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Development of a Facile Technique to Detect Zinc in Solutions

Ebony Schultz, Carl White, Nicole Gipp, Ram Krishna Hona*

Environmental Science Department, United Tribes Technical College, Bismarck, ND, USA
Email: *rhona@uttc.edu

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Abstract

This study presents a novel and facile technique for the rapid and sensitive detection of zinc (Zn) in foods and drinking water. The need for a reliable method to monitor Zn levels in consumables is crucial due to its significance in both nutritional assessment and environmental safety. The proposed technique integrates state-of-the-art sensing technology with an easy-to-implement approach, aiming to provide an efficient solution for Zn detection. The methodology involves the utilization of complexation of Zn^{2+} ion with resorcinol and use of UV-vis spectrophotometry, which demonstrates high sensitivity towards Zn^{2+} ions. It detected zinc up to 10^{-5}M solution.

Keywords

UV-vis Spectrophotometer, Dilution, Calibration Curve, Molar Absorptivity

1. Introduction

Zinc (Zn) is an essential trace element vital for numerous biological functions, including enzyme activity, immune system regulation, and protein synthesis. It plays a critical role in human health, particularly in growth, development, and wound healing [1]. Despite its importance, both zinc deficiency and overexposure can have adverse effects [2]. Zinc deficiency is a global nutritional concern, especially in developing regions, where it contributes to stunted growth and compromised immune function. Conversely, excessive zinc levels in food and drinking water, often resulting from industrial pollution or the corrosion of plumbing materials, can pose significant environmental and health risks, leading to conditions such as nausea, diarrhea, and long-term organ damage [2].

Due to these health concerns, monitoring zinc levels in consumables such as food and drinking water has become a priority for public health and safety. Traditional methods of detecting zinc include atomic absorption spectrophotometry

(AAS) and inductively coupled plasma mass spectrometry (ICP-MS) [3] [4]. While these techniques are highly sensitive, they require expensive instrumentation, skilled operators, and lengthy sample preparation procedures, making them inaccessible for routine testing, particularly in resource-limited settings. Therefore, there is a growing need for simple, cost-effective, and efficient methods to monitor zinc concentrations in various matrices.

In this study, we present a novel and facile technique for the detection of zinc using a complexation reaction between Zn^{2+} ions and resorcinol, followed by UV-visible spectrophotometric analysis. The quantitative accuracy of UV-visible spectrophotometric analysis relies on the linear relationship described by the Beer-Lambert law within the tested concentration range

$$A = \varepsilon \cdot c \cdot \ell$$

The molar absorptivity coefficient constant, ε is the absorbance for a solution of concentration (c) 1 mole/dm^{-3} and a path length (ℓ) of 1 cm. UV-vis spectrophotometry is valued for its simplicity, rapidity, and cost-effectiveness in detecting and quantifying zinc ions in various samples, including environmental water, biological fluids, and industrial effluents. However, it's important to consider potential interference from other substances in complex samples, and careful experimental design is necessary for accurate and reliable results. **Figure 1** shows the working principle of a UV-vis spectrophotometer.

The method offers a rapid, sensitive, and reliable approach to quantifying zinc levels in food and water samples. The development of such an accessible and efficient method could provide significant improvements in public health, environmental safety, and food quality assurance.

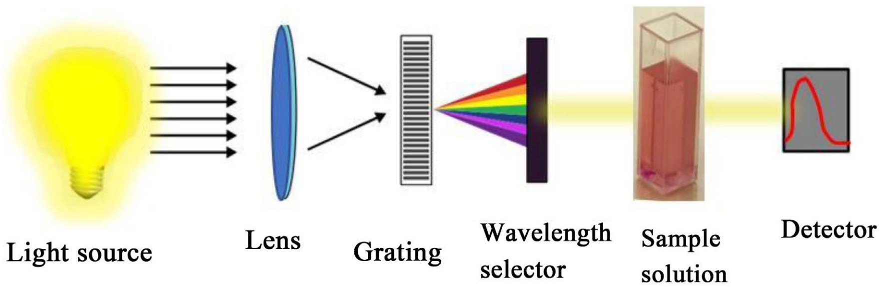

Figure 1. UV-vis spectrophotometer working principle.

2. Experiment

2.1. Resorcinol Solution Preparation

Resorcinol solution was prepared by accurately weighing 5.505 g of resorcinol and dissolving it in 100 mL of distilled water in a volumetric flask. The solution was stirred thoroughly using a magnetic stirrer to ensure complete dissolution of the resorcinol. This resulted in a 0.5 M solution, which was stored in a tightly sealed container at room temperature to avoid degradation. The prepared solution was subsequently used in the complexation reactions with zinc ions in all experiments, ensuring consistent reagent quality throughout the study.

