/tcc3.htm&link=reports/home.php

Figure 2: Working Mechanism of a Spectrophotometer

2.3 (1) Beer Lambert's law

This law relates the amount of the incident light absorbed and the amount of the light transmitted from the solution to find its concentration.

$$A = \epsilon lc$$

Where,

A : absorbance

c : concentration of ions in the solution

l: the length (thickness of the solution that the light has to pass)

ϵ : the molar absorption coefficient or the molar absorbtivity is the absorbance for per unit length and unit concentration for a solution with a concentration of 1 mol dm^{-3} .

(Vogel's textbook of quantitative inorganic analysis 1978, pg 697)

Since the molar absorption coefficient and the length of the solution remains constant, it can be deduced from Beer Lambert's law that concentration of a solution is directly proportional to the absorbance of the substance.

$$A = \epsilon lc$$

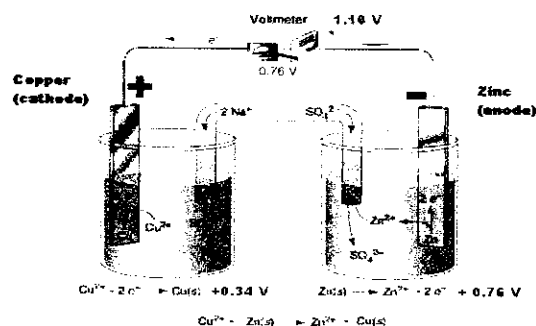
Taking ϵl to be the constant k,

$$A = kc$$

$$A \propto c$$

2.4 Redox potential

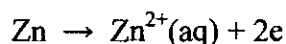
Redox potential uses the principle of a Galvanic cell. The cell works in a way depending upon the reactivity of the metals and how readily they lose electrons compared to one another. The galvanic cell consists of a zinc rod immersed in zinc sulphate while the other half cell consists of copper rod dipped in copper sulphate solution. The cell is made complete by the use of a salt bridge. When a wire is connected to the two metal rods, current flows in between them. The current is produced due to the flow of electrons whose direction depends upon the reactivity of the metal ions.



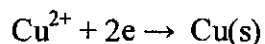
<http://mooni.fccj.org/~ethall/2046/ch18/galvanic.htm>

Figure 3: Setting of the mechanism of Redox Potential

When in contact with their corresponding solutions, zinc has more tendencies to be oxidized to zinc ions than copper. Formation of zinc ions from zinc releases electrons which flow through the wire to the copper rod.



Here, copper ions from the solutions are reduced to copper which deposits on the copper rod.



As a result the concentration of zinc ions increases while concentration of copper ions decreases. The release of electrons of the zinc rod gives it a negative potential (anode) while the copper rod becomes positively charged (cathode). With the flow of electrons, the voltmeter measures the potential difference between the two half cells and gives a voltage reading.

The salt bridge connecting the two half cells is made of a filter paper soaked in a salt solution such as potassium chloride solution. The salt bridge allows the flow of ions to prevent charge from building up in the two half cells which causes the electrons to flow giving a difference in potential.

2.4.1. Nernst equation:

The Nernst equation can be used to measure the concentration of ions of the electrolyte by the use of the potential difference or the electromotive force of the cell.

$$E = E^{\ominus} + (RT/zF) \ln([R.A]/[O.A]) \dots\dots\dots \text{equation (1)}$$

Where,

- E : sum of electrode potential of the metal rods in contact with electrolyte
- E^{\ominus} : standard electrode potential of the metal rod
- R : gas constant (8.313JK^{-1})
- T : temperature(in Kelvin)
- z : number of positive charges on the metal ion
- F : Faraday constant (96485 C mol^{-1})
- [O.A] : concentration of the oxidizing agent
- [R.A] : concentration of the reducing agent

The standard electrode potential (E^{\ominus}) is the potential of the metal under standard conditions when the concentration of the electrolyte is 1M, the temperature is 298K and the pressure is 1atm.

(Introduction to physical chemistry, G I Brown third edition 1983, pg- 431)

Taking,

E^\ominus : sum of standard potential i.e 1.1V(Introduction to Physical Chemistry pg-430)

R : 8.313JK^{-1}

T : 298 K

z : 2+

F : 96485 C mol^{-1}

[O.A] : concentration of the oxidizing agent

[R.A] : concentration of the reducing agent

And inserting into equation (1), gives:

$$E = 1.1 + 0.0296 \lg ([\text{R.A}]/[\text{O.A}])$$

2.5 How would the raw data for the two experimental techniques be used?:

Using the spectrophotometer, absorbance readings for the different concentrations of Cu^{2+} ions are plotted onto a graph of Absorbance against concentration. Similarly a graph of Voltage against $\log (1/[\text{Cu}^{2+}])$ is plotted using the different concentrations and calculating using Nernst Equations. This would allow us to calculate the experimental values for the concentrations of the solutions from the graphs.

Accuracy of the two techniques and the errors involved can be determined by looking at the difference between the experimental values from the graphs and the prepared concentrations used to plot the curves. Comparing the experimental data and the actual concentration together with the error analysis would help determine which method is more reliable and precise.

