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Methodological study of the spectral estimation of cobalt ions in some environmental models (food and pharmaceuticals)

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Abstract

This work is centered on the development of a sensitive and accurate spectroscopic method for the determination of cobalt (II) ions (Co (II)) in some environmental, food, and pharmaceutical samples using the laboratory-prepared Schiff-azo organic reagent ABIDAPH. The method is based on UV-Vis spectroscopy. The general procedure consists of preparing standard solutions and the organic reagent, studying the spectral behavior of the resulting cobalt complex, and determining the optimal conditions of complex formation and stability. The results obtained indicated that the cobalt complex with the organic reagent has the highest absorbance at a maximum wavelength of 520 nm; for the free reagent, it was 457 nm, thus confirming the formation of a clear and stable complex between. The best medium for complex formation was found to be at pH 9.0, where, at higher pH values, the absorbance started to decrease due to the possible precipitation of cobalt ions or the formation of less stable complexes. The optimum concentration of the organic reagent was 1×10^{-4} M, and for the cobalt ion, it was 5×10^{-5} M. The effect of the order of addition of the reaction components was also studied. The results indicated that the maximum absorbance was obtained when the cobalt ion was added first, then the alkaline medium, and lastly the organic reagent (M + pH + R), giving an absorbance of 0.33. The results further confirmed the 1:1 ratio of cobalt to organic reagent and implied that a stable complex was formed with a clear coordination structure. The titration curve analysis demonstrated that Beer-Lambert's law is valid for the method in the studied concentration range and that it is sensitive enough to determine very low concentrations of cobalt ions. The proposed method was applied successfully to estimate cobalt ions in several food samples after fresh digestion. Cobalt concentrations ranged from 11 to 20 ppm in the samples under study; lentils recorded the highest cobalt concentration at 20 ppm, and celery recorded the least at 11 ppm. Generally, these results show the efficiency of the organic reagent ABIDAPH in forming stable-colored complexes with cobalt ions and the potential of the proposed method as a simple, accurate, and sensitive analytical tool for estimating cobalt in different environmental, food, and herb samples.

Keywords: ABIDAPH, food toxicity, heavy metals, spectrophotometric, efficient reagents

Introduction

Analytical chemistry is that branch of chemistry which deals with the study of the composition of matter, both qualitatively and quantitatively. The importance of this field can be judged from the fact that it not only helps in characterizing the elements and compounds but also develops methods for accurate measurement of concentration^[1,2]. structure, and composition, which can support the development of science in different fields such as environmental science, biomedicine, as well as genetic and hereditary analysis in biological research, forensic medicine^[3], and the pharmaceutical industry^[4]. Traditionally, analytical methods are divided into two types: qualitative analysis, which detects elements or functional groups' presence, and quantitative analysis, which determines substances' exact concentration. The most recent addition to these methods is spectroscopic techniques that are based on the interaction between matter and electromagnetic radiation. Each element has its own spectrum that can be used to study and measure it. The electromagnetic spectrum covers all types of light, from low-frequency radio waves to high-energy gamma rays^[5,6].

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Notable reagents in the spectroscopic analysis are Schiff bases, imine compounds resulting from the reaction of amines with carbonyl compounds. These bases can be defined by their aptness to form stable complexes with metal ions [7]. Azo dyes are organic compounds that contain the (N=N-) group. They are known for their bright colors and their ability to bind to metal ions; therefore, they are suitable reagents in spectroscopy [8]. Cobalt (Co) is one of the vital transition metals that find use in a wide range of industrial and biological applications, including lithium-ion batteries and the synthesis of vitamin B12 [9]. Some studies have shown that high concentrations of cobalt in the environment or in food might lead to health effects. This fact necessitates the development of accurate analytical methods for the estimation of cobalt in different environmental samples [10, 11].

Cobalt ions have been estimated in several organic reagents by spectroscopic methods because of their sensitivity and applicability [12, 13]. This is particularly important in the case of azo compounds because they have been widely used, and their application is constantly increasing due to the fact that they can form colored complexes suitable for spectroscopic analysis [14, 15]. Therefore, the present work is focused on developing and validating a new spectrophotometric method for cobalt determination as a Schiff-azo derivative, optimizing the reaction parameters, constructing a calibration curve, and applying the method for real sample analysis. Such improvements will eventually lead to more accurate and reliable results of cobalt assays in environmental, food, and pharmaceutical samples.

