DOI: https://doi.org/10.57233/ijsgs.v12i2.1105 ISSNp: 2488-9229; ISSNe: 3027-1118

IJSGS FUGUSAU VOL . 12 (2) WEBSITE: https://fugus-ijsgs.com.ng

INTERNATIONAL JOURNAL OF SCIENCE FOR GLOBAL SUSTAINABILITY

(A PUBLICATION OF FACULTY OF SCIENCE, FEDERAL UNIVERSITY GUSAU, NIGERIA)

# Synthesis, Analysis, and Antimicrobial Screening of a New Thiophene-Based Schiff Base Complexes

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**Received on:** April 2026 **Revised and Accepted on:** June, 2026 **Published on:** July, 2026

***ABSTRACT***

Copper (II) and zinc(II) complexes from (2E)-N-phenyl-2-[1-(thiophen-2-yl)ethylidene]hydrazine-1-carbothioamide (AT-PTSC) Schiff base were synthesized and characterized. A variety of analytical techniques were used to confirm their structure and properties. Elemental analysis supported a 2:1 ligand-to-metal ratio, while molar conductivity showed they were electrolytes. The complexes exhibited excellent thermal stability, with decomposition temperatures above 220°C. Magnetic measurements identified the copper complex as paramagnetic (2.2 BM) and the zinc complex as diamagnetic (0.0 BM). IR spectroscopy confirmed the ligand's coordination to the metal through the azomethine nitrogen, as indicated by a shift in the v(C=N) peak from 1648 $cm^{-1}$ to a lower frequency. In antimicrobial testing, both the ligand and the complexes showed moderate activity against various microbes. Notably, the metal complexes were significantly more effective than the free ligand, a result attributed to the chelation effect. This research highlights the potential of these new complexes as promising antimicrobial agents.

**Keywords:** Schiff base, thiophene, metal complexes, antimicrobial agents, chelation.

## 1.0 INTRODUCTION

Metal-based compounds are everywhere, from the catalysts that power our industries to the drugs that treat our diseases (Malinowski et al., 2020). Among the most exciting are metal chelates, which are being developed to fight major health challenges like cancer and infectious diseases. A fascinating class of molecules known as Schiff bases is at the heart of this research. Formed in a simple condensation reaction between an amine and a carbonyl compound, they produce a distinctive carbon-nitrogen double bond (C=N) (Sunitha *et al.*, 2023). These versatile molecules, first named after Hugo Schiff, are powerful chelating agents, meaning they can "grab" onto a single metal ion at multiple points (Sakhare, 2020). Thiosemicarbazone Schiff bases are particularly special because they have both nitrogen and sulfur atoms, creating a perfect setup for forming strong bonds with metals (Bai et al., 2022). Their therapeutic history is remarkable; they have been used against diseases like leprosy and tuberculosis (Thakor *et al.*, 2024), and one derivative, methisazone, was a pioneering antiviral drug that helped combat smallpox (Mahmood, 2022). This history of success has made them a hot topic in anticancer research (Bayeh *et al.*, 2020). The thiophene molecule, with its unique five-membered ring containing a sulfur atom, is another star in medicinal chemistry and materials science. It's a building block for everything from pharmaceuticals to advanced electronics (Elasaved *et al.*, 2022). The combination of a thiophene ring with a Schiff base has proven to be a winning strategy. For instance, thiophene-based copper complexes have shown potent activity against human ovarian cancer and bacterial infections (Krupa *et al.*, 2026), and other thiophene Schiff bases have recently been found to be effective against a wide range of pathogens (Saira *et al.*, 2023). Inspired by these findings, our work explores the synthesis and antimicrobial potential of new copper (II) and zinc(II) complexes derived from the Schiff base (2E)-N-Phenyl-2-[1-(thiophen-2-yl) Ethylidene] Hydrazine-1-Carbothioamide.

