

Research Article

Synthesis and conductivity evaluation of a novel Cu(II) complex derived from 4-(diphenylamino)benzaldehyde-4-(ethyl)thiosemicarbazone: An integrated EIS and DFT investigation

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Abstract

A new Cu(II) complex containing the 4-(diphenylamino)benzaldehyde-4-(ethyl)thiosemicarbazone ligand (CuL₂) was synthesised via the reaction of 4-(diphenylamino)benzaldehyde-4-(ethyl)thiosemicarbazone ligand with copper(II) acetate. The resulting CuL₂ complex was characterised using various spectroscopic and analytical techniques, namely, CHNS elemental analysis, Fourier transform infrared spectroscopy (FTIR), magnetic susceptibility, molar conductivity, and ultraviolet-visible (UV-Vis) spectroscopy. The FTIR analysis confirmed the mononegative bidentate coordination of the ligand to the Cu(II) ion through the azomethine (C=N) and thiosulfur (C=S) functional groups, with characteristic bands at 497 and 443 cm⁻¹, respectively. The experimental HOMO-LUMO band gap of 2.76 eV indicates that the Cu(II) complex exhibited semiconducting behaviour. The UV-Vis spectrum showed an absorption at 738 nm (*d*→*d* transition) while magnetic susceptibility measurements (1.72 BM) supported a square planar geometry for CuL₂. Solid biopolymer electrolyte (SBE) films doped with CuL₂ were prepared using a solution casting method, in which a mixture of carboxymethylcellulose (CMC) served as the polymer matrix, polyethylene glycol (PEG) acted as the plasticiser, and isophthalic acid (IA) served as the deprotonator. Electrochemical impedance spectroscopy (EIS) analysis revealed that the highest electrical conductivity of 1.08 × 10⁻⁴ S cm⁻¹ at 353 K was achieved with the SBE composition of CMC (1 g) + PEG (0.1 ml) + CuL₂ (15 wt%) + IA (15 wt%). Moreover, the prepared SBE composition followed Arrhenius behaviour with a low activation energy (*E*_a) of 0.34 eV, indicating that only a small amount of thermal energy is required to activate the charge carriers.

Keywords: Synthesis, thiosemicarbazone complex, conductivity, solid biopolymer electrolyte

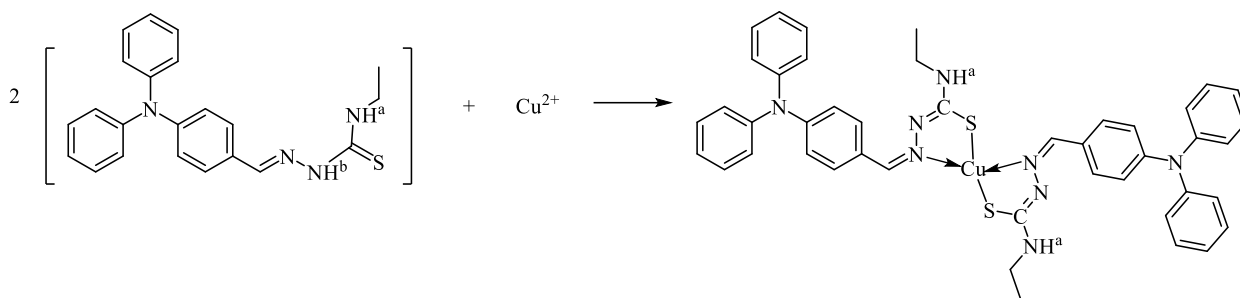
Introduction

In recent years, researchers have focused more on environmentally friendly materials for electronic devices, such as batteries, to help reduce electronic waste 1. Thus, solid biopolymer electrolytes (SBEs) are being studied as a safer and more effective alternative 1. SBEs are known for being leak-free, more stable, and exhibiting good mechanical strength, which makes them a promising option for future battery systems. One of the main challenges associated with solid biopolymer electrolytes (SBEs) is their low ionic conductivity. To overcome this issue, a dopant is often introduced to enhance their conductivity 2.

In this study, a thiosemicarbazone derivative was chosen as the dopant to improve the ionic conductivity of the SBE system. Thiosemicarbazones have

garnered increasing interest due to their diverse functional properties. Their metal complexes have also been extensively studied for various biological activities, including antibacterial, antifungal, antitumor, and antiviral effects 3. Beyond their biological applications, thiosemicarbazones have been explored for their potential in materials science, particularly in the development of conductive materials. This shift in focus reflects their promising role in enhancing the electrical properties of systems such as solid biopolymer electrolytes.

Thiosemicarbazone compounds and their derivatives contribute to electrical conductivity through the presence of nitrogen (N) and sulfur (S) donor atoms, which facilitate electron delocalisation within the molecule. These donor sites enable coordination with metal ions such as Cu(II) to form stable metal

Scheme 1. Synthesis of CuL₂ complex

complexes 4. The combination of the electronic properties of N, S-donor ligands and their ability to form diverse coordination geometries enhances the effectiveness of thiosemicarbazones as chelating agents in conductive systems 5.

Chelation with metal complexes has been shown to enhance the conductivity properties of ligands, as the incorporation of metal ions can facilitate ion transport, particularly within a polymer matrix. This effect is especially significant in solid biopolymer electrolytes, where achieving high ionic conductivity is essential for practical applications 6. Among various metal ions, Cu(II) has been widely studied and consistently demonstrates good conductivity behaviour. Building on our previous work involving the synthesis of 4-(diphenylamino)benzaldehyde-4-(ethyl)thiosemicarbazone 7, this study extends the investigation by synthesising its Cu(II) metal complex and evaluating its potential as a dopant to improve the ionic conductivity of carboxymethylcellulose-based solid biopolymer electrolyte systems.