2.2. $ZnCl_2$ Solution Preparation

Zinc chloride ($ZnCl_2$) solution was prepared by accurately weighing 1.3629 g of $ZnCl_2$ and dissolving it in 100 mL of distilled water in a volumetric flask. The solution was stirred thoroughly until the $ZnCl_2$ was completely dissolved, resulting in a 0.1 M zinc chloride solution. This solution was stored in a clean, sealed container to prevent contamination or evaporation. The prepared Zn^{2+} solution was used in the complexation experiments, providing a reliable and consistent source of zinc ions for the detection and analysis procedures in this study.

2.3. Dilutions of $ZnCl_2$ Solution

The dilution of zinc chloride ($ZnCl_2$) solutions was carried out systematically to prepare a series of solutions with decreasing concentrations. Initially, 10 mL of the 0.1 M $ZnCl_2$ stock solution was pipetted into a 100 mL volumetric flask and diluted to the mark with distilled water, resulting in Solution A (0.01 M). Following the same procedure, 10 mL of Solution A was further diluted to 100 mL, yielding Solution B (0.001 M). This process was repeated for each subsequent dilution: 10 mL of Solution B was diluted to prepare Solution C (0.0001 M), 10 mL of Solution C was diluted to prepare Solution D (0.00001 M), and finally, 10 mL of Solution D was diluted to obtain Solution E (0.000001 M or 1 μM). Figure 2 shows the dilution process of the solutions. These diluted solutions were used for the calibration and detection experiments, ensuring a precise range of Zn^{2+} concentrations for analysis. This sequential dilution provides solutions of progressively lower concentrations, ideal for sensitivity analysis or calibration curves.

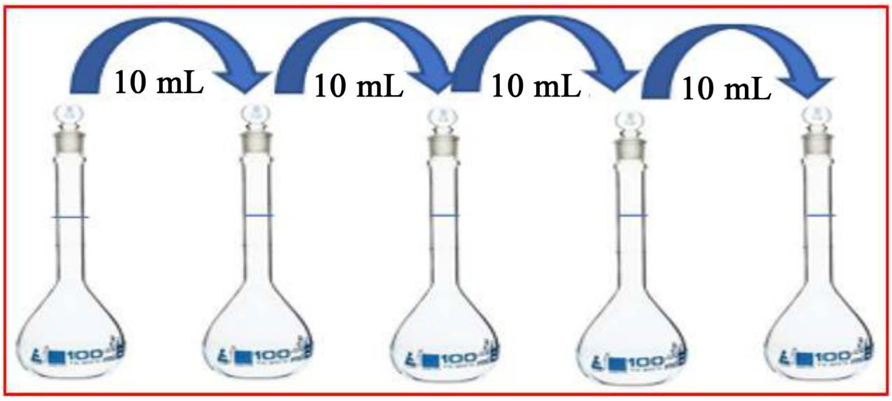

Figure 2. Dilution of solution to a desired concentration.

2.4. Preparation of Standard Sample Solutions

The standard solutions for the detection of zinc ions were prepared by combining specific volumes of resorcinol, ammonium hydroxide (NH_4OH), zinc chloride ($ZnCl_2$), and sulfuric acid (H_2SO_4) solutions in a stepwise manner. First, 5 mL of the prepared 0.5 M resorcinol solution was transferred into a clean test tube. Then, 2 mL of 2.3 M NH_4OH was added to create an alkaline environment, and the mixture was allowed to react for 5 minutes. After the waiting period, 5 mL of the desired Zn^{2+} solution (either the stock or one of the diluted solutions) was added, followed by another 5-minute wait to ensure complete complexation. Finally, 3 mL of 2 M H_2SO_4 was added to the mixture to stabilize the formed Zn^{2+}-resorcinol complex. The concentrations of NH_4OH and H_2SO_4 were chosen to optimize pH for complex formation and subsequent stabilization. These standard solutions were prepared in triplicate for each zinc concentration and were used for UV-visible spectrophotometric analysis, ensuring consistent and reliable measurements throughout the study.

2.5. Timing Summary: (Refer to Figure 3)

- 5 mL resorcinol solution + 2 mL NH_4OH → Wait 5 minutes
- Add 5 mL Zn^{2+} solution → Wait 5 minutes
- Add 3 mL H_2SO_4 → Final mixture

This procedure allows for the formation of the Zn^{2+}-resorcinol complex in the presence of NH_4OH, followed by stabilization with sulfuric acid, which is essential for further analysis.