3. Hypothesis:

I predict that of the two methods stated in this paper, redox potential by the application of the Nernst equation would give a better accurate and precise result than spectrophotometer. This accuracy is measured by using a known solution for both the methods and then comparing the experimental results with prepared one. The results obtained from the spectrophotometry can be affected due to the presence of ions other than copper which may form colored compounds. This would absorb some of the transmitted light and emit light which is then detected. On the other hand, the presence of additional ions besides copper in redox potential doesn't have an effect on the result because the electrode is specified as copper which causes only copper ions to be affected in the solution.

4. Methodology:

4.1 Spectrophotometer

4.1.1 Materials/ apparatus are being used:

- 1 M Copper (II) sulphate solution
- 6 M ammonia solution
- Spectrophotometer
- Pipette 5cm³
- 10 cm³, 50 cm³ measuring cylinder

4.1.2 The procedure of carrying out the experiment is:

Preparation of 1 M tetraamminecopper(II) ion solution:

- I. Pipette 5 cm³ of 1M copper(II) sulphate solution into a 50 cm³ measuring cylinder.
- II. Add 5 cm³ of 6M ammonia solution to the copper(II) sulphate solution using a pipette. Deep blue color is formed. Since the concentration of ammonia solution used is much greater than the concentration of copper sulphate solution, it acts as excess compensating for using equal volume of the solution.

Preparation of 0.1 M tetraamminecopper(II) ion solution:

- I. Pipette 0.5 cm³ of 1M copper(II) sulphate solution in a 50 cm³ measuring cylinder.
- II. Add 0.5 cm³ of 6M ammonia solution to the copper(II) sulphate solution using a pipette. Deep blue color is formed.
- III. Top up the measuring cylinder up to 10 cm³.

Solutions of different concentrations can be obtained by adding distilled water to different amount of 0.1 M tetraamminecopper(II) ion solution. The following table illustrates the ratio of the volume of the solutions used to get the desired concentration of copper sulphate solution.

Table 1: Preparation of different concentration of Tetraamminecopper(II) ion solution:

Concentration of Tetraamminecopper(II) ion solution / mol dm^{-3}	Volume of 1 mol dm^{-3} Tetraamminecopper(II) ion solution Used	Volume of 0.1 mol dm^{-3} Tetraamminecopper (II) ion solution used	Volume of water used
0.2	2	-	8
0.1	1	-	9
0.05	5	-	5
0.01	-	1	9
0.005	-	0.5	9.5

4.1.3 Calibrating a curve:

- I. Turn on the spectrophotometer for fifteen minutes before taking readings for it to warm up.
- II. Select the particular wavelength of the complimentary color of the solution 600nm
- III. Pipette 4 cm^3 of water into the cuvette and insert it into the spectrophotometer.
- IV. Check whether the water gives a zero reading. (blank)
- V. Next pipette 4 cm^3 of 0.2 M tetraamminecopper(II) sulphate solution into the cuvette.
- VI. Check the reading for the absorbance level.
- VII. Rinse the cuvette thoroughly with water and then use solutions of other concentrations.
- VIII. Repeat the above steps for copper(II) sulphate solutions of concentrations 0.1 mol dm^{-3} , 0.05 mol dm^{-3} , 0.01 mol dm^{-3} and 0.005 mol dm^{-3} .

4.2 Redox potential:

4.2 (1) Apparatus required:

1. voltmeter
2. electrolytic cells
3. wire and crocodile clips
4. filter paper

Chemicals involved:

1. 1 M copper sulphate solution
2. 1 M zinc sulphate solution
3. 1 M potassium nitrate solution as a salt bridge

4.2 (2) The procedures are as follows:

Preparation of copper sulphate solutions of different concentrations:

Add adequate amount of water to definite amount of 1M copper sulphate solution to get the desired concentrations.

1. Add 10 cm³ of 1M copper sulphate solution to 90 cm³ of water to get 0.1 M copper sulphate solution
2. Add 10 cm³ of 0.1 M copper sulphate solution to 90 cm³ of water to obtain 0.001 M copper sulphate solutions.

Manipulate the above concentrations to get volumes of further concentrations as given in the table below:

Table 2: Preparation of different concentration of Copper (II) sulphate solution:

Concentrations/ moldm ⁻³	0.5	0.05	0.005	0.001
Volume of 1M copper sulphate solution / ± 0.5 cm ³	20	0	0	0
Volume of 0.1M copper sulphate solution / ± 0.5 cm ³	0	20	0	0
Volume of 0.01M copper sulphate solution	0	0	20	10
Volume of water / ± 0.5 cm ³	20	20	20	90

4.2 (3) Construction of a calibration curve:

1. Take 40 cm³ of 1M zinc sulphate solution in one of the cell using a measuring cylinder
2. Pour 40 cm³ of 1M copper sulphate solution in the other cell.
3. Put a zinc strip and a copper strip in their corresponding solutions connected to a voltmeter.
4. Bend a filter paper and soak it in 1M potassium nitrate solution and place it in between the two solutions that acts as a salt bridge.
5. Record the potential difference of the two cells from the voltmeter.