Materials and Methods

Materials

All chemicals were obtained from BDH, ACROS, and Fluka. Elemental analysis was carried out using an Elementar (Unicube) analyser. Magnetic susceptibility measurements were performed using a Johnson Matthey Mark I MSB magnetic susceptibility balance model MKIC. The molar conductance of 1.0×10^{-3} M freshly prepared in DMSO solutions of the CuL₂ complex was measured using a Jenway 4320 conductivity meter equipped with a platinised electrode dip-cell. FTIR spectra were recorded using a Bruker spectrometer ($4000\text{--}450\text{ cm}^{-1}$) at Universiti Malaysia Terengganu, and the synthesised CuL₂ was analysed directly using the attenuated total reflectance (ATR) technique. Electronic spectra were recorded using a Shimadzu UV-1800 UV spectrophotometer, with samples prepared with a molar conductance of 1.0×10^{-5} M in DMSO solutions.

The molecular geometry optimisation and electronic structure calculations, including the determination of HOMO–LUMO energy levels, were carried out using Gaussian 09W software. Density functional theory (DFT) calculations were performed using a hybrid approach, in which the LANL2DZ basis set was

applied to the metal atoms. At the same time, the ligand was treated using the B3LYP functional with the 6-311G(d,p) basis set.

Synthesis of LH

4-(diphenylamino)benzaldehyde-4-(ethyl)thiosemicarbazone (LH) was synthesised by condensation of 4-diphenylaminobenzaldehyde with 4-ethyl-3-thiosemicarbazide in a 10 mL tetrahydrofuran solution. The synthesis of LH has been published previously 7.

Synthesis of CuL₂ complex

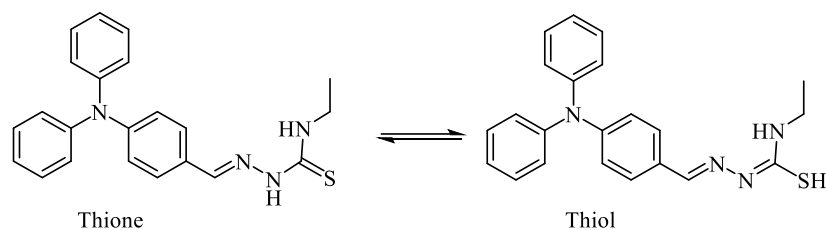
This complex was synthesised by refluxing a mixture of LH (0.3 mmol) and copper(II) acetate (0.6 mmol) in 40 mL of hot ethanol for 3 hours. The dark brown precipitate was filtered, washed with cold ethanol, and kept in a desiccator. The chemical equation for the reaction is shown in Scheme 1.

Yield: 90.4%. Melting point: 191.9°C. Analysis calculated for C₄₄H₄₂N₈NCuS₂: C, 65.2; H, 5.22; N, 13.82; S, 7.87. Found: C, 65.99; H, 6.01; N, 14.35; S, 7.65%. λ_{max} (nm): 367 n $\rightarrow$ π^* , 738 ($d\rightarrow d$ transition). Molar conductance: $12.40\ \Omega^{-1}\text{ cm}^2\text{ mol}^{-1}$. μ_{eff} (BM): 1.72.

Preparation of the film and conductivity measurement using electrochemical impedance spectroscopy (EIS)

The films were prepared using the solution casting method, where 1g of carboxymethylcellulose (CMC) was dissolved in 20 mL of distilled water. The solution was doped with different weight percentages (0 – 25 wt%) of the CuL₂ complex and isophthalic acid (0 – 25 wt%). The solution was stirred until it became homogeneous, and then it was dried in an oven at 55–60 °C to form the film. The films were then cut into small discs, 2 cm in diameter, and clamped under spring pressure between two stainless steel electrodes connected to the electrochemical impedance spectroscopy (EIS) model HIOKI 3532-50 LCR Hi-tester. Measurements were performed at room temperature and continued at different temperatures ranging from 303 to 353 K to determine the ionic conductivity (σ) of CuL₂ using the following equation:

$$\sigma = \frac{t}{A \times R_b} \quad (\text{Eq. 1})$$



Scheme 2. Representation of thione-thiol tautomerism in the LH ligand

Where t is the thickness of the film (cm), R_b is the bulk resistance determined from the intercept of the Cole-Cole plot, and A is the surface contact area of the film and electrode. The activation energy (E_a) can also be determined using the Arrhenius equation:

$$\sigma = \sigma_0 \exp \frac{-E_a}{KT} \quad (\text{Eq. 2})$$

Results and Discussion

Synthesis

Theoretically, the thioamide group (NH-C=S), which is a primary component of the ligand LH, can undergo thione-thiol tautomerism, as depicted in **Scheme 2**. Upon complexation with Cu^{2+} ion, the LH ligand predominantly exists in its thione form, which subsequently converts to the thiolate form. The complexation was prepared by direct reactions between Cu^{2+} and LH in a molar ratio of 1:2, corresponding to a chemical formula of CuL_2 . The CuL_2 complex was found to be paramagnetic with an experimental magnetic moment of 1.75 BM measured at ambient temperature. This indicated the presence of one unpaired electron in the split d -orbitals, confirming the square planar geometry of the CuL_2 complex **8**. Furthermore, the molar conductivity values of $12.40 \, \Omega^{-1} \text{ cm}^2 \text{ mol}^{-1}$ in $1 \times 10^{-3} \text{ M}$ DMSO solution indicated non-electrolytic behaviour, which is consistent with previous reports **9**.

