REVIEW ARTICLE

# The use of rhodanine derivative compounds as sensor materials in different analytical techniques

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**Abstract:** Rhodanine, also known as 2-thioxo-4-thiazolidinone, is a five-membered cyclic compound containing sulfur, oxygen and nitrogen, and its compounds have found significant applications in photochemistry, medicinal chemistry, biochemistry, and various other industries. The –NH group in rhodanine compounds allows for hydrophobic interactions, hydrogen bonding, and complexation with metal ions. Analytical chemists have exploited these properties in order to use rhodanine derivatives as sensor materials, and developed sensors suitable for use in many areas. Rhodanine derivatives exhibit properties significantly superior to many organic compounds known as sensor materials, making them highly suitable as sensor materials. This review provides an overview of the uses and applications of rhodanine derivative molecules as sensor materials in various analytical techniques, including colorimetric, fluorescence, or electrochemical methods.
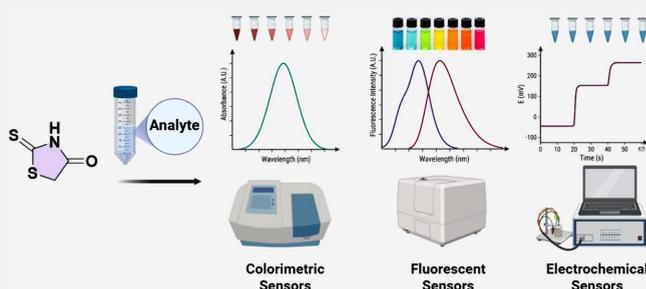
**Keywords:** Rhodanine, sensor, heterocyclic compounds, materials, potentiometry

## ■ CONTENTS

## 1 Introduction

Heterocyclic compounds are cyclic organic compounds that contain atoms such as oxygen, nitrogen and sulfur in their structure.[1] Heterocyclic compounds are widely used in the development and design of new drugs due to their broad biological activities and versatile binding capacities.[2] Rhodanine (also known as 2-thioxo-4-thiazolidinone) is a five-membered heterocyclic compound containing heteroatoms such as sulfur and nitrogen. Synthesis strategies of rhodanine derivatives are given in Scheme 1.[3] The first two methods are based on the use of primary amines, hydrazine derivatives and other compounds containing a primary amino group (**1**). Another method for synthesizing the rhodanine ring is through the reaction of isothiocyanates (**6**) with mercaptacetic acid (**7**).[3]

Rhodanine derivatives are widely used in photochemistry, medicinal chemistry, biochemistry, and industry, and play an important role in human biological systems.[4] Rhodanine derivative compounds, thanks to their –NH group, can form hydrophobic interactions, hydrogen bonds, and complexes with metal ions. They can also interact with the ligand-binding sites of target proteins through various types of interactions.[5] Rhodanine derivatives have a wide range of biological activities such as anti-diabetic, anti-HIV, anti-infective, anti-Alzheimer, anti-cancer, anti-bacterial, anti-tubercular and anti-fungal functions.[6,7]
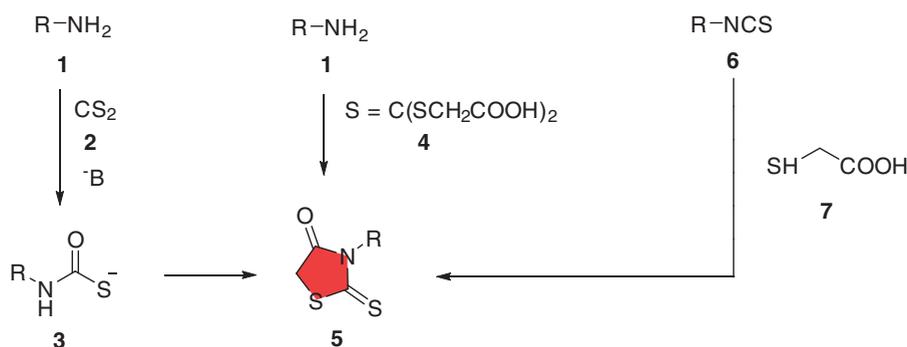
**Scheme 1.** Methods for constructing of a rhodanine

Rhodanine exhibits distinctive spectroscopic characteristics due to its heterocyclic structure containing sulfur, oxygen, and nitrogen atoms, as well as carbonyl (C=O) and thiocarbonyl (C=S) functional groups. These features give rise to well-defined UV–Vis, IR, and NMR signals, enabling straightforward structural identification and confirmation.[8] The electronic transitions observed in UV–Vis spectroscopy are highly sensitive to conjugation and substituent effects, while the characteristic C=O and C=S stretching vibrations in IR spectra show noticeable shifts upon metal ion coordination, providing clear evidence of chelation.[9,10] NMR spectroscopy further supports structural analysis through diagnostic chemical shifts associated with the rhodanine unit.[11,12] Although native rhodanine displays weak fluorescence, structural modification or metal binding can induce significant photophysical changes, making rhodanine derivatives particularly suitable for optical sensing applications. Overall, the responsive and informative spectroscopic behavior of rhodanine highlights its potential as a versatile molecular platform for sensor and materials chemistry.