## 2.0 MATERIALS AND METHODS

The compounds were characterized using a suite of instruments. An Electrical Meter Balance AB 54 was employed for weighing. Magnetic susceptibility and melting points were determined using a "Sherwood Scientific MSB MK1 Magnetic Susceptibility Balance" and a digital "WRS-IB Microprocessor Melting Point Apparatus", respectively. "A Shimadzu FTIR-8400S Fourier Transform Infrared Spectrophotometer" recorded IR spectra (4500-250 $cm^{-1}$), and a "George Kent model 5003 conductivity meter" determined molar conductivity. Elemental and metal analyses were sent to 'Robertson Microlit Laboratories', New Jersey, U.S.A. For the biological assays, microbial isolates were provided by the Department of Medical Microbiology at Aminu Kano Teaching Hospital, identified, and subsequently tested for antimicrobial activity at the Department of Microbiology, Bayero University, Kano. The standard antibacterial and antifungal agents were Ciprofloxacin and Ketoconazole, respectively. The growth media used were Mueller-Hinton agar and Potato Dextrose**.**

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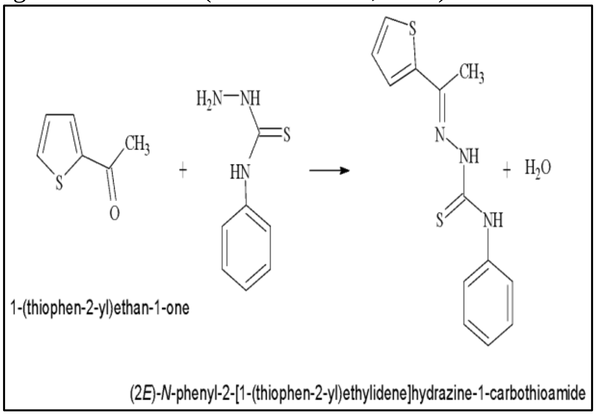
### 2.1 Preparation of Schiff Base (AT-PTSC)

Schiff base (AT-PTSC) was prepared by condensing 1-(thiophen-2-yl)ethan-1-one with N-phenylhydrazinecarbothamide in a 1:1 molar ratio using ethanol as the solvent. Following this, the copper(II) and zinc(II) complexes were synthesized by reacting the new Schiff base with the respective metal salts in a 2:1 ligand-to-metal ratio, also in ethanol. The Schiff base was isolated as a yellow solid having a high yield of 85.2% and a melting point of 176°C. [Cu(AT-PTSC)2]Cl2 and [Zn(AT-PTSC)2]Cl2 complexes were obtained as pale green and pale yellow solids, having yields of 78.9% and 74.5%, respectively.

The synthesis involved reacting 4-phenylthiosemicarbazone (1.67 g, 0.01 mol) with 2-acetylthiophene (1.08 cm³, 0.01 mol) in hot ethanol. Acetic acid was added in drops to the mixture, which was then stirred and heated under reflux for 3 hours. The solution was subsequently cooled at 5°C for a day to allow a 0precipitate to form. This solid was then collected by filtration, washed with ether multiple times, and dried in a desiccator using $P_2O_5$ as the drying agent for 72 hours (Abdullah *et al*., 2025).




**Scheme 1: AT-PTSC preparation**

### 2.2 Synthesis and Preparation of AT-PTSC Complexes of Copper(II) and Zinc(II)

*T*o prepare the Cu(II) and Zn(II) complexes of AT-PTSC, a 2:1 ligand-to-metal ratio was used. The Schiff base (0.002 mol) was dissolved in 20 cm³ of ethanol and mixed with an ethanolic solution of either the Cu(II) or Zn(II) salt (0.001 mol in 10 cm³ ethanol). The resulting mixtures were then refluxed for three hours with stirring. After cooling, the solid complexes were filtered, washed with Ethoxyethane, and dried over phosphorus pentoxide for 72 hours.

### 2.3 IR Measurements

A Shimadzu FTIR-8400S Fourier Transform Infrared Spectrophotometer was utilized to perform infrared spectral analysis. The instrument was set to scan from 250 to 4500 $cm^{-1}$. For each measurement, a small quantity of the sample powder was combined with KBr powder at a ratio of about 1-2% sample to KBr. The findings of this analysis are detailed in Table 4.

### 2.4 Molar Conductance Measurement

In order to assess the electrolytic nature of the complexes, their molar conductivity was measured. This was done by preparing a 0.001 M solution of each complex in dimethylformamide (DMF) and taking the measurements at 25°C. The method described by Nwade *et al*. (2020) was then used to calculate the molar conductance.

$$\Lambda_M = \frac{1000L}{C}$$

To calculate molar conductance (ΛM), the specific conductance (**L**) of the solution was divided by the molar concentration (**C**) of the complex, following the equation: ΛM=L/C. The calculated values are listed in Table 5.