Repeat the above steps for different concentrations of 40 cm³ copper sulphate solution and record the voltmeter reading.

5. Data collection:

5.1. Redox potential

Table 3: Voltage reading for the specific concentrations of copper sulphate solution:

Concentration of copper sulphate/ mol dm^{-3}	Voltmeter reading/ $\pm 0.01\text{V}$
1.000	1.07
0.500	1.06
0.100	1.05
0.050	1.03
0.010	1.02
0.005	1.01
0.001	0.99

5.2 Spectrophotometry

Table 4: Absorbance level for different concentrations of Tetraamminecopper(II) ion solution:

Concentration of tetraamminecopper(II) ion solution/ mol dm^{-3}	Absorbance level
0.200	3.7276
0.100	1.8638
0.050	1.2338
0.010	0.3079
0.005	0.0706

6. Data analysis:

6.1. Redox potential

Using the equation expressed in section 2.5 is:

$$E = 1.1 + 0.0296 \lg ([R.A]/[O.A])$$

Where,

[O.A] : concentration of the oxidizing agent

[R.A] : concentration of the reducing agent

In this case the concentration of the reducing agent (zinc solution) is kept constant; i.e. 1M. Therefore, we can write:

$$\begin{aligned} E &= 1.1 + 0.0296 \lg ([R.A]/[O.A]) \\ \text{Or,} \quad E &= 1.1 + 0.0296 \lg (1/[Cu^{2+}]) \\ \text{Or,} \quad E - 1.1 &= 0.0296 \lg (1/[Cu^{2+}]) \end{aligned}$$

The value of 0.0296 remains constant since it is a product of the following factors which remains same throughout the experiment:

$$R : 8.313JK^{-1}$$

$$T : 298 K$$

$$z : 2+$$

$$F : 96485 C mol^{-1}$$

Taking ($E - 1.1$) to be ΔE and k to be 0.0296, we can write:

$$\begin{aligned} E - 1.1 &= 0.0296 \lg (1/[Cu^{2+}]) \\ \text{Or,} \quad \Delta E &= k \lg (1/[Cu^{2+}]) \\ \text{Or,} \quad \Delta E &\propto \lg (1/[Cu^{2+}]) \end{aligned}$$

From the above it can be seen that the ΔE is directly proportional to the $\lg (1/[Cu^{2+}])$ of the solution. Hence it can be deduced that any curve of ΔE against $\lg (1/[Cu^{2+}])$ would have a proportionality relationship i.e. a straight line

6.1.1 Calibrating a curve:

We use the concentration of the prepared solutions to get $\lg (1/[Cu^{2+}])$ values and plot against ΔE . From the calibrated graph, $\lg (1/[Cu^{2+}])$ are calculated from the best straight line for the specific ΔE values. Using the straight line graph, the experimental values for the concentrations can be calculated.

Table 5: Voltage reading for the specific concentrations of copper sulphate prepared solution and their differences:

Concentration of prepared solutions of $\text{Cu}^{2+}/\text{mol dm}^{-3}$	E values/ V	(E - 1.1) V	$\Delta E / V$
1.000	1.07	1.07 - 1.1	-0.03
0.500	1.06	1.06 - 1.1	-0.04
0.100	1.05	1.05 - 1.1	-0.05
0.050	1.03	1.03 - 1.1	-0.07
0.010	1.02	1.02 - 1.1	-0.08
0.005	1.01	1.01 - 1.1	-0.09
0.001	0.99	0.99 - 1.1	-0.11