Materials science enables the development of highly sensitive and selective analytical systems for a wide variety of analytes.[13–15] Sensors prepared using electrochemical methods, as well as spectroscopic methods, are important analytical tools for the determination of numerous analytes.[16] Sensors based on dynamic electrochemical methods such as voltammetry, amperometry, or potentiometry are excellent alternatives, especially for use in industrial samples, due to their short response time, high selectivity, and low detection limits.[17–22] Sensors are devices that detect environmental or chemical stimuli, and convert them into measurable electrical, optical, or mechanical signals.[23] They are currently used in many fields such as environmental monitoring, agriculture, pharmaceuticals, medicine, biomedical diagnosis, and industrial process control.[24,25] The performance of sensors largely depends on the chemical structure, surface properties, and conductivity of the sensor material used.[26] In recent years, organic-inorganic hybrid materials, polymers, metal-organic frameworks (MOFs), nanoparticles, and organic molecules containing various functional groups have been used as sensor materials.

## 2 Sensor Properties of Rhodanine Derivative Molecules

Rhodanine derivatives possess potent biological activities and can form very strong complexes with metal ions. Rhodanine nucleus has sulfur, oxygen and nitrogen atoms with unpaired electrons; thus, it has excellent chelating properties with metal ions.[3] Rhodanine derivative molecules can be considered as active reagents, especially in the determination of heavy metals.[27] Therefore, rhodanine-based sensor materials have potential applications in both optical and electrochemical sensors.

Park et al. (2020) developed a fluorescence chemosensor for the determination of $Zn^{2+}$ and $Cd^{2+}$ ions using a rhodanine derivative ((*E*)-3-((2-hydroxy-3-methoxybenzylidene)amino)-2-thioxothiazolidin-4-one) **(10)** (Scheme 2).[28] The developed sensor has low detection limits for $Zn^{2+}$ and $Cd^{2+}$ ions (1.07 μM and 1.37 μM, respectively). The sensors have been successfully applied in different water samples.
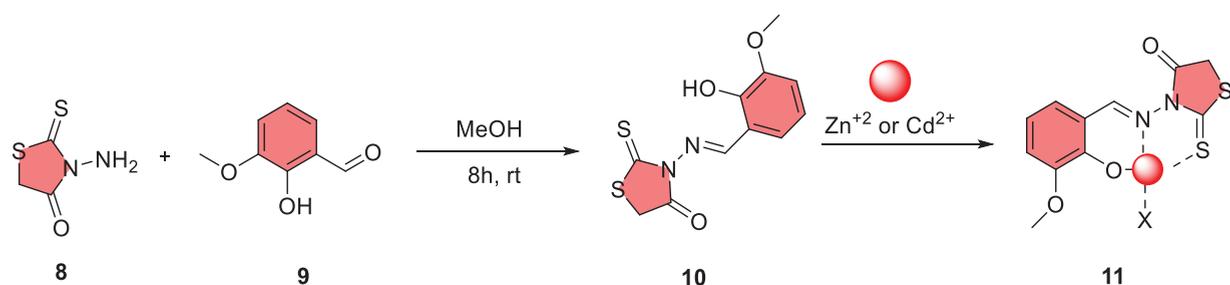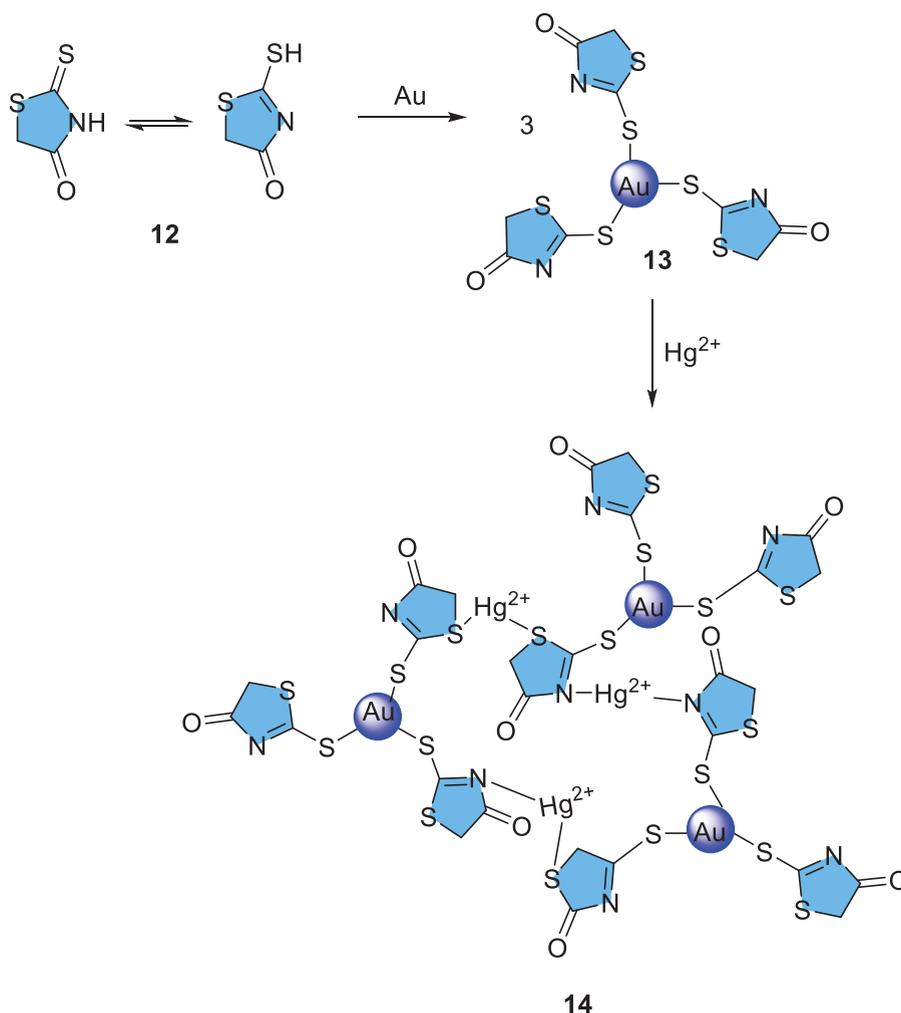