Materials and Methods: Preparation of Standard Solutions and Reagents

The standard solutions and reagents used in this work were prepared as per routine procedures of our laboratory to

obtain reliable analytical results in the estimation of cobalt in environmental, food, and pharmaceutical samples. The cobalt standard solution was prepared at a molar concentration. An amount of 0.5920 g of aqueous cobalt chloride was weighed with a precision analytical balance and then dissolved in 25 mL of absolute ethyl alcohol in a suitable volumetric flask with constant stirring until a completely homogeneous solution was obtained.

The reagent standard solution was also prepared at a molar concentration. 0.4611 g of the reagent was weighed and dissolved in 25 mL of absolute ethanol. This solution was used to prepare a series of dilute standard solutions within the concentration range 1 to 1 molar by sequential dilution to get solutions of various concentrations used in constructing the titration curve. Two drops of 25% concentrated ammonium hydroxide solution were added to 25 mL of distilled water in a 25 mL volumetric flask to prepare the dilute ammonium hydroxide solution. The solution was then thoroughly mixed to ensure homogeneity. This solution was used to establish the alkaline medium required for the analytical reaction. Clean and pre-calibrated laboratory glassware was used for all preparations. Great care was taken to ensure the accuracy of measurements and volumes to be able to minimize experimental errors and to keep the stability of the analytical conditions throughout the experiments.

Calculations and Discussion

Spectroscopic Study of the Organic Reagent ABIDAPH

A spectroscopic study was performed on the pre-prepared organic reagent (ABIDAPH) in the UV-Vis region with the cobalt(II) ion Co(II). The spectrum showed an absorption band at the maximum wavelength of the [ABIDAPH-Co(II)] complex, where $\lambda_{\max} = 520$ nm, while the maximum wavelength of the organic reagent is $\lambda_{\max} = 457$ nm [16]

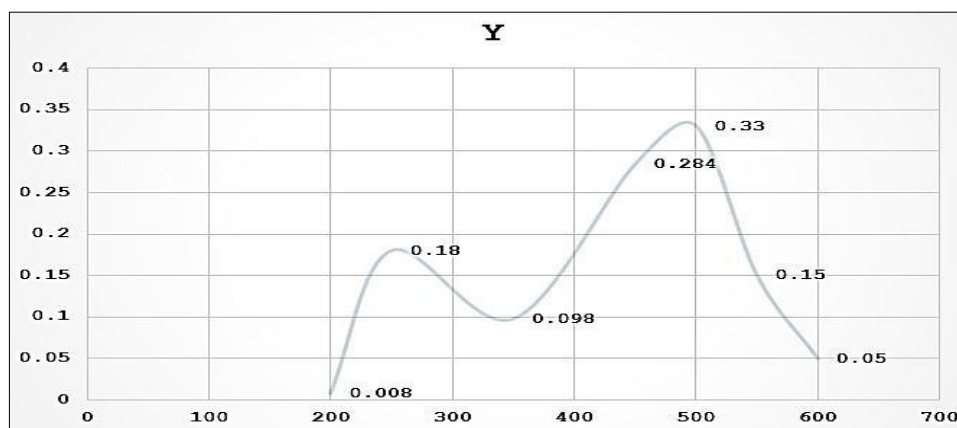


Fig 1: Results of the spectroscopic analysis of the organic reagent [ABIDAPH]

Study of Optimal Conditions Effect of pH

To identify the optimal pH, a wide range of pH values between 6-11 was selected by measuring the absorbance at the maximum wavelength of 250 nm for the organic reagent at a concentration of ($M1 \times 10^4$) and for the metal ion ($M5 \times 10^{-5}$). The cobalt complex has the optimal pH, as it was observed that the optical intensity of the complex solutions

gradually increases to reach its peak at the optimal pH, which was best at pH = 9, to reach the highest absorption. The optical intensity of the complex decreases with increasing pH values. At this limit, the reason is due to the start of the precipitation of the element ion or due to the formation of unstable complex ions [17].