Infrared spectroscopy

The FT-IR spectrum of the Cu(II) coordination complex (**Figure 1**) was analysed to investigate the binding modes of nitrogen and sulfur donor ligands to the Cu^{2+} ion. The $\text{C}_{44}\text{H}_{42}\text{N}_8\text{CuS}_2$ complex, consisting of 97 atoms, was also examined. The characteristics of N-H^a stretching modes are typically observed in the range of $3500\text{--}3000 \text{ cm}^{-1}$. Experimentally, they were detected at 3434 cm^{-1} . In addition, the absence of both the N-H^b at 3157 cm^{-1} and C=S at 1322 cm^{-1} stretching modes **7**, together with the presence of a C-S stretching mode at 692 cm^{-1} in the IR spectrum, indicated that the LH ligand existed predominantly in thione tautomeric form in the solid state **1111**. The C-H stretching vibrations typically appear in the range of $3100\text{--}3000 \text{ cm}^{-1}$. Experimentally, they were observed at 3080 cm^{-1} . The bending vibrations of the ethyl group, specifically $\delta(\text{CH}_2\text{CH}_3)$, were identified at 1488 cm^{-1} **12**. As for the thiosemicarbazone

derivatives of fluorenone, the C-H stretching vibration has been reported at 2916 cm^{-1} **13**.

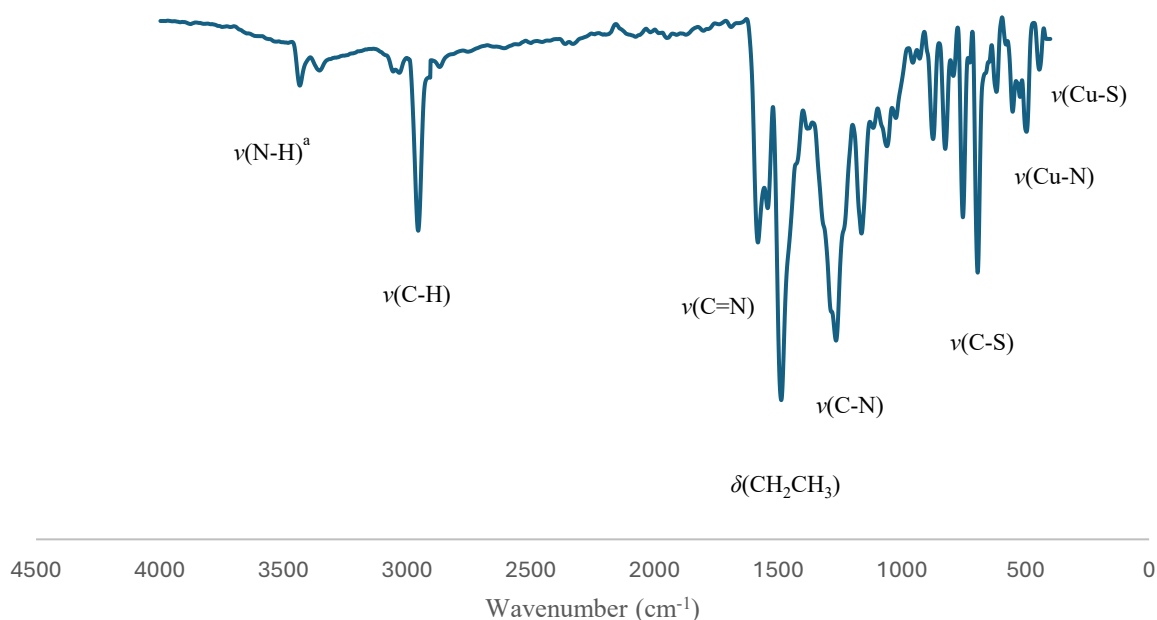
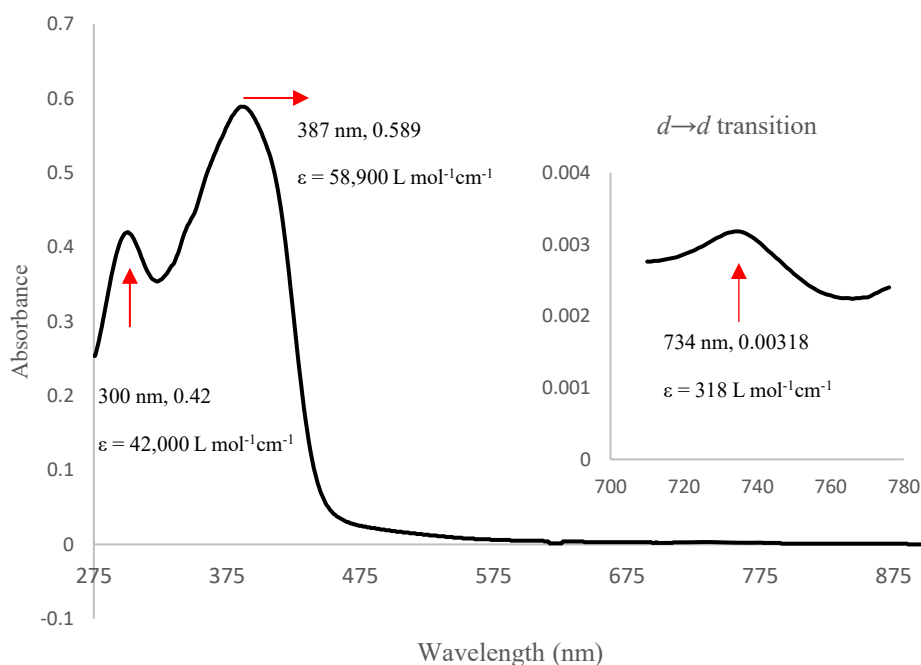
For the title complex, the $\nu(\text{C}=\text{N})$ mode was observed at 1578 cm^{-1} . In the previously reported ligand molecule, this mode appeared at 1663 cm^{-1} , indicating a slight shift upon complexation **14**. The $\nu(\text{C}-\text{N})$ vibrations were detected in the range of 1267 cm^{-1} to 1370 cm^{-1} **15**. The $\nu(\text{C}-\text{N})$ was observed at 1263 cm^{-1} in the FT-IR spectrum. In the literature, the M-S and M-N stretching vibrations were observed at $436\text{--}490 \text{ cm}^{-1}$ in the IR spectrum **16**. Both Cu-S and Cu-N stretching vibrations in the title complex were observed as weak bands at 443 and 497 cm^{-1} , respectively. The FT-IR spectra thus indicate the formation of a mixed ligand Cu(II) coordination complex, suggesting that the ligand coordinates to the Cu^{2+} ion through both its nitrogen and sulfur atoms.