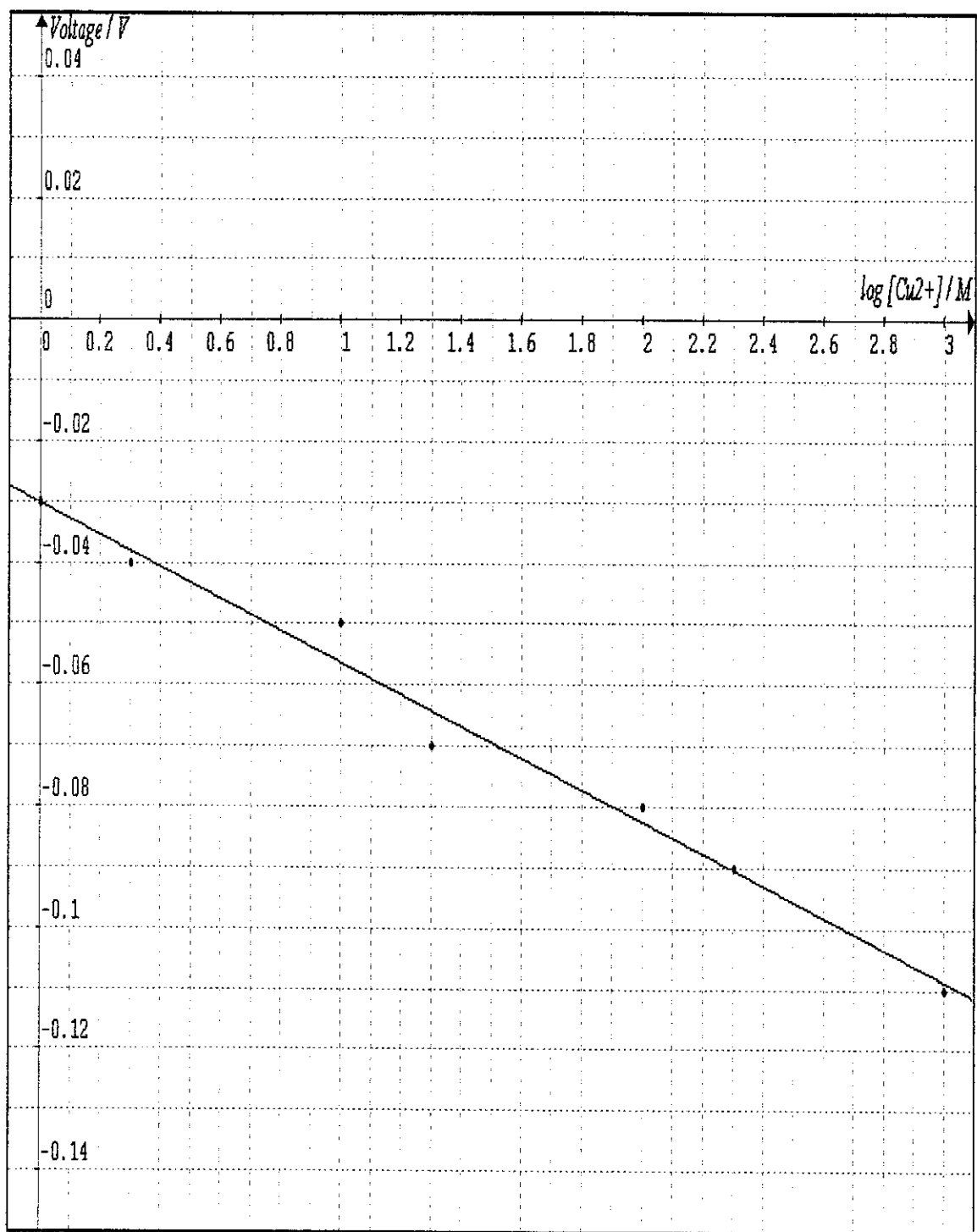
Table 6: Concentrations of copper sulphate solution and specific their log values:

Concentration of prepared solutions of $\text{Cu}^{2+}/\text{mol dm}^{-3}$	(1/[Cu^{2+}]) / $\text{mol}^{-1} \text{ dm}^3$	Log (1/[Cu^{2+}])	Log (1/[Cu^{2+}])
1.000	(1/1)	Log 0	0.000
0.500	(1/0.5)	Log 2	0.301
0.100	(1/0.1)	Log 10	1.000
0.050	(1/0.05)	Log 20	1.301
0.010	(1/0.01)	Log 100	2.000
0.005	(1/0.005)	Log 200	2.301
0.001	(1/0.001)	Log 1000	3.000

Table 7: Values of log(1/ concentration) to form Calibrated curve:

Concentration of prepared solutions of $\text{Cu}^{2+}/\text{mol dm}^{-3}$	Log (1/[Cu^{2+}])	$\Delta E / V$
1.000	0.000	-0.03
0.500	0.301	-0.04
0.100	1.000	-0.05
0.050	1.301	-0.07
0.010	2.000	-0.08
0.005	2.301	-0.09
0.001	3.000	-0.11