**Scheme 2.** Synthesis scheme of ((*E*)-3-((2-hydroxy-3-methoxybenzylidene)amino)-2-thioxothiazolidin-4-one) **(10)**

The colorimetric determination of mercury(II) ions was carried out in water samples by Chen et al. (2017) using rhodanine–gold nanoparticles (14) (Scheme 3).[29] The proposed mercury(II) colorimetric sensor has a detection limit of 6.0 nM in the concentration range of 0.02–0.5 μM.

The rhodanine-based (17) fluorescence sensor developed by Bayindir (2019) was used for the determination of $Hg^{2+}$ and $Cu^{2+}$ ions in organic solvent systems (Scheme 4).[30] The

detection limit of the proposed sensors was reported as 3.36 μM for $Hg^{2+}$ and 2.31 μM for $Cu^{2+}$.

Determination of $In^{3+}$ ions in living organisms using a rhodanine-based (20) fluorescence chemosensor was performed by Yang et al. (2023) (Scheme 5).[31] The developed $In^{3+}$ sensor has a detection limit of 1.69 μM. The sensing behavior of the rhodanine derivative molecule, prepared by the reaction of 3-aminorhodanine and a salicylaldehyde,
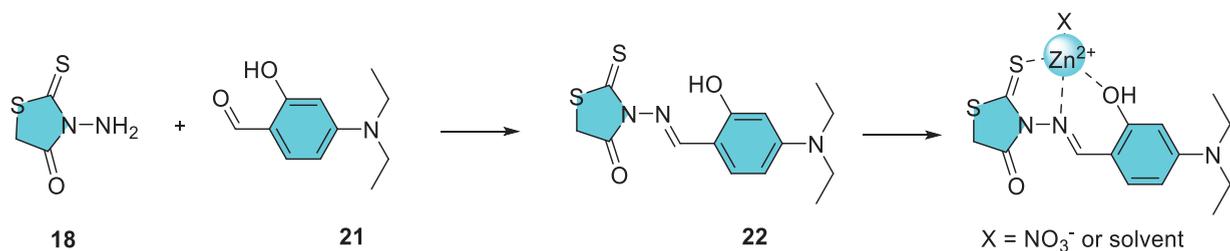


**Scheme 3.** Synthesis scheme of rhodanine–gold nanoparticles (14)
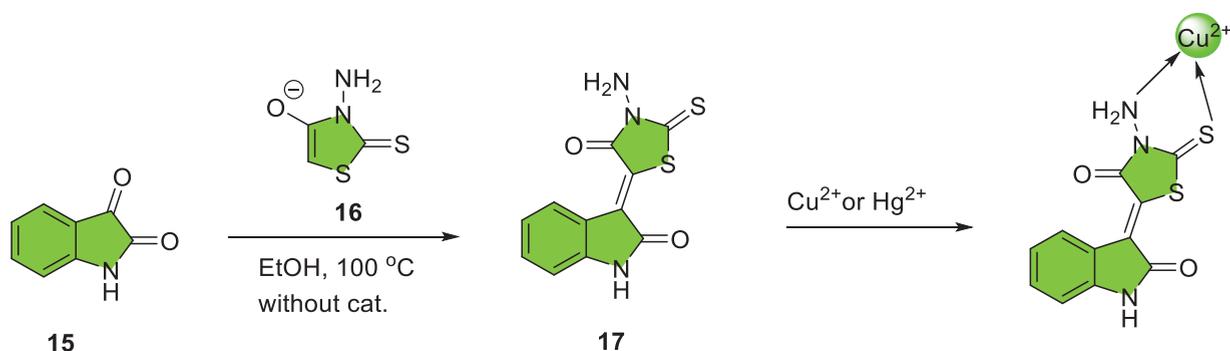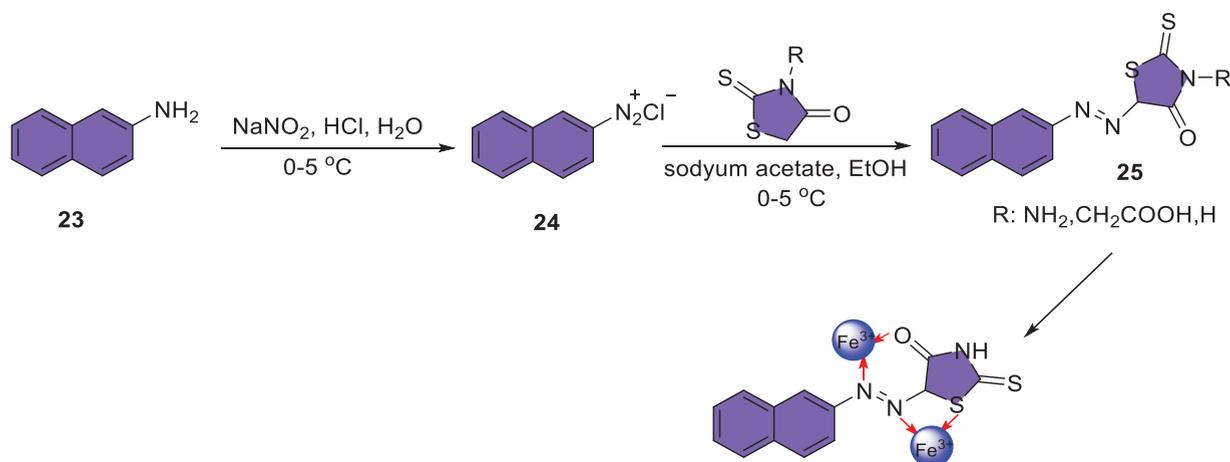