### 2.5 Analysis of Elements

Elemental composition was determined using a Perkin-Elmer CHN 2400 Elemental Analyzer. The method followed the classical Pregl-Dumas technique. Each sample, roughly 20 mg in mass, was sealed in an aluminum vial and then subjected to high-temperature combustion with excess oxygen and reagents. This step broke down the sample into its elemental gaseous components, namely $CO_2$, $H_2O$, and nitrogen $N_2$. The instrument then automatically calculated the percent weight of each element, which is documented in Table 6.

### 2.6 Antimicrobial Test

An *in vitro* study was carried out to evaluate the antimicrobial effects of the AT-PTSC Schiff base and its metal complexes. The compounds were tested against a range of microbes, including both Gram-positive and Gram-negative bacteria, as well as three common fungal species. We used the well diffusion technique to apply varying concentrations of the compounds (15, 30, and 60 µg/ml) to the test *organisms*. The efficacy of the compounds was judged by the size of the clear area of no growth, known as the zone of inhibition. These results were then benchmarked against standard pharmaceutical controls: Ciprofloxacin for antibacterial activity and Ketoconazole for antifungal activity. ( Raju *et al*., 2022).

## 3.0 RESULTS AND DISCUSSION

### 3.1 Physicochemical Properties

The color change observed when the ligand forms complexes is a key indicator of successful coordination, resulting from d-d orbital transitions. The high decomposition temperatures of the complexes (227°C for Cu and 223°C for Zn) also suggest they have higher thermal stability than the uncoordinated ligand (Omenya *et al*., 2020).

**Table 1: Physicochemical Analysis of the Schiff Base and its Metal(II) Complexes**

| Schiff base/ Complex | Colour | MP (°C) | DT (°C) | (%)Yield |
|---|---|---|---|---|
| Schiff base | Yellow | 176 | - | 85.2 |
| Copper(II) Complex | Pale Green | - | 227 | 78.9 |
| Zinc(II) Complex | Pale Yellow | - | 223 | 74.5 |

**Mp = Melting point, DT= Decomposition Temperature**

### 3.2 Solubility

A good solubility in several organic solvents, including acetone, dichloromethane, chloroform, and DMSO, was demonstrated by the Schiff base and its complexes; conversely, their solubility was poor in methanol and ethanol (refer to Table 2). This preference for less polar solvents suggests that the compounds themselves are not highly polar, a characteristic that aids in the selection of solvents for upcoming spectroscopic experiments.

**Table 2: Evaluation of the Solubility of the Schiff Base and Its Metal(II) Complexes**

| Solvents | Schiff base | Copper(II) complex | Zinc(II) Complex |
|---|---|---|---|
| Acetone | D | D | D |
| Benzene | ND | ND | ND |
| Chloroform | D | D | D |
| Dichloromethane | D | D | D |
| DMSO | D | D | D |
| Ethanol | SD | SD | SD |
| Ether | ND | ND | ND |
| Methanol | SD | SD | SD |
| n- Hexane | ND | ND | ND |
| Water | ND | ND | ND |

**Key: ND => Not Dissolvable, SD =>Slightly Dissolvable, D => Dissolvable**

### 3.3 Magnetic Susceptibility

A magnetic susceptibility of 2.2 BM was observed for the copper complex (Table 3). This result is indicative of a paramagnetic, high-spin compound with an octahedral geometry. In a clear difference, the Zinc complex registered a magnetic susceptibility of 0.0 BM, confirming that it is diamagnetic (Gehad et al., 2006).

**Table 3: Characterization of Metal(II) Complexes via Magnetic Susceptibility.**

| Measured Parameters | Copper(II) Complex | Zin(II) Complex |
|---|---|---|
| *Gram susceptibility* $(X_g)10^{-6}$ | 3.04 | -0.75 |
| *Molar Magnetic Susceptibility* $(X_m)10^{-3}$ | 2.09 | -51.90 |
| *Magnetic Moment* | 2.20 | 0.00 |
| *Magnetic Property* | Paramagnetic | Diamagnetic |

### 3.4 Fourier Transform Infrared Spectroscopy (FTIR)

IR spectral analysis revealed significant changes upon the complexation of the Schiff base. A prominent band in the ligand's spectrum at 1648 $cm^{-1}$, attributed to the azomethine C=N stretch, shifted to lower wavenumbers (1641-1644 $cm^{-1}$) in the spectra of the metal complexes. This negative shift is a key indicator that the azomethine nitrogen atom is acting as a donor site. Further evidence for coordination includes shifts in the N-H stretching vibration, from 3289 $cm^{-1}$ in the free ligand to 3318 $cm^{-1}$ and 3287 $cm^{-1}$ in the complexes. The appearance of new absorption bands in the complexes' IR spectra, specifically at 496-522 $cm^{-1}$ and 392-394 $cm^{-1}$, is consistent with the formation of M-N and M-S bonds, respectively. Finally, the C=S stretching vibration, which was observed at 852 $cm^{-1}$ in the ligand, shifted to lower frequencies (849 $cm^{-1}$ and 844 $cm^{-1}$) upon complexation, providing conclusive proof of complex formation (Mahmoud et al., 2020).