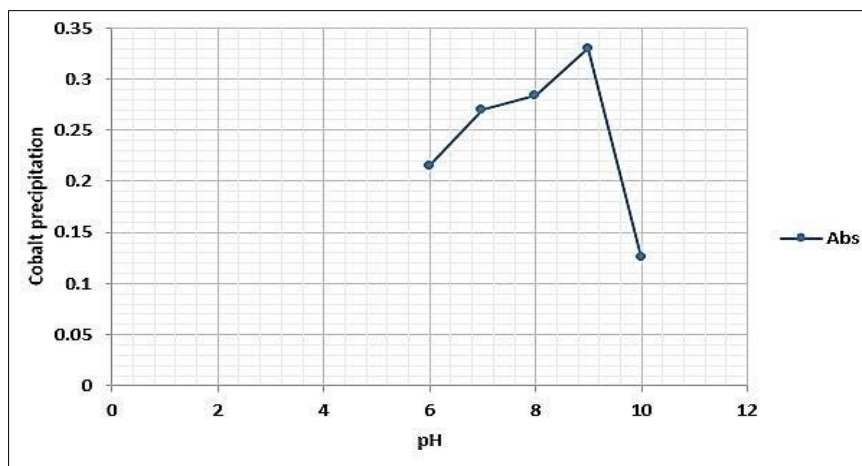


Fig 2: Effect of acidity on the formation of the cobalt complex (II)

Effect of Reagent Concentration

The purpose of this study was to determine the optimal concentration of the two prepared reagents for complex formation. Different concentrations of the reagent, ranging from 6×10^{-4} to 8×10^{-5} , were used, along with a metal ion concentration of 5×10^{-5} and pH 9. The absorbance was recorded at the maximum wavelength. It was observed that the absorbance values of the complex solutions at the maximum absorbance wavelength increased, reaching a 1×10^{-4}

10^{-4} was obtained as the peak for the cobalt complex (Figure 3). Probably, an interaction between the metal ion and the reagent was responsible for driving the formation of the complex. Thereafter, the absorbance values decreased with increasing concentration of the reagent, either due to saturation of the coordination field between the ion and the reagent or because the reagent was not completely soluble in the solvent [18]. In general, the best concentration of the organic reagent was 1×10^{-4} .

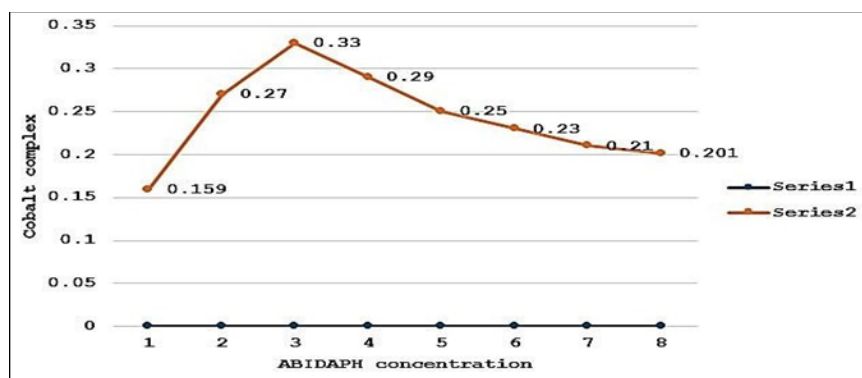


Fig 3: Effect of optimal concentration of the reagent ABIDAPH on cobalt complex yielding

Effect of addition order: To demonstrate the effect of the addition order on the absorbance value of the prepared addition order of the reaction components on the absorbance complexes under study. Only the first, second, and fourth of

the prepared complexes under study, four addition sequences of mixing gave lower absorbance, while the third method was adopted as shown in Table 1. A spectral mixing gave the highest absorbance [19, 20].

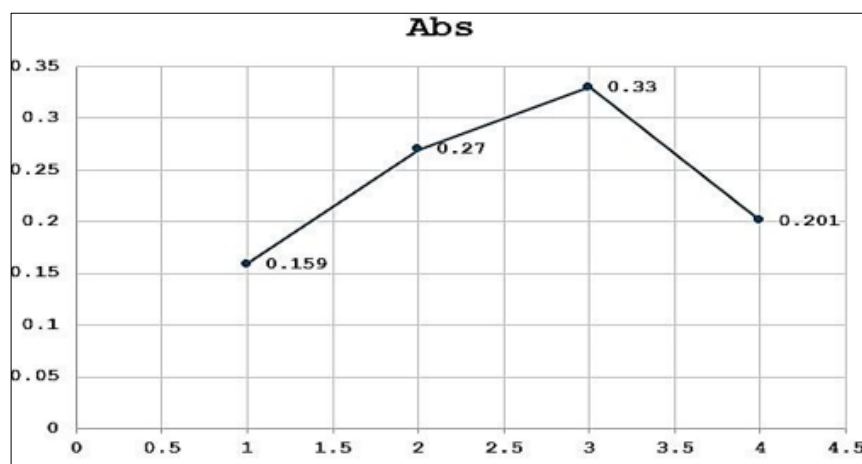


Fig 4: Determination of metal ion concentration

Table 1: Order of addition in absorbance complexes to form a complex with the reagent