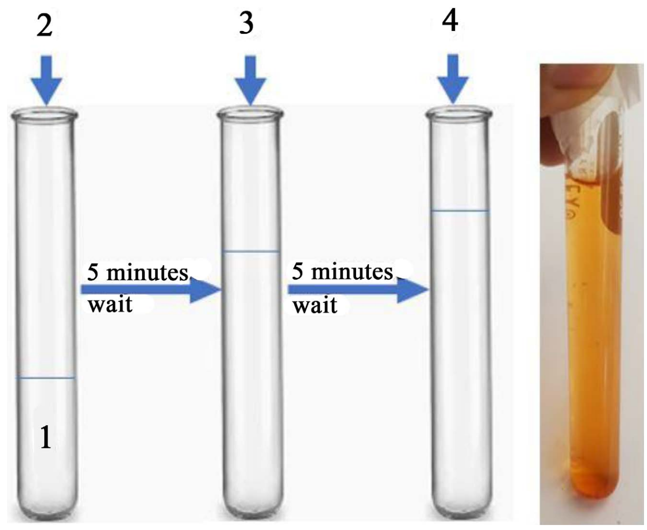

Figure 3. Mixing the reagents and waiting time before the UV-vis measurement.

2.6. UV-vis Absorption Measurement

The UV-visible (UV-vis) spectrophotometric measurements were performed using a standard UV-vis spectrophotometer. Each standard solution, prepared as described earlier, was transferred into a clean quartz cuvette with a path length of 1 cm. The absorbance spectra were recorded over the wavelength range of 200–800 nm, with a specific focus on the absorbance at the maximum wavelength (λ_{max} = 478 nm), which corresponds to the Zn^{2+}-resorcinol complex (**Figure 4**). The spectrophotometer was blanked using a solution containing all reagents except Zn^{2+} to account for background absorbance.

For each concentration of Zn^{2+}, absorbance values were measured at 478 nm, and the data were recorded. These values were used to construct a calibration curve of absorbance versus Zn^{2+} concentration. All measurements were performed at room temperature, and each sample was measured in triplicate to ensure accuracy and reproducibility. The results demonstrated a linear relationship between absorbance and zinc ion concentration within the tested range.

3. Results and Discussion

The primary objective of this study was to develop a sensitive and facile method for detecting zinc ions (Zn^{2+}) in food and drinking water using resorcinol as a complexing agent and UV-visible spectrophotometry for quantification. The experiment successfully demonstrated the formation of a Zn^{2+}-resorcinol complex, with a characteristic absorption peak observed at a wavelength of 478 nm.

3.1. Absorption Spectrum

The UV-visible spectrophotometric analysis of the Zn^{2+}-resorcinol complex revealed a distinct absorption maximum (λ_{max}) at 478 nm (**Figure 4**). This consistent absorption peak indicates the successful complexation of Zn^{2+} ions with resorcinol under the given conditions. The wavelength of 478 nm suggests that the Zn^{2+}-resorcinol complex absorbs strongly in the visible region, making it suitable for detection using standard UV-vis spectrophotometers.

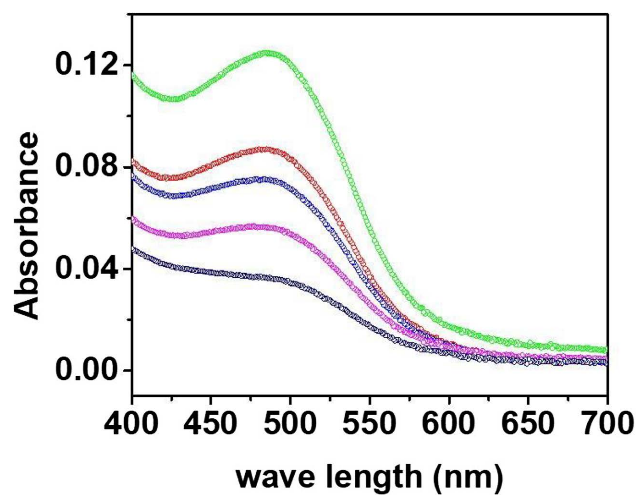

Figure 4. UV-vis spectra of Zn^{2+} solutions of different concentrations showing λ_{max} of 478 nm.