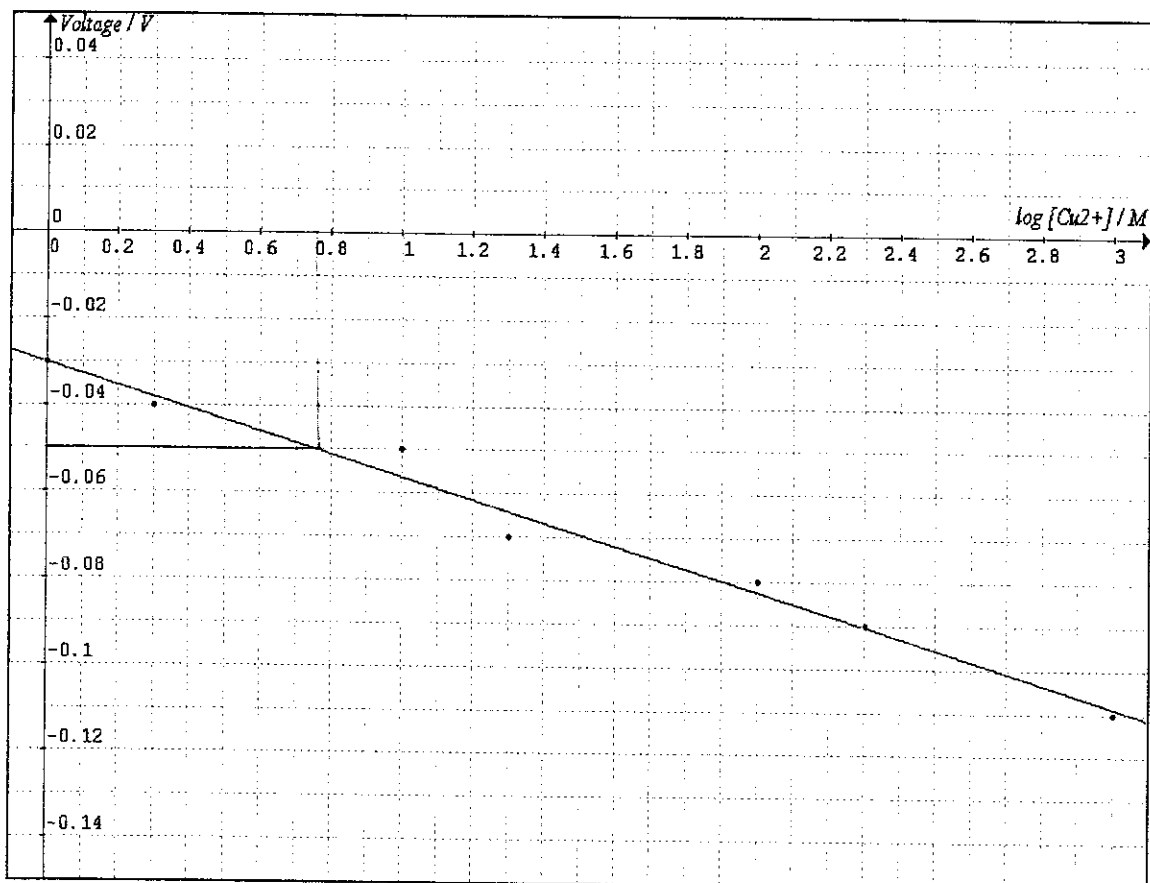
Graph 1 : Voltage Vs. $\log(1/[Cu^{2+}])$ (using values from Table 7)



From the above graph, specific ΔE values can be used to figure out the $\log(1/[Cu^{2+}])$ from which we can obtain the experimental concentration of the copper solutions.

The ΔE value for the prepared concentration of copper sulphate solution of 0.1 mol dm^{-3} is -0.05 V (refer to table 5). We use this voltage to determine the $\log(1/\text{concentration})$ from the curve of the calibrated graph from which the experimental concentration can be obtained. This is done at the point where the voltage reading of -0.05 V gives a reading in the curve plotted which can be used to determine the concentration of copper ions in the solution.

When ΔE is -0.05 V , using Graph 1, the actual concentration of Cu^{2+} can be determined as shown below:



From the graph $\log(1/[\text{Cu}^{2+}])$ value for -0.05 V is 0.7595 . Hence the experimental concentration of the solution is calculated as follows:

$$\log \frac{1}{\text{Cu}^{2+}} = 0.7595$$

$$\frac{1}{\text{Cu}^{2+}} = 10^{0.7595}$$

$$\frac{1}{\text{Cu}^{2+}} = 5.7477$$

$$\therefore \text{Cu}^{2+} = 0.1739 \text{ mol dm}^{-3}$$

Following this method we can find the experimental concentration for the rest of the solutions using their specific ΔE values.

Table 8: Concentration of the prepared solution and the experimental concentration of the copper sulphate solution:

Concentration of prepared solution of copper sulphate /mol dm^{-3}	$\Delta E / V$	Value of $\log(1/[\text{Cu}^{2+}])$	Experimental concentration of copper sulphate solution / mol dm^{-3}
1.000	-0.03	-0.0038	1.00800
0.500	-0.04	0.3779	0.41889
0.100	-0.05	0.7595	0.17398
0.050	-0.07	1.5229	0.02999
0.010	-0.08	1.9046	0.01245
0.005	-0.09	2.2863	0.00517
0.001	-0.11	3.0496	0.00089