Electronic spectra

The UV-Vis spectrum of the CuL_2 dopant (**Figure 2**) exhibited a profile similar to that of the corresponding free ligand **7**, with differences observed in the molar extinction coefficients (ϵ). For the free ligand, two absorption bands appeared at 299 nm ($\epsilon = 21,700 \text{ L mol}^{-1} \text{ cm}^{-1}$) and 369 nm ($\epsilon = 31,700 \text{ L mol}^{-1} \text{ cm}^{-1}$), which are assigned to the $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ transitions of the conjugated triphenylamine moiety and the lone pairs on nitrogen and sulfur atoms **7**. In the CuL_2 dopant, the absorption peaks were slightly shifted to 300 nm ($\epsilon = 42,000 \text{ L mol}^{-1} \text{ cm}^{-1}$) and 387 nm ($\epsilon = 58,900 \text{ L mol}^{-1} \text{ cm}^{-1}$), reflecting the influence of complexation while maintaining the overall spectral features of the free ligand. In addition, a broad and weaker absorption band was observed at 739 nm , corresponding to a $d \rightarrow d$ electronic transition, more precisely from the d_{xy} orbital to the higher-energy $d_{x^2-y^2}$ orbital. This type of transition is commonly seen in square planar Cu(II) complexes. Due to the d^9 configuration of the Cu(II) ion and its coordination with nitrogen and sulfur donor atoms in a planar arrangement, the d -orbitals experienced significant splitting. Among these, the $d_{x^2-y^2}$ orbital lies highest in energy, being singly occupied, while the d_{xy} orbital is fully occupied and sits at a lower energy level. The observed transition is spin-allowed but Laporte-forbidden, leading to its low intensity in the visible region **17**.

Table 1. Infrared spectra data (cm^{-1}) of CuL_2

Compound	Bands (Wavenumber, cm^{-1})							
	$\nu(\text{N-H})^a$	$\nu(\text{C-H})$	$\nu(\text{C=N})$	$\nu(\text{C-N})$	$\nu(\text{C-S})$	$\nu(\text{Cu-S})$	$\nu(\text{Cu-N})$	$\delta(\text{CH}_2\text{CH}_3)$
CuL_2	3434	2979	1578	1263	692	443	497	1488

**Figure 1.** FTIR of CuL_2 **Figure 2.** UV-Vis of CuL_2

This spectral feature supports the presence of a square planar geometry, which is typical for Cu(II) when coordinated to thiosemicarbazone-type ligands 18. Further evidence for this geometry was provided by

the magnetic moment of the complex, measured at 1.72 Bohr Magnetron (BM), indicating the presence of a single unpaired electron, consistent with a Cu(II) species.

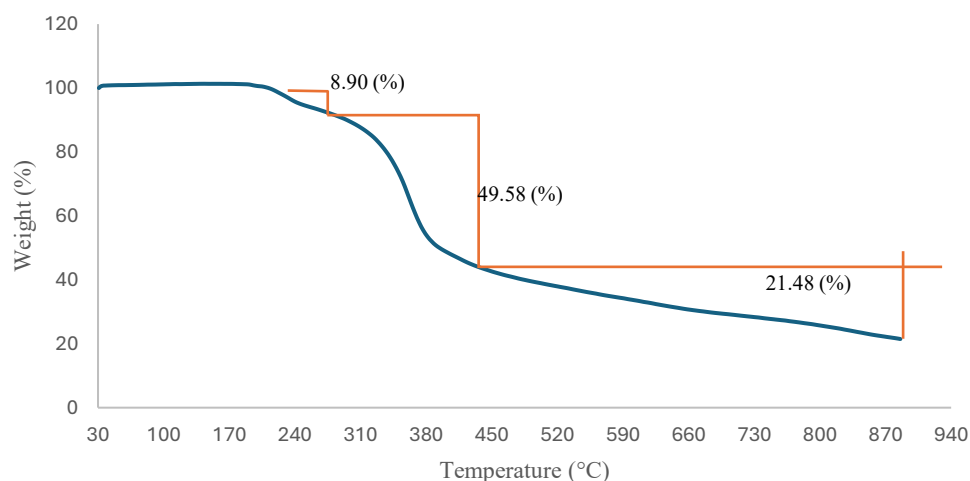


Figure 3. TGA decomposition of CuL_2

Table 2. TGA decomposition data of CuL_2

Temperature Range (°C)	Assignments	Weight Loss Found (Calc. %)
213 – 279	(C_6H_5)	8.9 (9.5)
279 – 442	(C_6H_5) ₅ + N_2	49.58 (50.8)
442 – 885	$[\text{CH}_3\text{CH}_2]_2 + [\text{N}=\text{C}-\text{NH}]_2 + [\text{C}_2\text{H}_2]$	21.48 (20.5)
Residue	$\text{N}_2\text{S}_2\text{Cu}$	20.04 (19.11)