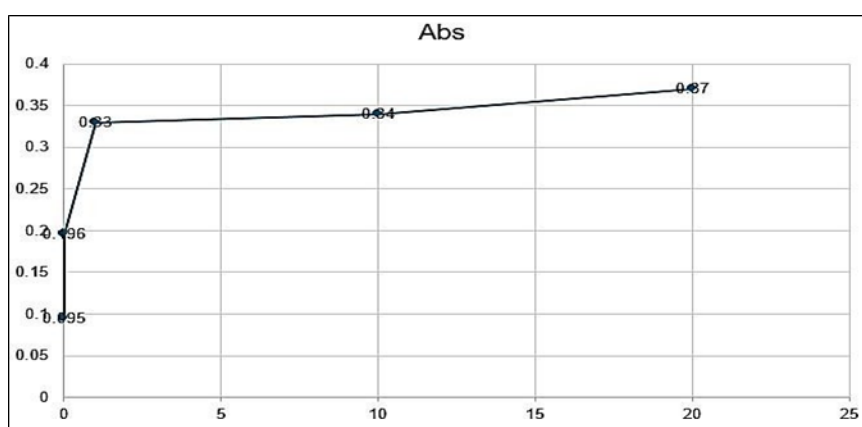
Sequence of number	Sequence of addition	Abs. of CO ⁺ complex
1	M + R + pH	0.205
2	R + M + pH	0.259
3	M + pH + R	0.33
4	R + pH + M	0.215

Determining the concentration of the metal ion reagent [ABIDAPH] was added at pH 9. The absorbance of A group of solutions of the metal ion was measured for each solution, and the concentration of different ranges from (1×10^{-5} to 8×10^{-5}). The organic metal ion solution was reacted with its equivalent in organic reagent. The absorbance of each of these solutions was then plotted on the y-axis to obtain the was then recorded at the maximum wavelength (max = 520 final figure. The best concentration of the metal ion was nm against Planck's solution. The values representing the (5×10^{-5} m) (Figure 4).

Concentration of the metal ion on the x-axis and the Studying the Static Isometrics of Complexes. The metal/reagent ratio of the complexes under study was determined using the mole ratio method and the continuous variation method (radio method). The reagent-to-metal ratio was found to be 1:1.

Mole Ratio Method

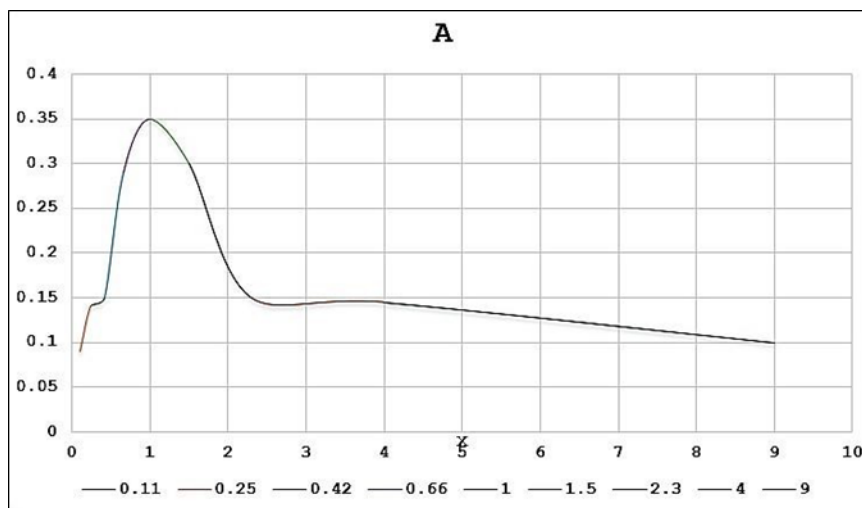
This is one of the most common and simple methods for determining possible formulas, in addition to providing good results. The mole ratio of the cobalt-reagent complex [ABIDApH] was determined by using a set of 10 ml volumetric bottles. One ml of each metal ion solution with a concentration of 1×10^{-4} was added at pH 9. Organic reagent solutions with concentrations of 5×10^{-4} to 8×10^{-5} were added, and the volume was completed to 10 ml with absolute ethanol. The absorbance of the collected solutions was then measured at $\lambda_{\text{max}} = 520$ nm for each complex against the blank solution (Figure 5).

