Separating Selected Metal Cations by Paper Chromatography

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Chemical separation plays a vital role in the field of chemistry, particularly when it comes to identifying and analyzing substances within a mixture. In both academic laboratories and industrial settings, scientists often encounter complex mixtures that must be broken down into their individual components. To achieve this, a variety of separation techniques are used, each based on specific physical or chemical properties such as solubility, polarity, or molecular size. Among these techniques, paper chromatography stands out as a simple, cost-effective, and efficient method for separating and identifying different substances.

Paper chromatography is especially useful for separating pigments, dyes, and even certain inorganic ions under suitable conditions. It works on the principle of differential partitioning between a stationary phase (the paper) and a mobile phase (the solvent). As the solvent travels up the paper by capillary action, it carries along the components of the mixture at different rates depending on their interaction with the solvent and the paper. This results in the separation of the components into distinct spots, which can then be analyzed.

In this experiment, paper chromatography was used to separate and identify metal cations present in an aqueous mixture(Chemistry LibreTexts, n.d.; International Union of Pure and Applied Chemistry [IUPAC], 2025). The specific cations under investigation were iron(III) ions (Fe^{3+}), copper(II) ions (Cu^{2+}), and nickel(II) ions (Ni^{2+}). These metal ions were chosen because they produce distinct color reactions and can be differentiated based on their movement on the chromatographic paper. The main objective of this experiment was to determine the composition of an unknown solution by comparing it with known standard solutions.

Methods

The experimental procedure began with the preparation of the solvent system, which consisted of a mixture of 19 mL of acetone and 6 mL of 8 M hydrochloric acid (HCl). This solvent mixture served as the mobile phase and played a crucial role in transporting the metal ions along the chromatography paper.

Next, chromatography paper was prepared by drawing a light pencil line near one end, which served as the baseline for spotting the samples. Two types of solutions were used: known standard solutions

containing Fe^{3+}, Cu^{2+}, and Ni^{2+} ions, and an unknown solution labeled as “Solution A.” Small drops of each solution were carefully applied onto the baseline using a capillary tube, ensuring that the spots were not too large or too close to each other.

The prepared chromatography paper was then placed vertically inside a 1-liter beaker containing the solvent mixture. Care was taken to ensure that the solvent level was below the baseline so that the spots would not dissolve directly into the solvent. The beaker was covered to prevent evaporation and allow the solvent to rise steadily up the paper.

As the solvent moved upward through capillary action, it carried the metal ions along with it. Due to differences in their chemical properties, each ion traveled a different distance, resulting in distinct spots appearing on the paper. Once the solvent front had neared the top of the paper, the chromatogram was removed and allowed to dry.

Results and Discussion

The identification of the metal cations in the unknown solution was carried out by comparing both the color of the spots and their retention factors (Rf values) with those of the known standard solutions. The retention factor is a key parameter in chromatography and is defined as the ratio of the distance traveled by the solute (spot) to the distance traveled by the solvent front.

The formula used is:

Retention factor (Rf) = Distance traveled by spot / Distance traveled by solvent

For the Fe^{3+} ion, the distance traveled by the spot was measured as 24.4 cm, while the solvent front traveled 25 cm. This gives:

Rf = 24.4 / 25 = 0.98

Similarly, the Rf values for the other cations were calculated and recorded alongside their observed colors. The results are summarized in the table below:

Solution Used	Color of Spot	Retention Factor (Rf)
Fe^{3+}	Rust	0.98
Ni^{2+}	Pink	0.18
Cu^{2+}	Blue-Green	0.48

Solution Used	Color of Spot	Retention Factor (Rf)
Unknown A	Rust	0.96
Unknown A	Blue-Green	0.50

From the table, it can be observed that the unknown solution produced two distinct spots: one with a rust color and another with a blue-green color. The Rf values of these spots (0.96 and 0.50) closely match those of Fe^{3+} (0.98) and Cu^{2+} (0.48), respectively. This strong similarity indicates that the unknown solution contains iron(III) and copper(II) ions.

Interestingly, no spot corresponding to the pink color of Ni^{2+} (Rf = 0.18) was observed in the unknown solution. This suggests that nickel(II) ions were not present in Solution A.

While the results are generally consistent and reliable, it is important to acknowledge potential sources of error. Small variations in spotting technique, solvent composition, or measurement of distances can affect the accuracy of Rf values. Additionally, overlapping spots or faint color development may make interpretation more challenging. Despite these limitations, paper chromatography remains a valuable tool for preliminary analysis and identification.

Conclusion

In conclusion, this experiment successfully demonstrated the use of paper chromatography as a method for separating and identifying metal cations in a mixture (Skoog et al., 2014). By comparing the color and retention factors of the spots obtained from the unknown solution with those of known standards, it was determined that Solution A contains Fe^{3+} and Cu^{2+} ions.

This experiment highlights the effectiveness of paper chromatography as a simple and low-cost analytical technique. Although it is considered a low-resolution method compared to more advanced techniques, it provides valuable insights into the composition of mixtures and is particularly useful in educational laboratory settings.

Furthermore, the experiment reinforces the importance of careful observation, accurate measurement, and systematic analysis in chemical investigations. Through such techniques, chemists are able to better understand the composition of substances and make informed conclusions about their properties.

References

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