**Scheme 4.** Synthesis scheme of (Z)-3-amino-5-(2-oxoindolin-3-ylidene)-2-thioxothiazolidin-4-one (17)
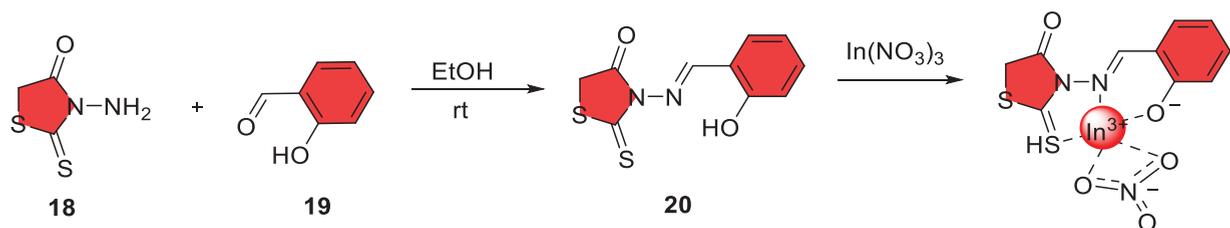
**Scheme 5.** Synthesis scheme of (*E*)-3-((2-hydroxybenzylidene)amino)-2-thioxothiazolidin-4-one **(20)**



**Scheme 6.** Synthesis scheme of (3-[(E)-{[4-(diethylamino)-2-hydroxyphenyl]methylidene}amino]-2-sulfanylidene-1,3-thiazolidin-4-one) **(22)**



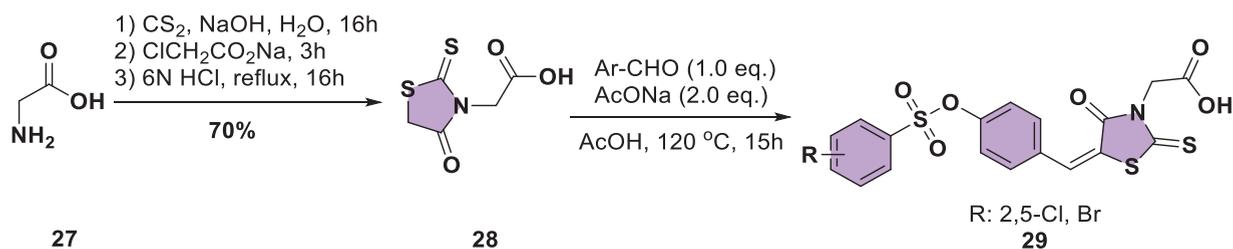**Scheme 7.** Synthesis scheme of rhodanine derivative molecule containing a naphthalene **(25)**

towards $In^{3+}$ was investigated using photophysical experiments, ESI-mass and theoretical calculations.

Rhodanine-based (3-[(E)-{[4-(diethylamino)-2-hydroxyphenyl]methylidene}amino]-2-sulfanylidene-1,3-thiazolidin-4-one) (Scheme 6) **(22)** fluorescent chemosensor was designed and synthesized by Kim et al. (2022).[32] The developed sensor was reported to exhibit unique optical properties with a large fluorescence change in the detection of $Zn^{2+}$ ions. This sensor can detect $Zn^{2+}$ with a low detection limit (1.33 μM). The binding property of the synthesized molecule to $Zn^{2+}$ was demonstrated by ESI mass, nuclear magnetic resonance (NMR) titration, and calculations.
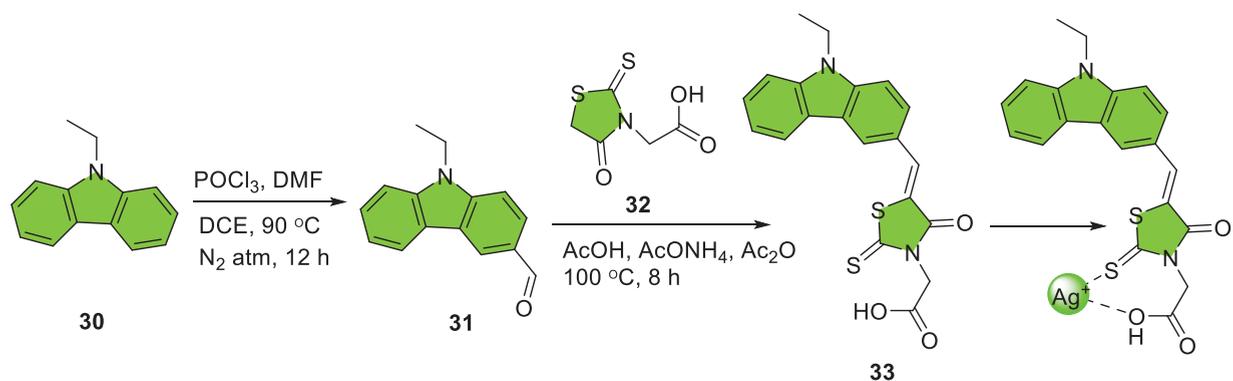
The synthesis of rhodanine derivative molecules containing three different naphthalene rings **(23)** and the spectrophotometric determination of $Fe^{3+}$ ions using these molecules were reported by Akram et al. (2020) (Scheme 7).[33]