6.2 Spectrophotometer

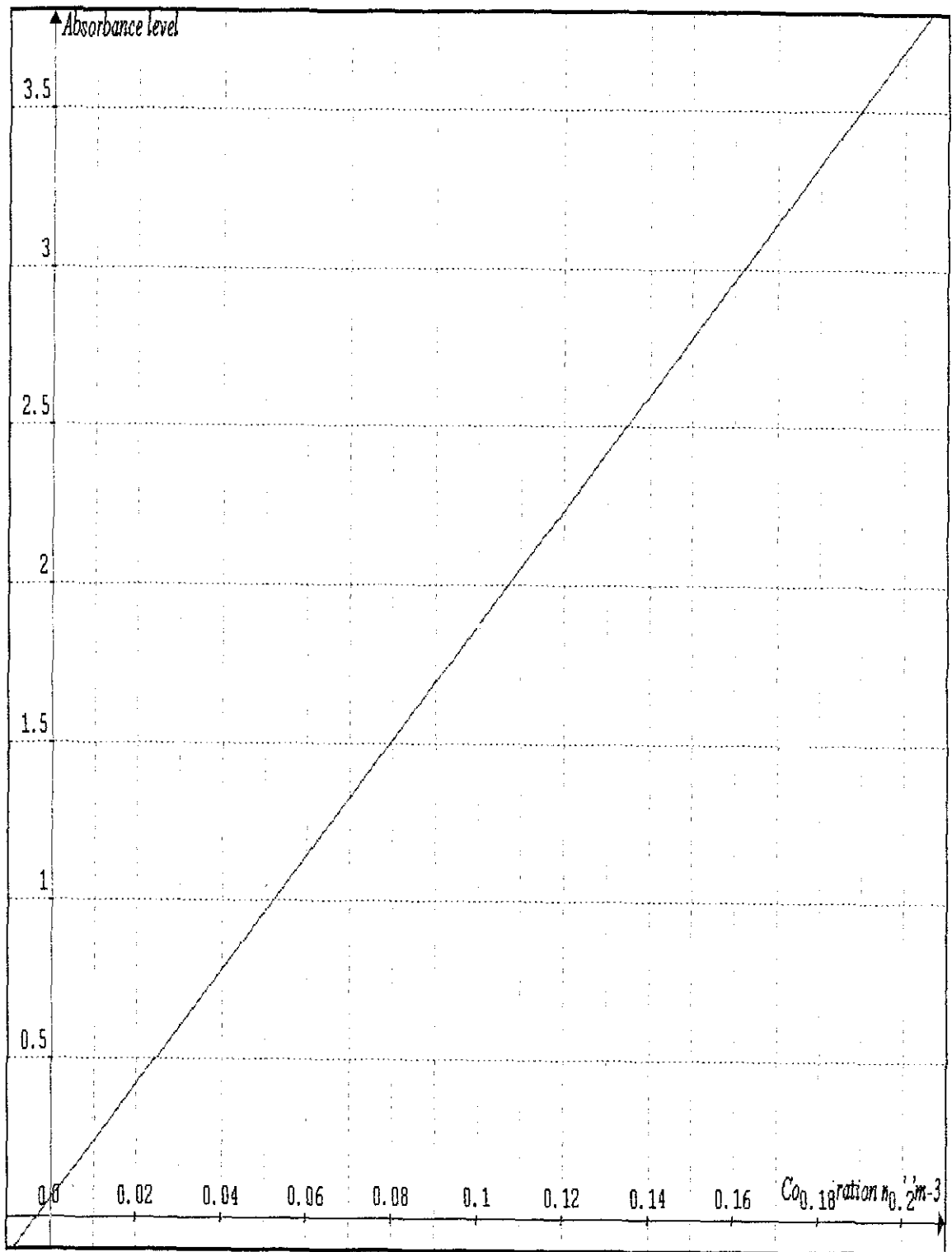
6.2 (1) Calibrating a curve:

The calibration curve is made by using the absorbance level of the prepared solutions. From Beer Lambert's law, we know that concentration of solution is directly proportional to absorbance level. Thus a calibrated curve of concentration against absorbance would have a proportionality nature; i.e. straight line passing through the origin.

Table 9: Concentration of the prepared solution and their specific absorbance levels:

Concentration of tetraamminecopper(II) ion solution/ mol dm^{-3}	Absorbance level
0.200	3.7276
0.100	1.8638
0.050	1.0534
0.010	0.3079
0.005	0.0091
0.000	0.0000

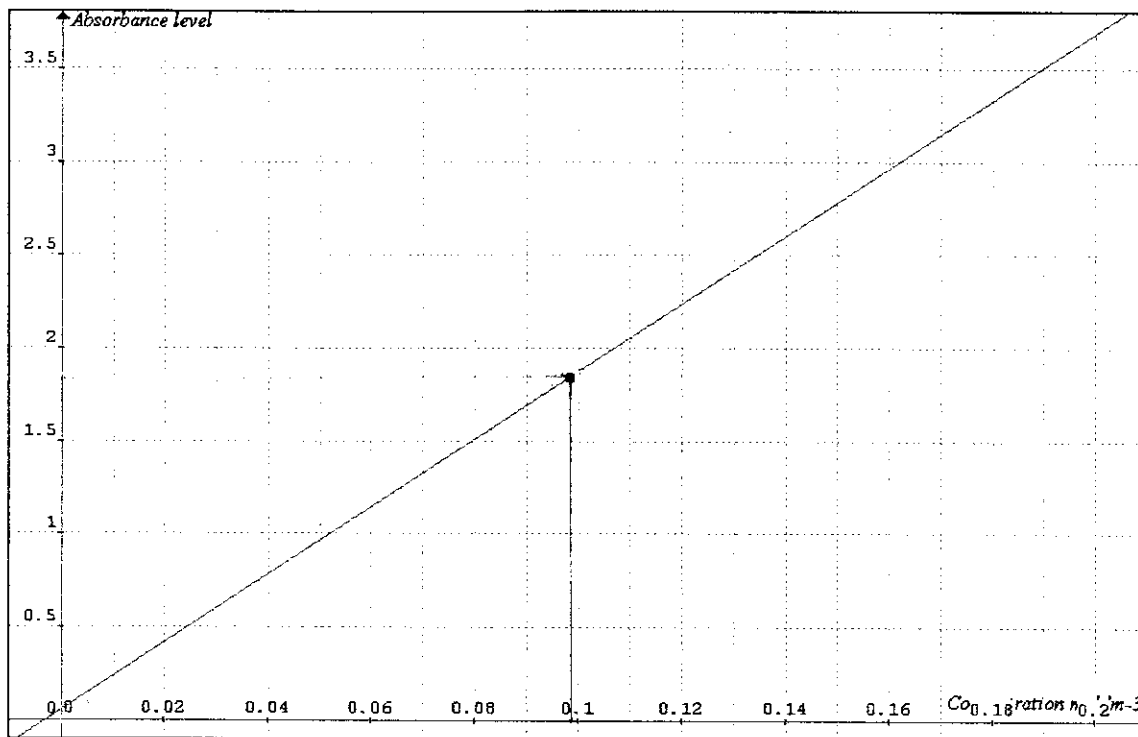
Graph 2: Absorbance Vs. Concentration (using data from Table 9)