**Table 4: Interpretation of IR Spectra for the Schiff Base and Its Metal(II) Complexes**

| Absorption Bands ($cm^{-1}$) | Schiff base | Copper(II) complex | Zinc(II) complex |
|---|---|---|---|
| *υ (C=N)* | 1648 | 1641 | 1644 |
| *υ (N-H)* | 3289 | 3318 | 3287 |
| *υ (C=S)* | 852 | 849 | 844 |
| *υ(M-N)* | - | 496 | 522 |
| *υ(M-S)* | - | 392 | 394 |

### 3.5 Molar Conductance

As shown in Table 5, molar conductivities of the Copper(II) and Zinc(II) complexes were determined in a $10^{-3}$ M DMF solution. The values obtained were 134.11 $\Omega^{-1}cm^2mol^{-1}$ and 71.72 $\Omega^{-1}cm^2mol^{-1}$, respectively. These results confirm the electrolytic nature of the complexes, demonstrating that they dissociate into ions when dissolved (Radhika *et al.*, 2025).

**Table 5: Investigating the Molar Conductance of Schiff's Base Metal(II) Complexes**

| Conductance | Copper(II) complex $2.04 \times 10^{-3}$ $Moldm^{-3}$ | Zinc(II)complex $2.33 \times 10^{-3}$ $Moldm^{-3}$ |
|---|---|---|
| Molar Conductance $\Omega^{-1}cm^2mol^{-1}$ | 134.11 | 71.72 |
| Specific Conductance $\times 10^{-4}$ $S\Omega^{-1}$ | 2.74 | 1.67 |

### 3.6 Elemental Analysis

As shown in Table 6, the elemental analysis results for carbon, hydrogen, and nitrogen match the calculated

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values for the proposed chemical formulas of the Schiff base and its metal(II) complexes. These results confirm a 2:1 ligand-to-metal ratio.

**Table 6: Investigating the Elemental Composition of the Schiff Base Ligand and Its Metal(II) Complexes.**

| Schiff base/Complex | %Carbon, Calc value | %Hydrogen, Calc value | %Nitrogen, Calc value | % M, Calc value |
|---|---|---|---|---|
| AT-PTSC | (62.20), 62.40 | (5.22), 5.70 | (20.72), 20.80 | |
| [Cu(AT-PTSC)$_2$]Cl$_2$ | (45.57),45.30 | (3.82),4.10 | (12.26),12.30 | (9.27), 9.31 |
| [Zn(AT-PTSC)$_2$]Cl$_2$ | (45.45) | (3.18) | (12.23) | (9.52), 9.71 |

### 3.7 Antimicrobial Properties

The antimicrobial properties of the AT-PTSC Schiff base and its metal(II) complexes were assessed against a range of microbial organisms. This included three bacterial strains, the Gram-positive *S. aureus*, the Gram-negative *S. typhi*, and *E. coli*, as well as three fungi: *C.albicans*, *M. indicus*, and *A. flavus*. Using a dose-dependent approach, tests were performed at concentrations of 15, 30, and 60 µg per disc. Ciprofloxacin and ketoconazole served as the standard reference drugs for bacterial and fungal assays, respectively. The results indicated that all tested compounds displayed moderate antimicrobial activity. Their effectiveness increased as the concentration rose, though their overall potency remained less than that of the standard controls. A significant finding was the generally enhanced activity of the metal complexes compared to the free ligand. This is attributed to the chelation theory, which posits that the chelation process makes the complex a more potent antimicrobial agent than the uncoordinated ligand (Kanti and Nath, 2024). However, an exception was noted with the [Zn(AT-PTSC)$_2$]Cl$_2$ complex. At all tested concentrations, this complex showed lower antibacterial activity against *S. aureus* and lower antifungal activity against *C. albicans* compared to the Schiff base itself. Based on these findings and supporting literature, a general molecular structure for the complexes was proposed.