The selectivity and sensitivity of the newly prepared rhodanine azo compounds with the transition metals $Co^{2+}$, $Cu^{2+}$, $Zn^{2+}$, $Ni^{2+}$, and $Fe^{3+}$ were investigated using UV-vis and fluorescence spectroscopy techniques. One of the synthesized compounds showed affinity for $Fe^{3+}$ ions with an association constant of $4.63 \times 10^8$ M$^{-1}$. The $Fe^{3+}$ chemosensor prepared with this compound had a detection limit of 5.14 μM, and this sensor has been applied in the analyses of various environmental and biological systems.

Kalay et al. (2025) evaluated the synthesis, characterization, and sensor and biological activities of two different rhodanine derivative molecules **(29)** (Scheme 8).[27] They developed potentiometric sensors with high selectivity for copper(II) ions using the synthesized molecules as ionophores. The proposed sensors have a wide concentration range of $1.0 \times 10^{-1}$–$1.0 \times 10^{-5}$ M, and low detection limits of

**Scheme 8.** Synthesis scheme of two different rhodanine derivative molecules (**29**)



**Scheme 9.** Synthesis scheme of carbazole-rhodanine derivative molecule (**33**)
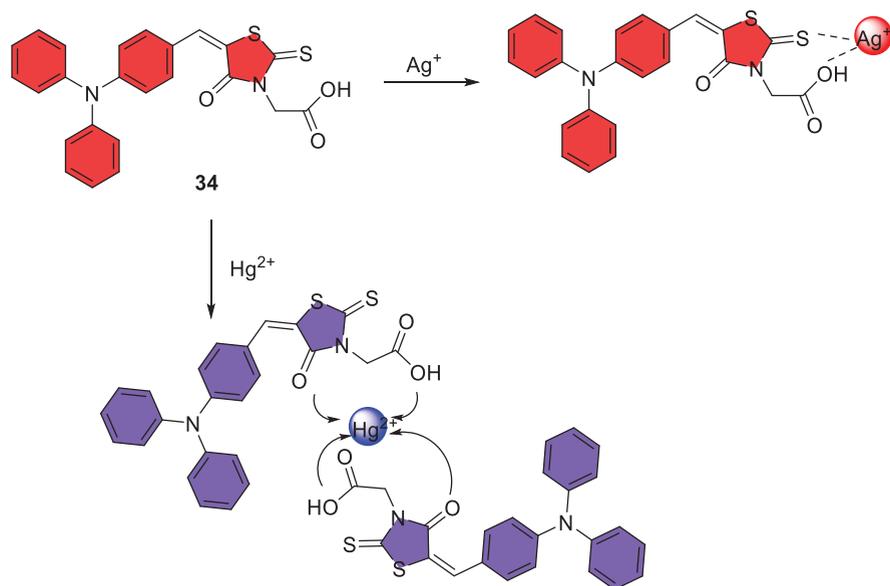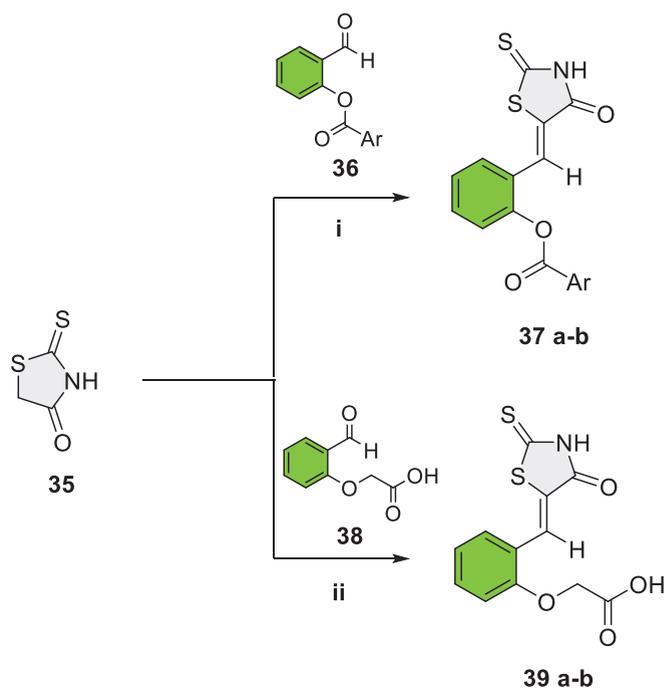


**Scheme 10.** Synthesis scheme of rhodanine-3-acetic acid derivative molecules (**34**)

$9.77 \times 10^{-6}$ M and $9.36 \times 10^{-6}$ M, respectively. After investigating the potentiometric performance properties of the developed sensors under laboratory conditions, they applied them to the analyses of various real samples with high recoveries.

Leslee et al. (2019) proposed a novel fluorescence sensor for the determination of Ag$^+$ ion in living cells using a carbazole-rhodanine derivative molecule (**33**) (Scheme 9).[34] The prepared sensor has a low detection limit ($12.8 \times 10^{-9}$ M) and is a biocompatible probe.