3.2. Calibration Curve

To evaluate the sensitivity of the method, a series of Zn^{2+} solutions with varying concentrations were prepared and analyzed. The absorbance values were recorded at 478 nm for each concentration, and a calibration curve was plotted. **Figure 5** shows the calibration curve of the Zn^{2+} solutions. The plot of absorbance versus concentration resulted in a linear relationship, indicating a direct correlation between Zn^{2+} concentration and the absorbance of the Zn^{2+}-resorcinol complex. The linearity of the curve suggests that the method follows Beer-Lambert's law within the tested concentration range, which is critical for quantitative analysis.

The equation of the calibration curve was determined to be:

$$A = mC + b$$

where A is the absorbance, C is the concentration of Zn^{2+}, m is the slope, and b is the y-intercept (close to zero in this case).

The non-zero y-intercept in the calibration curve may result from background absorption by reagents or solvent impurities, which can be mitigated using a reagent blank correction, or from matrix effects due to acidic/alkaline conditions.

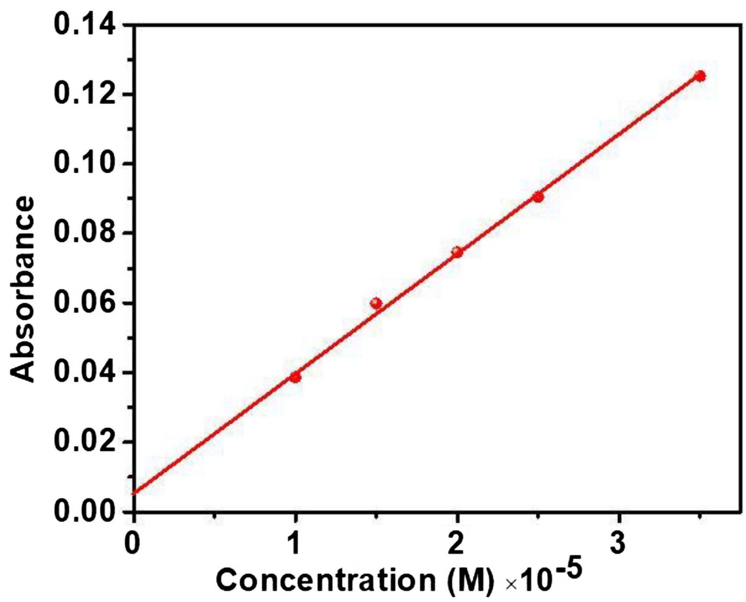

Figure 5. Calibration of Zn^{2+} ion concentrations.

3.3. Detection Limit and Sensitivity

The method demonstrated a high sensitivity for zinc detection, with successful quantification down to concentrations as low as 10^{-5} M. This level of sensitivity is comparable to more complex analytical techniques, such as atomic absorption spectrometry (AAS), but with the added advantage of simplicity and cost-effectiveness. This makes the technique particularly useful for routine monitoring of zinc levels in food and drinking water, especially in resource-limited settings [5].

3.4. Discussion of the Zn^{2+}-Resorcinol Complexation Mechanism

The formation of the Zn^{2+}-resorcinol complex [6] [7] was facilitated by the addition of ammonium hydroxide (NH_4OH), which created an alkaline environment conducive to the complexation reaction. The waiting time of 5 minutes before and after the addition of Zn^{2+} ensured sufficient interaction time for the complex to form, stabilizing upon the addition of sulfuric acid (H_2SO_4). The pH-dependent behavior of the reaction is crucial for optimizing the complexation and stabilizing the final product for spectrophotometric analysis [6] [8].

The λ_{max} observed at 478 nm corresponds to the specific electronic transitions within the Zn^{2+}-resorcinol complex, likely involving charge transfer between Zn^{2+} and the aromatic system of resorcinol. The strong absorbance at this wavelength provides a clear spectrophotometric signature that can be used for routine detection of zinc in various matrices. Though the experiments were performed with the aqueous Zn^{2+} solutions only, the method requires future validation with real-world samples to assess potential matrix effects in foods and drinking water.

4. Conclusion

The developed system offers a quick and cost-effective alternative to traditional analytical methods, making it suitable for routine monitoring and large-scale applications. The detection limits achieved with this technique meet or surpass the regulatory standards for Zn concentration in foods and drinking water. Furthermore, the proposed technique is adaptable to various sample matrices, allowing its application across a wide range of food and water samples. The simplicity of the procedure makes it accessible to non-specialized personnel, enabling on-site analysis and reducing the dependency on centralized laboratories.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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