Thermogravimetric analysis (TGA)

The TGA analysis of CuL_2 was performed to gather information about its thermal stability, conducted at a controlled heating rate of $10^\circ\text{C}/\text{min}$ under a nitrogen atmosphere. The weight loss was measured from room temperature of 30°C to 900°C . The TG of CuL_2 (**Figure 3**) shows a three-step decomposition. The compound remained stable up to 213°C , with no weight loss till 100°C , indicating that the solid compound does not contain any water molecules. In the first stage, between 213°C and 279°C , an 8.90% weight loss occurred, corresponding to the loss of benzene (C_6H_5) molecules (calculated at 9.5%). From 279 to 442°C , 49.58% (Calc. 50.8%) weight loss indicated the elimination of (C_6H_5)₅+ N_2 , which is part of the remaining triphenylamine group in the compound (**Table 2**). The third stage, from 442 to 885°C with 21.48% weight loss (Calc. 20.5%), represented the removal of $[\text{CH}_3\text{CH}_2]_2 [\text{C}_2\text{N}_2\text{H}_2]_2$, the part that is not bonded to the Ni metal. The remaining weight of 20.04% corresponded to $\text{N}_2\text{S}_2\text{Cu}$, located at the centre of the compound. Its central position and the presence of electronegative (N, S) atoms allowed electrons to circulate around it, strengthening the bond while weakening the neighbouring bonds associated with it 19.

HOMO LUMO band gap

The frontier molecular orbitals of the Cu(II) complex with 4-(diphenylamino)benzaldehyde-4-ethylthio semicarbazone (**Figure 4**) were analysed to assess its electronic characteristics and their relation to

conductivity. The calculated energies of the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) were found to be -4.873 eV and -2.847 eV, respectively. This provided an energy band gap (ΔE_{gap}) of 2.03 eV, indicating a moderate separation between the HOMO and LUMO levels. Such a gap suggests that the complex has semiconducting properties 20, where electrons can be relatively easily excited from the HOMO to the LUMO upon thermal or electrical stimulation. The experimental optical band gap of the Cu(II) complex was also estimated using the Tauc plot method derived from UV-Vis absorption data (**Figure 5**). The Tauc plot showed an optical band gap of 2.76 eV, which is slightly larger than the theoretical energy gap of 2.03 eV obtained from HOMO-LUMO calculations using DFT. This difference is expected and commonly observed, as DFT calculations often underestimate energy gaps due to inherent limitations in exchange-correlation functionals 21. The relatively close agreement between the experimental and theoretical values supports the validity of the electronic structure predicted by computational methods. The optical band gap of 2.76 eV confirmed that the complex behaves as a semiconductor, aligning with its observed UV-Vis absorption in the visible region. This supports the role of the CuL_2 complex as an efficient dopant in solid biopolymer electrolytes (SBEs), where a suitable band gap can facilitate charge transfer and improve conductivity by reducing the energy barrier for carrier excitation.