Thamaraiselvi et al. (2019) developed fluorescence sensors for the determination of Ag$^+$ and Hg$^{2+}$ ions using rhodanine-3-acetic acid derivative molecules (**34**) (Scheme 10).[35] The developed sensors were reported to have low detection limits of 0.06 and 0.02 ppm for Ag$^+$ and Hg$^{2+}$ ions, respectively. The applicability of these sensors in biological environments has also been tested, and it has been reported that these probes can also be used as potential biosensors.

Altunoluk et al. (2025) synthesized four new rhodanine derivative molecules (**37 a–b** and **39 a–b**) and used

**i)** Rhodanine (1.5 mmol), aldeyde **36** (1 mmol), piperidine (%50 mol), EtOH, reflux, 5s,
**ii)** Rhodanine (1.5 mmol), aldeyde **38** (1 mmol), NaOAc (4 eqv.), AcOH (5 mL), reflux, 15s.

**Scheme 11.** Synthesis scheme of four rhodanine derivative molecules (**37 a–b** and **39 a–b**)
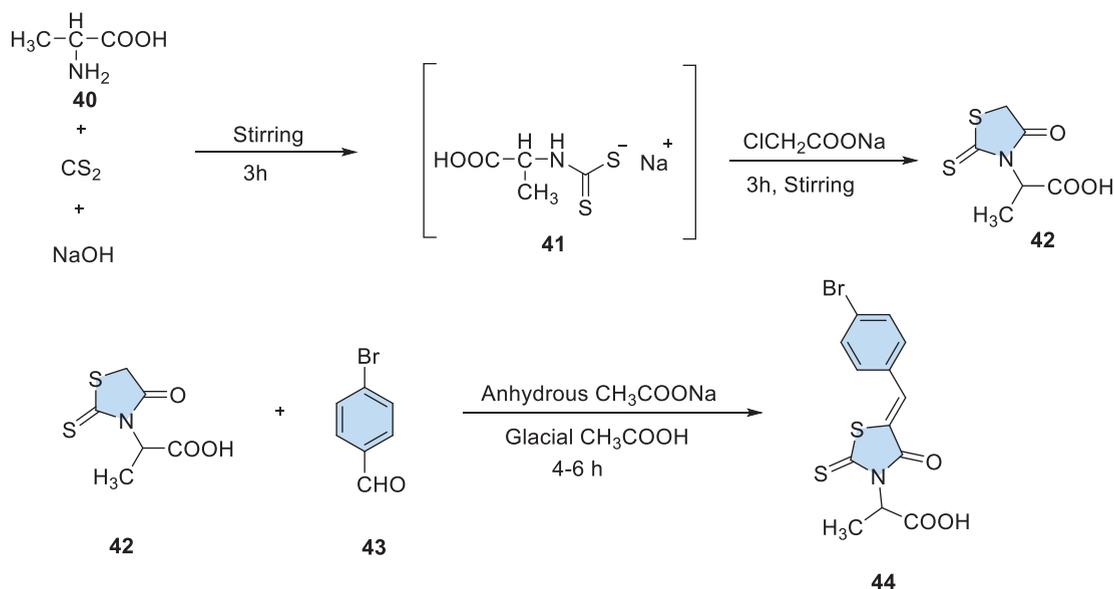


**Scheme 12.** Synthesis scheme of (Z)-2-(5-(4-bromobenzylidene)-4-oxo-2-thioxothiazolidin-3-yl)propanoic acid (**44**)

them as ionophores for the potentiometric determination of toxic heavy metals (Scheme 11).[4] They investigated the potentiometric performance characteristics of these sensors in detail. They performed validation studies using atomic absorption spectroscopy (AAS), which demonstrated high recoveries in environmental water samples. Consequently, they developed new sensors selective for $Cd^{2+}$ and $Cu^{2+}$ ions using rhodanine derivative molecules and investigated their working conditions.