From the above graph, the experimental value for the concentration of the copper sulphate solution can be measured using the specific absorbance level.

For example, the absorbance level for the prepared copper sulphate solution of concentration 0.1 mol dm^{-3} is 1.8638. Using this absorbance value, we can find the experimental concentration value from the calibrated curve.

Graph 3: To show how the experimental value is obtained from the plotted graph of Absorbance Vs. Concentration



The circle represents the value of concentration for the specific absorbance level. For the absorbance value of 1.8638 (refer to table 9), the experimental concentration of the copper sulphate solution is 0.0994. Hence we can find the other experimental concentration values using the specific absorbance level as shown below:

Table 10: Prepared concentration of solution and experimental concentrations of tetramminecopper (II) solution:

Concentration of prepared copper sulphate solution / mol dm^{-3}	Absorbance levels	Experimental values of copper sulphate solution / mol dm^{-3}
0.000	0.0000	0.0000
0.005	0.0918	0.0020
0.010	0.3079	0.0120
0.050	1.0634	0.0549
0.100	1.8638	0.0994
0.200	3.6720	0.2010

6.3 Determining the accuracy:

Error analysis:

To compare the errors involved in both the methods, we take the concentration of 0.05 mol dm^{-3} as the initial literature value since this concentration of the solution has been used for both the experiments.

Redox potential:

Table 11: Calculation of the errors incorporated into the equipments

Equipments used	Error	Calculation	Percentage error
Measuring cylinder (10 cm ³)	±0.1	$(0.1/10) \times 100$	1%
Measuring cylinder (25 cm ³)(being used twice)	±0.4	$((0.4/20) \times 100) \times 2$	4%
Measuring cylinder (100 cm ³)	±1	$(1/100) \times 100$	1%
Voltmeter	±0.01	$(0.01/1.03) \times 100$	0.9%
Total percentage error			6.9%

Experimental value for concentration of $[\text{Cu}^{2+}]$: $0.02999 \text{ mol dm}^{-3}$ (refer to table 8)

Percentage random error: 6.9%

$$\begin{aligned} \text{Total percentage error} &= [(\text{initial value} - \text{calculated value}) / \text{initial value}] \times 100 \\ &= \left(\frac{0.05 - 0.02999}{0.05} \right) \times 100 \\ &= 40.2\% \end{aligned}$$

$$\begin{aligned} \text{Total systematic error} &= \text{Total percentage error} - \text{total random error} \\ &= 40.2\% - 6.9\% \\ &= 33.3\% \end{aligned}$$

Spectrophotometer:

Table 12: Calculation of the errors incorporated into the equipments

Equipment used	Error	Calculation	Percentage error
Measuring cylinder (10 cm ³)(being used twice)	±0.1	$(0.1/5) \times 100 \times 2$	4%
Measuring cylinder (50 cm ³)	±0.5	$((0.5/50) \times 100)$	1%
Pipette (5 cm ³)(being used twice)	±0.01	$(0.01/5) \times 100 \times 2$	0.4%
Spectrophotometer	±0.01	$(0.01/1.0534) \times 100$	0.9%
Total percentage error			6.3%

Experimental value for concentration of [Cu²⁺] : 0.0549 moldm⁻³ (refer to table 10)

Total percentage random error: 6.3%

$$\begin{aligned} \text{Total percentage error} &= [(\text{initial value} - \text{calculated value}) / \text{initial value}] \times 100 \\ &= \left(\frac{0.05 - 0.0549}{0.05} \right) \times 100 \\ &= 9.8\% \end{aligned}$$

$$\begin{aligned} \text{Total systematic error} &= \text{Total percentage error} - \text{total random error} \\ &= 9.8\% - 6.3\% \\ &= 3.5\% \end{aligned}$$

7. Conclusion and Evaluation:

From the whole experiment it can be seen that spectrophotometry proves to be far better method to find the concentration of the solution than redox potential. This contradicts my hypothesis made earlier. My hypothesis was based on the fact that the reading of the spectrometer would be affected by the ions present in the solution other than copper ions. But using light of a definite wavelength narrows down the number of ions which can affect the reading of the spectrometer and hence the errors produced by it is minimized.