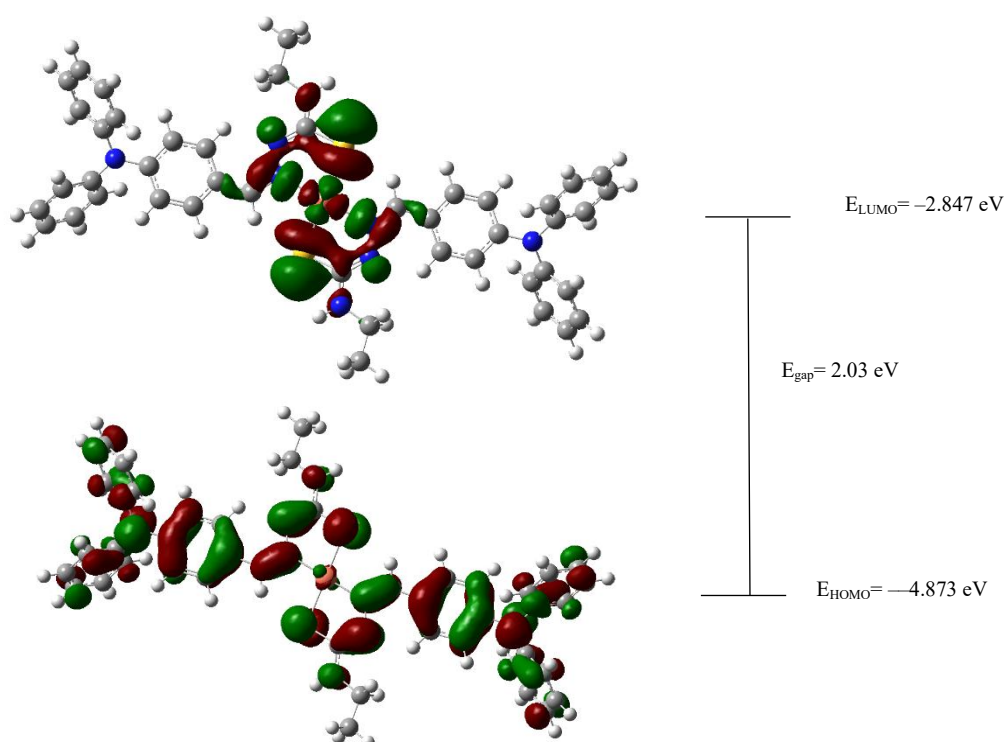


Figure 4. HOMO-LUMO band gap of CuL_2

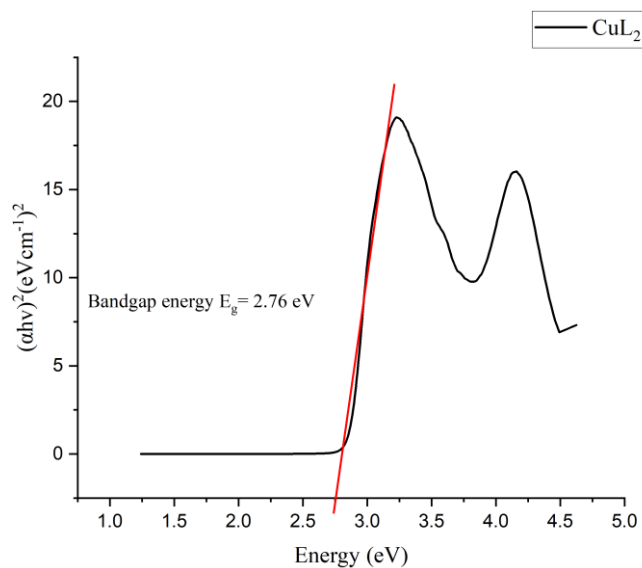


Figure 5. Tauc Plot of CuL_2

Conductivity analysis

The impedance measurements were performed on CMC-PEG film with various concentrations of 4-(diphenylamino)benzaldehyde-4-(ethyl)thiosemicarbazone chelate with Cu(II) metal (CuL_2) dopant (Mixture 1) and isophthalic acid (IA) (Mixture 2) at ambient temperature. The Nyquist plots for both

systems are shown in **Figures 6** and **7**, respectively. **Table 3** presents the ionic conductivity for all samples, expressed as a percentage.

In Mixture 1, the addition of the new synthesis doping agent, CuL_2 , from 5 wt% to 25 wt% initially showed a clear trend of increasing conductivity up to 15 wt% of

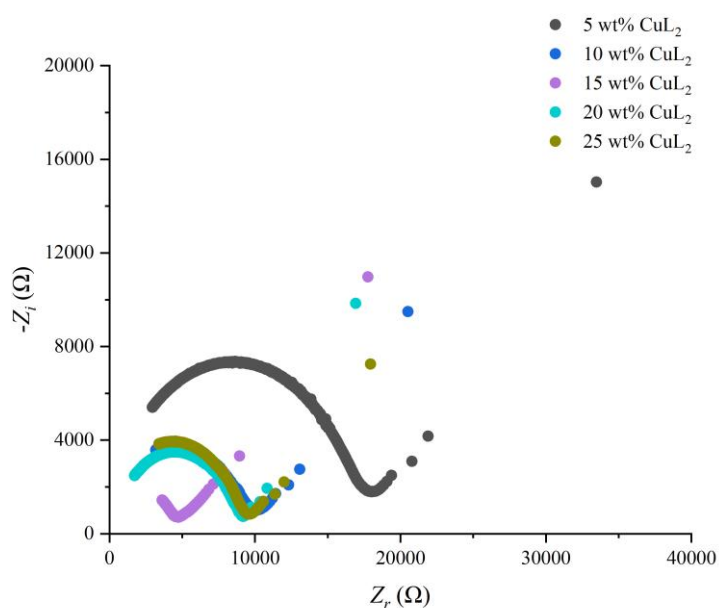


Figure 6. Nyquist plot for samples with various CuL_2 concentrations at room temperature

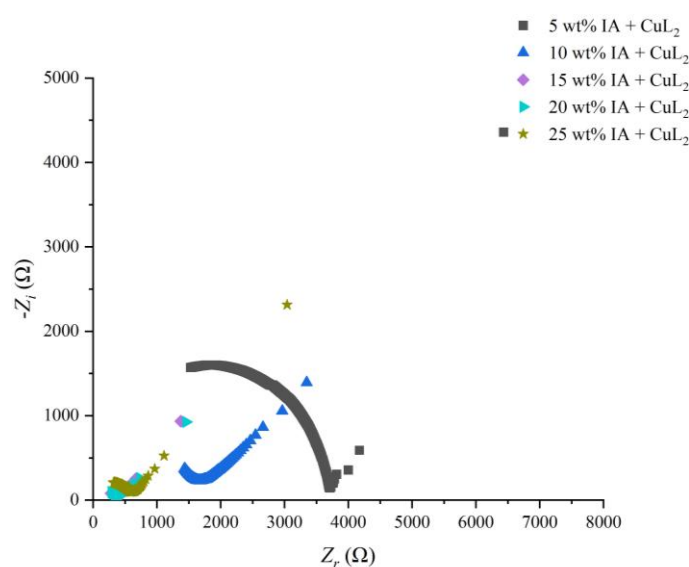


Figure 7. Nyquist plots for samples with various IA concentrations at room temperature

Table 3. Room temperature conductivity against CuL_2 and isophthalic acid (IA) content