A rhodanine-based (**44**) (Scheme 12) chemosensor for $Ag^+$ ion detection was reported by Narmatha et al. (2025).[36] The detection limit and quantification limit of the proposed chemosensor were reported as $1.7 \times 10^{-8}$ M and $5.4 \times 10^{-8}$ M, respectively. The authors confirmed the stoichiometric binding of the synthesized rhodanine and $Ag^+$ complexation by ESI-TOF, jobs plot, and DFT analysis. They successfully used the produced probe in real sample analysis and bio-imaging.
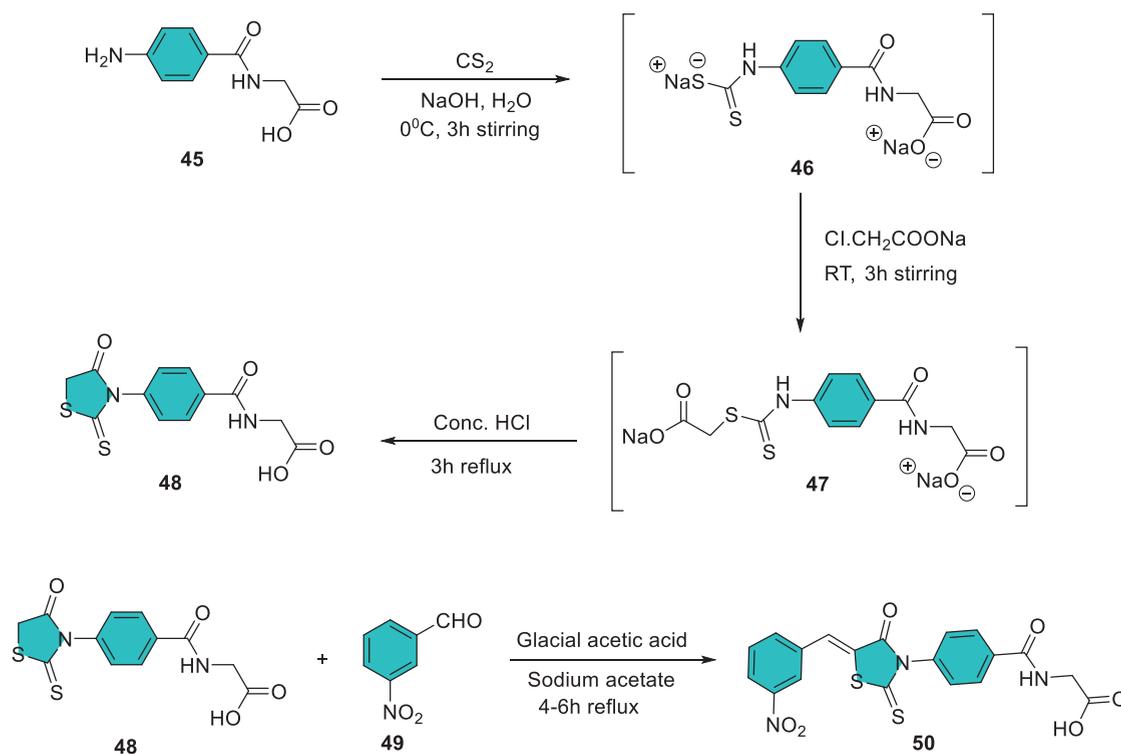
**Scheme 13.** Synthesis scheme of (Z)-(4-(5-(3-nitrobenzylidene)-4-oxo-2-thioxothiazolidin-3-yl)benzoyl)glycine **(50)**
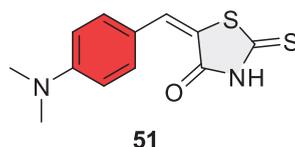


**Figure 1.** The chemical structure of 5-(4-dimethylaminobenzylidene)rhodanine **(51)**

Rhodanine-based **(50)** fluorometric analysis of $Ag^-$ and $I^-$ ions was reported by David et al. (2021) (Scheme 13).[37] The LOD and LOQ values of the proposed sensor for $Ag^+$ were $24.23 \times 10^{-7}$ M and $80.77 \times 10^{-7}$ M, respectively. The authors stated that the proposed sensor can be used in a wide variety of applications, including paper strip, silica-assisted analysis, latent fingerprint staining tests, logic behavior, smartphone-assisted quantitative detection, and studies of real water samples.

A potentiometric electrode selective for silver(I) ions using 5-(4-dimethylaminobenzylidene)rhodanine **(51)** (Figure 1) as an ionophore was reported by Pérez et al. (2019).[38] The developed silver(I)-selective electrode has Nernstian behavior ($58.2 \pm 0.8$ mV/decade), a low detection limit ($9.77 \times 10^{-7}$ M), and a response time of 20 seconds.

The concentration range and detection limits of all mentioned sensors are given in Table 1. Table 1 provides a comparative summary of literature reports on the determination of various heavy metal ions using different analytical methods. Electrochemical techniques, particularly applied to

$Cu^{2+}$, $Cd^{2+}$ and $Ag^+$ detection, generally offer wide linear concentration ranges ($10^{-1}$–$10^{-6}$ M) and reliable quantitative performance in the analyses of environmental water samples. In contrast, fluorescent-based sensors demonstrate significantly lower limits of detection, often at the micromolar or even nanomolar level, for ions such as $Zn^{2+}$, $Cd^{2+}$, $Hg^{2+}$, $Ag^+$, $Fe^{3+}$, and $In^{3+}$, and show strong applicability in biological systems including live cells and model organisms. Notably, fluorescent and colorimetric methods developed for $Hg^{2+}$ and $Ag^+$ exhibit particularly low detection limits, highlighting their suitability for trace-level analysis. Overall, Table 1 indicates that the choice of analytical method strongly depends on the target analyte, required sensitivity, and sample matrix, with electrochemical methods being more suitable for environmental monitoring and fluorescent sensors offering clear advantages for highly sensitive and biological applications. Applications of rhodanine derivatives used as sensor materials in different analytical techniques are given in Figure 2.