**Fig 5:** Molar ratios of the cobalt complex with the reagent [ABIDApH]

Continuous Change Method (Jobb's Method)

A set of 10 ml bottles was used, and different volumes of metal ions and organic reagents, from 0.9 to 0.1 ml, were added to them at an optimal pH of 9. The results were measured at a maximum wavelength of 520 nm against Planck's solution. The results (Figure 6) showed that the metal: reagent ratio was (1:1) for the cobalt complex with the reagent ABIDAPH. Study of the calibration curve: The calibration curve was prepared using optimal conditions

obtained from the study to determine the range of concentrations that give results within the Beer-Lambert's law for the cobalt (II) ion solution with the organic reagent [Co-ABIDAPH] under study from 1×10^{-5} to 8×10^{-5} , over a wide range of concentrations (Figure 8). Several concentrations were left out because they did not conform to Beer-Lambert's law within the range of 5×10^{-6} to 1×10^{-6} in 10 mL of solution. [21, 22].

**Fig 6:** Continuous changes of the cobalt complex with the reagent ABIDAPH

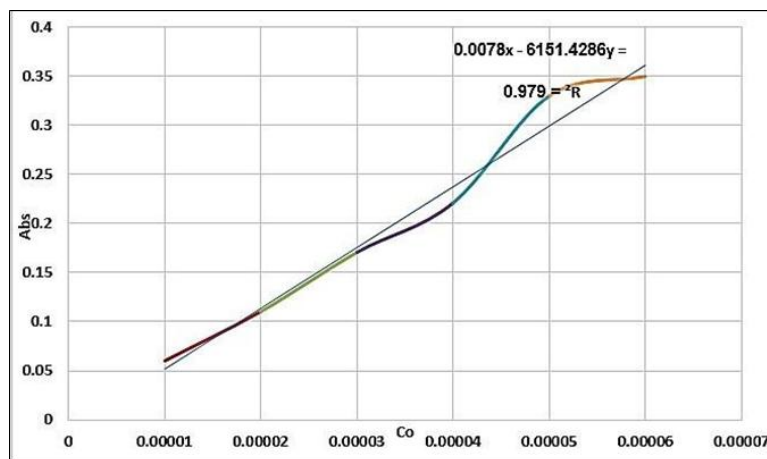


Fig 7: Calibration curve of the cobalt complex with the reagent ABIDAPH

Applications

Wavelength Of 520 nm was determined for the cobalt-reagent complex; this provides good sensitivity in the Some pre-prepared, wet-digested samples were used, and the cobalt (II) ion was determined after adding 4 IU/mL of sodium potassium tartrate to the solution. The results are shown in Table 2.

Table 2: Estimation of cobalt levels (ppm) in different food samples based on the complete sample and the analytical methods under study

Sample type	Cobalt level (ppm)
Celery	11
Orange	18
Parsley	16
Lentils	20
Leeks	15

Conclusions

It was found that the organic reagent ABIDAPH gives high efficiency in the formation of a stable colored complex with cobalt (II) ions, which can be tracked accurately spectroscopically by the UV-Vis technique. A maximum spectroscopic analysis. The optimal medium for complex formation was established to be at pH 9 since this value gives the highest absorbance and also the best stability for the formed complex. Generally, the organic reagent performed best at a concentration of 1×10^{-4} M, while that for cobalt ion was 5×10^{-5} M. The order of addition of the reaction components significantly affected the increase in absorbance, and the sequence (metal + basic medium + reagent) gave the highest value of absorbance compared to other methods of addition. Both the molar ratio method and the continuous variation method confirmed that the bonding ratio between the cobalt ion and the organic reagent was 1:1, which means that a stable coordination complex was formed. The analytical method showed good agreement with Beer-Lambert's law within the studied concentration range, qualifying it for the quantitative determination of cobalt ions. The method successfully determined cobalt in different food samples and, therefore, has high potential for environmental, food, and pharmaceutical applications due to its simplicity, sensitivity, and low cost compared to some advanced analytical methods. The present study reports a new spectroscopic method for the determination of divalent cobalt ions based on UV-Vis spectroscopy using the laboratory-prepared organic reagent ABIDAPH. The results showed that the reagent can form a stable complex with

cobalt ions that has a high absorbance, which makes it useful in quantitative analysis with good accuracy and remarkable sensitivity.

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