Sample Designation		Thickness, t (cm)	Bulk Resistance, R_b (Ω)	Conductivity, σ (S/cm)
Mixture 1	5 wt% CuL_2	0.010	1.84×10^4	1.73×10^{-7}
	10 wt% CuL_2	0.011	1.07×10^4	3.27×10^{-7}
	15 wt% CuL_2	0.013	5.32×10^3	7.78×10^{-7}
	20 wt% CuL_2	0.014	9.17×10^3	4.86×10^{-7}
	25 wt% CuL_2	0.015	9.90×10^3	4.82×10^{-7}
Mixture 2 (15wt% CuL_2)	5 wt% IA	0.015	3.73×10^3	1.28×10^{-6}
	10 wt% IA	0.018	1.79×10^3	3.20×10^{-6}
	15 wt% IA	0.020	3.90×10^2	1.63×10^{-5}
	20 wt% IA	0.022	4.69×10^2	1.49×10^{-5}
	25 wt% IA	0.024	6.93×10^2	1.10×10^{-5}

the dopant. This enhancement is attributed to the dopant's ability to facilitate electron mobility within the polymer matrix due to the involvement of the Cu(II) centre under an applied electric field 22. The increased electron mobility in the dopant molecules facilitated the formation of effective ionic pathways. At 15 wt%, the conductivity reached its maximum value of $7.78 \times 10^{-7} \text{ Scm}^{-1}$, representing an optimal balance where sufficient electron pathways are provided without significant hindrance or aggregation. However, beyond 15 wt%, the conductivity decreased due to excessive dopant, which induced bulkiness and aggregation, hindering charge transport 23.

In Mixture 2, the optimised film containing 15 wt% CuL₂ was further studied by incorporating varying concentrations of IA. Adding 5 wt% to 15 wt% of IA showed an increase in conductivity, with the highest value of $1.63 \times 10^{-5} \text{ Scm}^{-1}$. This improvement is attributed to the proton-transfer function of IA, in which protons from IA interact with the sulfur atom in the dopant, forming hydrogen bonds that facilitate charge transfer through the carboxymethylcellulose (CMC) polymer network via a hopping mechanism 24. The presence of IA increases the number of mobile protons, thereby enhancing proton conduction and overall ionic conductivity 26.

At higher IA concentrations exceeding 15 wt%, conductivity began to decline. This is explained by the

accumulation of IA molecules on the metal surface, forming a thicker but disordered interfacial layer 27. This layer reduced the ease of charge transfer and restricted ionic mobility near the interface, resulting in an initial increase in the R_b concentration. However, as the IA concentration continued to increase, the film became less uniform, which increases the surface conductivity of the metal, making the interface more electrochemically active 28. Consequently, the mobility of charge carriers increased, thus decreasing R_b . Overall, the semicircles in the Nyquist plots for IA-containing films were much smaller than in the CuL₂ system, indicating that R_b remained generally low across all IA concentrations, confirming the role of IA in facilitating charge transfer and ionic conduction.

Moreover, the DFT results indicated that the CuL₂ complex had a moderate HOMO–LUMO gap, facilitating electron delocalisation and lowering the energy barrier for charge transfer. These electronic properties support the formation of conductive pathways observed in EIS measurements. In addition, electron-rich regions in the HOMO can interact with mobile protons from IA. This synergy between the molecular electronic structure and proton mobility explains the low R_b and enhanced ionic conduction in the polymer electrolyte films. Figure 8 shows the illustration of the movement of ions within the SBE system.

