

INVESTIGATION OF OPTIMAL CONDITIONS FOR THE DETERMINATION OF BI(III) IONS USING SILICA GEL-IMMOBILIZED REAGENTS

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Abstract: The present study investigates the optimal conditions for the sorption-spectrophotometric determination of Bi(III) ions using organic reagents immobilized on silica gel. Silica gel was selected as a solid support due to its high surface area, mechanical stability, and excellent sorption properties. The influence of solution pH, contact time, temperature, and foreign ions on the sorption behavior of Bi(III) was evaluated. Maximum sorption efficiency was achieved in the pH range of 2.5-3.5, where stable colored complexes were formed on the sorbent surface. The equilibrium sorption time was found to be approximately 15 minutes. Under optimized conditions, the proposed method demonstrated high sensitivity and selectivity for Bi(III) determination. The developed sorption system can be applied for the analysis of environmental and industrial samples containing trace amounts of bismuth.

Keywords: Bi(III), silica gel, immobilized reagent, sorption, spectrophotometry, bismuth, analytical chemistry

INTRODUCTION

Bismuth is widely used in metallurgy, pharmaceutical industries, cosmetics production, semiconductors, and electronic materials. Excessive accumulation of bismuth compounds in environmental objects may negatively affect living organisms and ecosystems. Therefore, the development of sensitive, selective, and cost-effective methods for the determination of Bi(III) ions remains an important task of modern analytical chemistry. Traditional spectrophotometric methods often suffer from low sensitivity due to the low concentration of analytes in real samples. Sorption-spectrophotometric methods based on immobilized reagents allow preliminary concentration of analytes and significantly improve detection limits. Silica gel is one of the most promising inorganic carriers because of its developed porous structure, high chemical stability, and large specific surface area (300–800 m²/g). In this work, the possibility of using silica gel immobilized with a chromogenic reagent for the determination of Bi(III) ions was investigated. Particular attention was paid to the optimization of analytical conditions affecting sorption efficiency and determination accuracy.

MATERIAL AND METHODS

Reagents and materials:

1. Silica gel (particle size: 0.10–0.16 mm)
2. Bi(NO₃)₃·5H₂O analytical grade
3. Nitric acid (HNO₃)
4. Sodium hydroxide (NaOH)
5. Distilled water
6. Immobilized chromogenic reagent on silica gel

Instrumentation:

1. UV–Visible spectrophotometer
2. pH meter

3. Analytical balance (± 0.0001 g)

4. Mechanical shaker

Silica gel was washed with distilled water and dried at 105°C . The sorbent was then treated with a solution of the chromogenic reagent for 24 h. After immobilization, the material was washed repeatedly to remove excess reagent and dried at room temperature. A 50 mL aliquot containing Bi(III) ions was adjusted to the desired pH. Then 0.1 g of immobilized sorbent was added and the mixture was shaken for a predetermined period. The sorbent was separated and the absorbance was measured spectrophotometrically.

RESULTS AND DISCUSSION

The sorption-spectrophotometric behavior of Bi(III) ions on silica gel-immobilized reagents was investigated under various experimental conditions. The effects of solution pH, contact time, initial metal ion concentration, and the presence of foreign ions were systematically studied to establish the optimum analytical conditions for Bi(III) determination. The solution pH plays a crucial role in the formation of Bi(III)-reagent complexes and consequently affects the sorption efficiency. As shown in Table 1, the sorption degree increased significantly with increasing pH from 1.0 to 3.5. At pH 1.0, only 42% of Bi(III) ions were sorbed, whereas the sorption efficiency reached 98% at pH 3.5. The decrease observed at pH values above 4.0 can be attributed to the hydrolysis of Bi(III) ions and the formation of insoluble hydroxide species. Therefore, the pH range of 3.0-3.5 was selected as optimal for subsequent experiments.

The pH of the solution significantly influences the formation of Bi(III)-reagent complexes and the kinetics of sorption were investigated within 1-60 minutes. (Table 1)

Table 1

No	pH	Sorption degree (%)	No	Time (min)	Sorption (%)
1	1.0	42	1	1	48
2	2.0	71	2	5	73
3	2.5	89	3	10	90
4	3.0	97	4	15	98
5	3.5	98	5	20	98
6	4.0	91	6	30	98
7	5.0	76	7	60	99.6

The highest sorption efficiency was observed at pH 3.0–3.5. At lower pH values, competition between hydrogen ions and metal ions reduced sorption efficiency. At higher pH values, hydrolysis of Bi(III) ions occurred. The sorption equilibrium was reached after approximately 15 minutes, indicating rapid interaction between Bi(III) ions and the immobilized reagent.

The effects of common ions were investigated and analytical characteristics. (Table 2)

Table 2

No	Ion	Tolerance ratio (Bi : Ion)	No	Parameter	Value
1	Na ⁺	1:1000	1	Optimum pH	3.0–3.5
2	K ⁺	1:1000	2	Equilibrium time	15 min
3	Ca ²⁺	1:500	3	Sorbent mass	0.10 g
4	Mg ²⁺	1:500	4	Detection limit	0.015 mg/L
5	Zn ²⁺	1:100	5	Linear range	0.05–5.0 mg/L
6	Cu ²⁺	1:50	6	Correlation coefficient (R ²)	0.998
7	Fe ³⁺	1:20	7	Relative standard deviation (RSD)	2.8 %

The sorption capacity increased proportionally with increasing Bi(III) concentration up to 1.0×10^{-4} mol/L. Beyond this concentration, active centers of the sorbent gradually became saturated. Alkali and alkaline earth metal ions did not significantly interfere with Bi(III) determination. Fe(III) and Cu(II) exhibited the greatest interference due to their tendency to form colored complexes with the reagent. The obtained results indicate that the immobilized sorbent possesses high affinity toward Bi(III) ions and can be successfully used for trace analysis.

CONCLUSION

A sorption-spectrophotometric method for the determination of Bi(III) ions using silica gel-immobilized reagents was developed and optimized. The optimal conditions were established as pH 3.0–3.5, sorbent mass 0.10 g, and contact time 15 minutes. The proposed method demonstrated high sensitivity, good selectivity, and satisfactory analytical performance. The developed immobilized sorbent system can be effectively applied for the determination of Bi(III) ions in environmental, industrial, and laboratory samples.

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