**Table 1.** Data of sensors prepared using rhodanine derivatives

| Analyte | Method | Concentration range | Limit of detection | Sample | Ref. |
|---|---|---|---|---|---|
| $Cu^{2+}$ | Electrochemical | $1.0 \times 10^{-1} - 1.0 \times 10^{-5}$ M | $2.56 \times 10^{-6}$ M | Environmental water samples | [4] |
| $Cd^{2+}$ | | $1.0 \times 10^{-1} - 1.0 \times 10^{-6}$ M | $7.24 \times 10^{-7}$ M | | |
| $Cu^{2+}$ | Electrochemical | $1.0 \times 10^{-1} - 1.0 \times 10^{-5}$ M | $9.77 \times 10^{-6}$ M | Water samples | [27] |
| | | | $9.36 \times 10^{-6}$ M | | |
| $Zn^{2+}$ | Fluorescent | 0, 500–1000 µM | 1.07 µM | Water sample analysis and cell imaging | [28] |
| $Cd^{2+}$ | | 0, 250–500 µM | 1.37 µM | | |
| $Hg^{2+}$ | Colorimetric | 0.02–0.5 µM | 6.0 nM | Water samples | [29] |
| $Hg^{2+}$ | Fluorescent | | 3.36 µM | Organic solvent | [30] |
| $Cu^{2+}$ | | | 2.31 µM | | |
| $In^{3+}$ | Fluorescent | 0, 10–25 µM | 1.69 µM | Live organisms (hela cells and zebrafish) | [31] |
| $Zn^{2+}$ | Fluorescent | | 1.33 µM | Water samples | [32] |
| $Fe^{3+}$ | Fluorescent | | 5.14 µM | Various environmental and biological systems | [33] |
| $Ag^+$ | Fluorescent | | $12.8 \times 10^{-9}$ M | Live cells | [34] |
| $Ag^+$ | Fluorescent | | 0.06 ppm | Biological medium | [35] |
| $Hg^{2+}$ | | | 0.02 ppm | | |
| $Ag^+$ | Fluorescent | $6.0 \times 10^{-5} - 5.0 \times 10^{-7}$ M | $1.7 \times 10^{-8}$ M | Water samples | [36] |
| $Ag^+$ | Fluorescent | | $24.23 \times 10^{-7}$ M | Water samples | [37] |
| $Ag^+$ | Electrochemical | $1.0 \times 10^{-2} - 1.0 \times 10^{-6}$ M | $9.77 \times 10^{-7}$ M | | [38] |
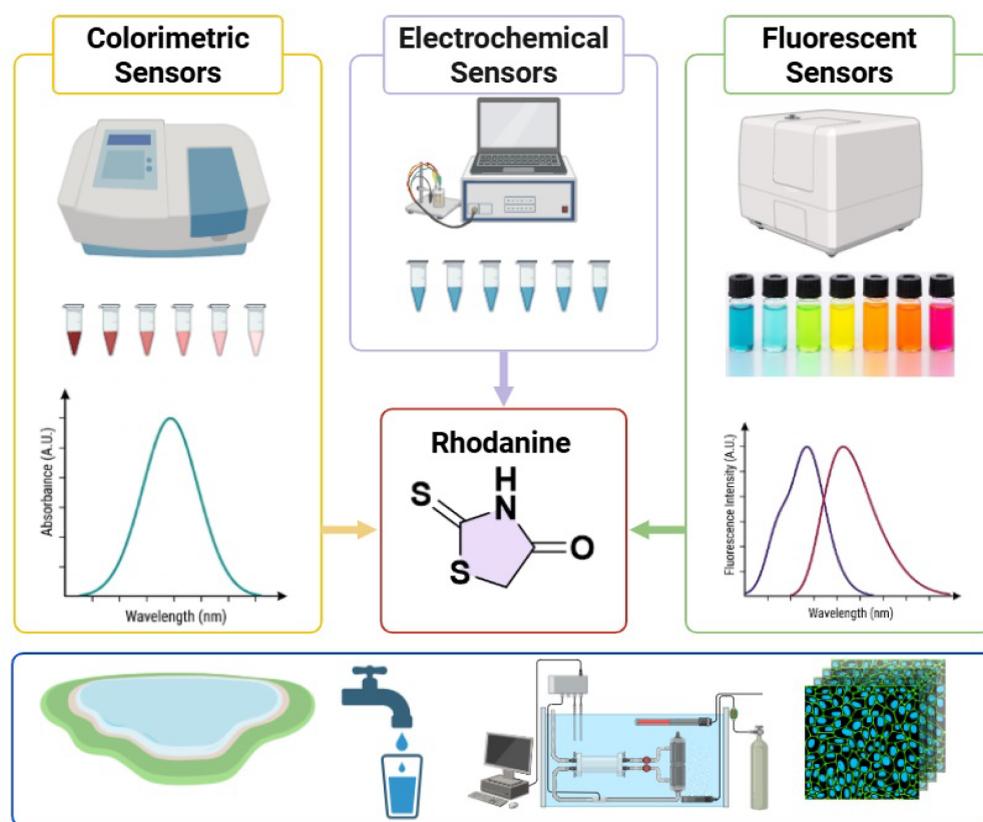


**Figure 2.** Applications of rhodanine derivatives used as sensor materials in different analytical techniques

## 3 Conclusion

Studies previously reported in the literature clearly demonstrate the high biological activity of rhodanine derivative compounds, while their versatile applications in materials chemistry further highlight their significance.[39,40] Given that the performance of sensors is strongly dependent on the molecular structures employed as sensing elements, rhodanine-derived molecules represent a promising class of sensor materials. The presence of sulfur, oxygen, and nitrogen atoms with lone pair electrons within the rhodanine core provides excellent chelating ability toward metal ions, making these compounds particularly attractive for

sensing applications. Accordingly, this review has discussed sensors based on rhodanine derivatives developed using various analytical techniques. Although the number of studies employing rhodanine-derived molecules as sensor components remains relatively limited compared to other well-established molecular scaffolds, the findings summarized herein clearly demonstrate that rhodanine derivatives exhibit sensor performances comparable to, and in some cases even exceeding, those of widely used molecular groups. Therefore, it is anticipated that rhodanine-based molecules will attract increasing attention and be more extensively and commonly utilized as functional sensor materials in future studies.

## Author Contributions

Onur Cem Altunoluk: Investigation, Analysis, Oguz Özbek: Investigation, Analysis, Writing—Review&Editing.

## Availability of Data and Materials

The authors declare that should any raw data files be needed about the further data of the study, they are available from the corresponding author upon reasonable request. Source data are provided with this paper.

## Conflicts of Interest

The authors declare that they do not have any conflict of interest.

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