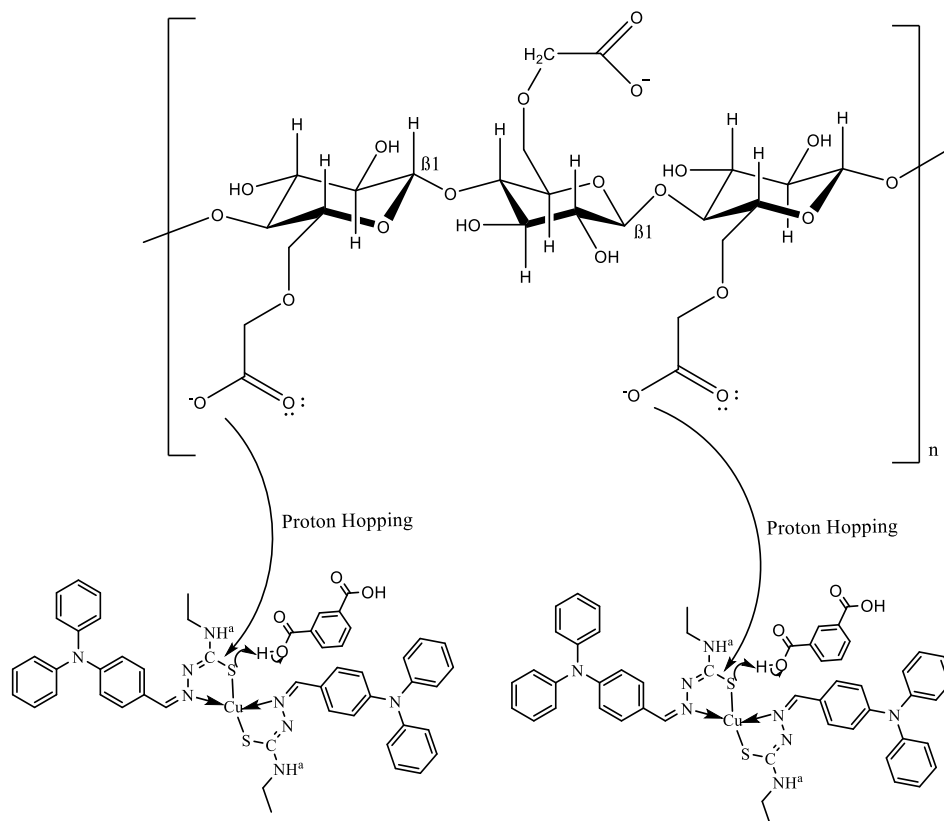


Figure 8. Illustration of the movement of ions within the SBE system

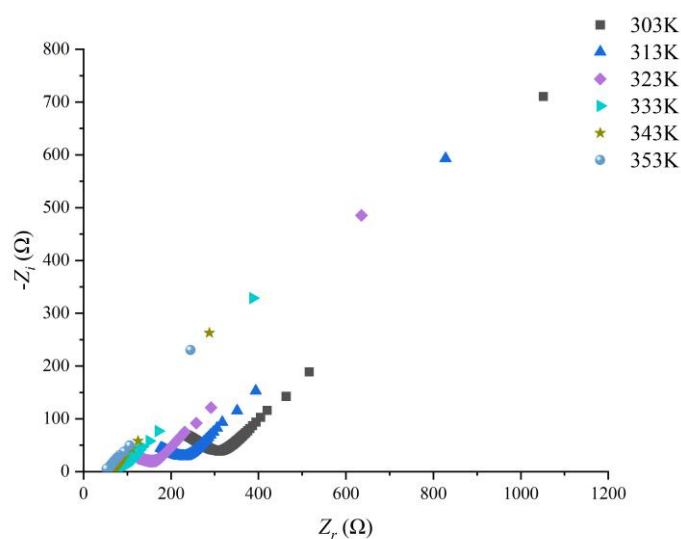


Figure 9. Nyquist plots for a sample containing 15 wt% CuL₂ + 15 wt% IA at various temperatures

Table 4. List of thickness, bulk resistance, and ionic conductivity values for a sample containing 15 wt% IA at various temperatures

Temperature (K)	Thickness, <i>t</i> (cm)	Bulk resistance, <i>R_b</i> (Ω)	Conductivity, <i>σ</i> (S/cm)
303	0.020	3.42 × 10 ²	1.86 × 10 ⁻⁵
313	0.020	2.68 × 10 ²	2.38 × 10 ⁻⁵
323	0.020	1.87 × 10 ²	3.40 × 10 ⁻⁵
333	0.020	1.10 × 10 ²	5.79 × 10 ⁻⁵
343	0.020	7.78 × 10 ¹	8.18 × 10 ⁻⁵
353	0.020	5.91 × 10 ¹	1.08 × 10 ⁻⁴

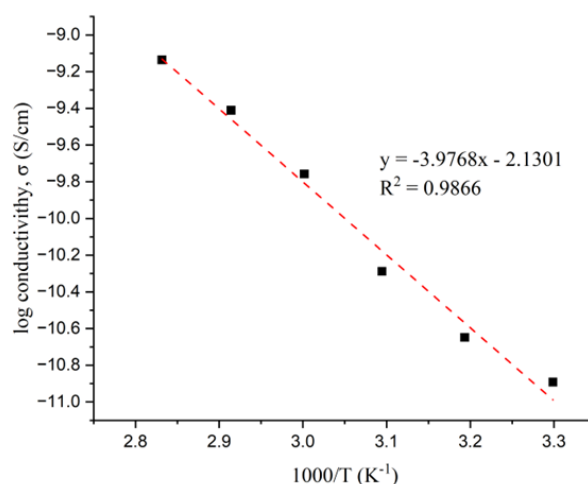


Figure 10. Temperature-dependent ionic conductivity for a sample containing 15wt% CuL₂ + 15 wt% IA

Figure 9 shows the Nyquist plots for the sample containing 15 wt% CuL₂ + 15 wt% IA at various temperatures. Table 2 summarises the values of ionic conductivity at different temperatures with the *R_b* retrieved from the plots in Figure 3. The results show that the highest ionic conductivity for this mixture is obtained at 1.08 × 10⁻⁴ S cm⁻¹ at 353 K. The increase in

ionic conductivity with temperature can be attributed to the enhanced kinetic energy of the polymer chains, CuL₂ dopant, and IA molecules within the film. As the temperature increases, the polymer chains gain additional energy, leading to more dynamic segmental motion that enhances their flexibility and reduces the rigidity of the polymer structure 29. This allows ions

to move more freely through the polymer network and along the film surface, facilitating charge transport 30. Moreover, higher temperatures reduce intermolecular forces within the matrix, lowering the energy required for ion transport. This combined effect of increased chain flexibility and reduced energy barriers significantly enhances the overall ionic conductivity of the system 31.

Figure 10 illustrates the linear relationship between ionic conductivity and temperature for the sample containing 15 wt% CuL₂ and 15 wt% IA, exhibiting Arrhenius behaviour. From the slope, the activation energy (E_a) is found at 0.34 eV, calculated from (Eq 2). Thus, it indicates that the conduction mechanism in the film requires minimal thermal energy to activate charge carriers. This low activation energy suggests efficient electrical conduction, even at low temperatures. The R^2 value of 0.9866 demonstrates an excellent fit of the data to the linear model, supporting the reliability of the Arrhenius equation in describing the temperature dependence of conductivity for this material. The low thermal activation energy observed suggests that this material may be suitable for application in low-power electronic devices, where minimal energy input is essential to activate the charge carrier 32. This makes the film ideal for various temperature environments, where it can maintain conductivity even at lower thermal energies.

Conclusion

Synthesis and characterisation of the Cu(II) complex containing 4-(diphenylamino)benzaldehyde-4-(ethyl)thiosemicarbazone (CuL₂) as a dopant was carried out using analytical techniques such as elemental analysis, FTIR spectroscopy, UV-vis spectroscopy, magnetic moment, and Gaussian analysis software to determine its structure and electronic properties. The CuL₂-doped films exhibited good ionic conductivity when incorporated into CMC films and could be further improved by the addition of isophthalic acid (IA), which facilitates proton interaction with the dopant and enhances ionic conductivity in the SBE film through a hopping mechanism. As a function of temperature, the conductivity followed the Arrhenius behaviour with an activation energy (E_a) of 0.34 eV, indicating that only a small amount of thermal energy is required to activate the charge carriers.

Acknowledgments

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