Overall the percentage errors produced by spectrophotometer is 9.8% which is less than the total error percentage of the by the redox potential (40.2%) showing that spectrophotometer gives more accurate experimental values of concentration which are closer to the original values than the redox potential.

The spectrophotometer method also produced less random errors. This is due to the fact that less number of instruments was used in spectrophotometry than redox potential. Using a pipette substantially reduces the random errors incorporated in the method while the excessive use of measuring cylinder in redox potential increases these errors. Since the redox potential method involved the use of more instruments, these errors reflected while carrying out the experiment giving a higher systematic error than spectrophotometer.

One more factor which contributed to the errors in the redox potential method is the fluctuating of the voltmeter reading. The reading of the voltmeter starts fluctuating as soon as current starts flowing. Reading from the voltmeter must to be taken quickly because the reading changes with time. It is hard to interpret when the reading is stable which contributes to an error of ± 0.01 V. As the difference in the readings of the voltmeter is so small, an error of ± 0.01 V can have significant effect on the overall accuracy.

Again, the reading of the voltage is only affected when there is a large change in the concentration of copper ions in the solution. The reading of the voltage falls by 0.025V only when the concentration of the solution is one tenth of the original one. The concentration of copper ions in water is usually low. The voltage reading might be too small for the concentration to have a reasonable value. On the other hand for the spectrophotometer, an absorbance reading is given for even the smallest concentration of copper ions in the water.

Precaution should be taken in order to ensure that no precipitation of insoluble copper (II) oxide $[\text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2]$, is left in the tetraammine copper solution. The precipitation may absorb some of the light and give incorrect readings for the absorbance.

If any one of this method is adopted to make a kit available to the agricultural department, the spectrometry method would be better than redox potential. Not only is the error lower in the case of spectrometer, there are other factors which influence this. In redox potential, the concentration of the zinc sulphate needs to remain constant. But when used once, the concentration of the zinc sulphate solution would change. In order to use again, the zinc sulphate solution would have to be prepared fresh once again. This can be inefficient and inconvenient.

Moreover, as stated earlier, the voltage drops by a small amount only when there is a large difference in the concentration of the two solutions. This may cause the reader to misinterpret the readings of the voltmeter. For example, when water from two different ponds is tested, the voltage reading for the two ponds might be the same despite having different levels of copper concentrations. The difference in their concentration is small enough to give the same voltage reading but, in reality, concentration of copper in the water from one of the sources might not be suitable for usage. On the other hand, such kind of drawback can be avoided by the use of spectrophotometer as different concentration levels give different readings.

While using Nernst equation to verify the concentration, standard temperature is taken into concern i.e. 298 K. In practical use, the solutions to be tested might not always have standard temperature and the equation used only implies for solutions under standard conditions. Any change in the temperature of the solutions would affect the readings and give wrong concentration values. Meanwhile, the readings of the spectrophotometer remain unaffected by change in temperature or pH of the solution.

The complexities involved in both the techniques should also be taken into account. Techniques involved in spectrophotometer allows qualitative analysis as well when the intensity of color of the two different solutions can be compared to give a rough estimate of which has a greater concentration. Moreover the concentration can easily be calculated from the graph since the graph plotted is absorbance against concentration. Unlike spectrophotometry, redox potential does not give any scope for qualitative analysis and it involves further calculation to be done to find the concentration from the graph of Voltage against $\log(1/[\text{Cu}^{2+}])$.

However, the turbidity of the water can affect the reading of the spectrophotometer. If the water has too many impurities, the impurities may allow less light to pass through it to the detector and give wrong absorbance levels. This problem is not encountered in the redox potential method since the impurities do not affect the voltage. Moreover when the concentration of copper ions is quite high in the solution, it tends to have the same intensity of the color for which the absorbance level is relatively same to one another. So it becomes hard to differentiate the concentrations of the two solutions using spectrophotometer.

Further experiment can be done by using spectrophotometer to determine the concentration of other metal ions such as iron, cobalt, manganese, arsenic. Arsenic is one of those metals which is highly hazardous for health and any new source of water should be tested for the level of arsenic that usually depends upon the geographical location. It can be determined in water samples based on micro particle formation of ethyl violet molybdoarsenate. (http://www.jstage.jst.go.jp/article/analsci/22/8/22_1085/article)

This involves the formation of micro particles using ethyl violet and molybdoarsenate which gives a blue color with arsenic. This can later be used to determine the concentration of arsenic. Arsenic is the biggest water hazard in Bangladesh and determination of arsenic levels in water is crucial to have safe drinking water in rural part of the country.

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