**Table 7: Antibacterial Activity Evaluation for the Schiff base and Its Metal(II) Complexes: Zone of Inhibition (mm)**

| Test Organisms | *S.aureus* (µg/disk) | | | *E.coli* (µg/disk) | | | *S.typhi* (µg/disk) | | |
|---|---|---|---|---|---|---|---|---|---|
| Concentration | 15 | 30 | 60 | 15 | 30 | 60 | 15 | 30 | 60 |
| Schiff base | 7 | 8 | 10 | 8 | 9 | 11 | 6 | 9 | 12 |
| Copper(II) Complex | 11 | 15 | 19 | 9 | 13 | 16 | 9 | 14 | 15 |
| Zinc(II) complex | 7 | 8 | 13 | 6 | 6 | 6 | 10 | 13 | 17 |
| Ciprofloxacin (At all conc.) | | 34 | | | 40 | | | 43 | |

**Table 8.: Evaluation of Antifungal Activity of AT-PTSC and Its Metal(II) Complexes: Zone of Inhibition (mm)**

| Test Organisms | *Mucor indicus* µg/disk | | | *Aspergillus flavus* µg/disk | | | *C.albicans* µg/disk | | |
|---|---|---|---|---|---|---|---|---|---|
| Concentration | 15 | 30 | 60 | 15 | 30 | 60 | 15 | 30 | 60 |
| Schiff base | 7 | 8 | 9 | 6 | 6 | 6 | 7 | 9 | 11 |
| Copper(II) complex | 12 | 15 | 17 | 7 | 11 | 13 | 9 | 12 | 15 |
| Zinc(II) complex | 9 | 10 | 12 | 6 | 8 | 10 | 6 | 6 | 6 |
| Ketoconazole (At all conc.) | | 27 | | | 32 | | | 38 | |

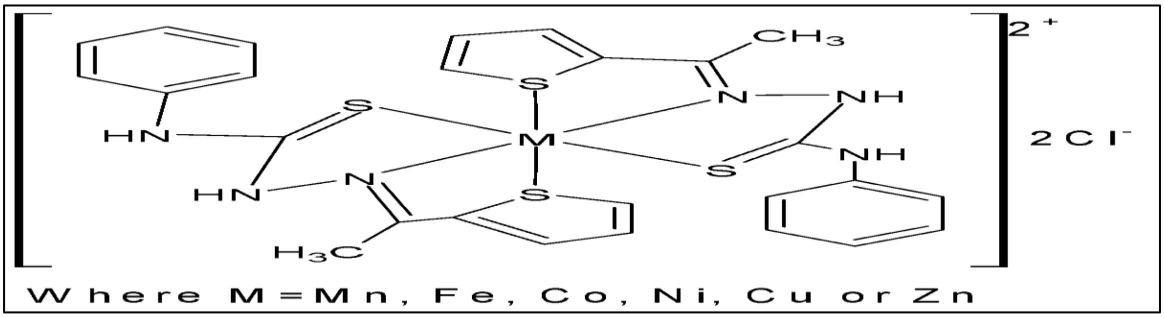


**Figure 1: Proposed Structure of (2E)-*N*-Phenyl-2-[1-(thiophen-2-yl) ethylidene]hydrazine-1-Carbothioamide Metal(II) Complexes.**

## 4.0 CONCLUSION

In this study, the Schiff base (2E)-N-phenyl-2-1-(thiophen-2-yl)ethylidene Hydrazine-1-carbothioamide (AT-PTSC) and its corresponding Cu(II) and Zn(II) complexes were successfully synthesized and characterized. The complexes exhibited excellent thermal stability, as their high decomposition temperatures indicated. Spectroscopic analysis confirmed that the ligand coordinates to the metal centers via the azomethine nitrogen, supported by shifts in the key infrared vibrational bands (v(N-H) and v(C=N)). Further characterization, including molar conductivity, magnetic susceptibility, and elemental analysis, confirmed an octahedral geometry and a 2:1 ligand-to-metal ratio. Biological evaluation demonstrated that the ligand and its complexes possess antimicrobial activity against various tested microorganisms, including bacteria and fungi. Notably, the metal complexes consistently showed enhanced activity compared to the free ligand, consistent with the chelation theory. These findings establish the potential of these thiophene-based Schiff base complexes as a promising class of antimicrobial agents, warranting further investigation into their pharmacological properties.

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DOI: https://doi.org/10.57233/ijsgs.v12i2.1105 ISSNp: 2488-9229; ISSNe: 3027-1118

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