



Original Research Article

Synthesis, Characterization and Thermal Analysis of Cr(III), Mn(II) and Zn(II) Complexes of a New Acidicazo Ligand

Rasha Khider Hussain Al-Daffay^{1,*}, Abbas Ali Salih Al-Hamdani²

¹Department of Chemistry, College of Science, University of Baghdad, Baghdad, Iraq

²Department of Chemistry, College of Science for Women, University of Baghdad, Baghdad, Iraq

ARTICLE INFO

Article history

Submitted: 2022-02-01

Revised: 2022-03-20

Accepted: 2022-04-26

Manuscript ID: CHEMM-2204-1467

Checked for Plagiarism: Yes

Language Editor:

Dr. Behrouz Jamalvandi

Editor who approved publication:

Professor Dr. Ghodsi Mohammadi

Ziarani

DOI:10.22034/CHEMM.2022.335777.1467

KEYWORDS

Acidic Azo ligand

Mass spectroscopy

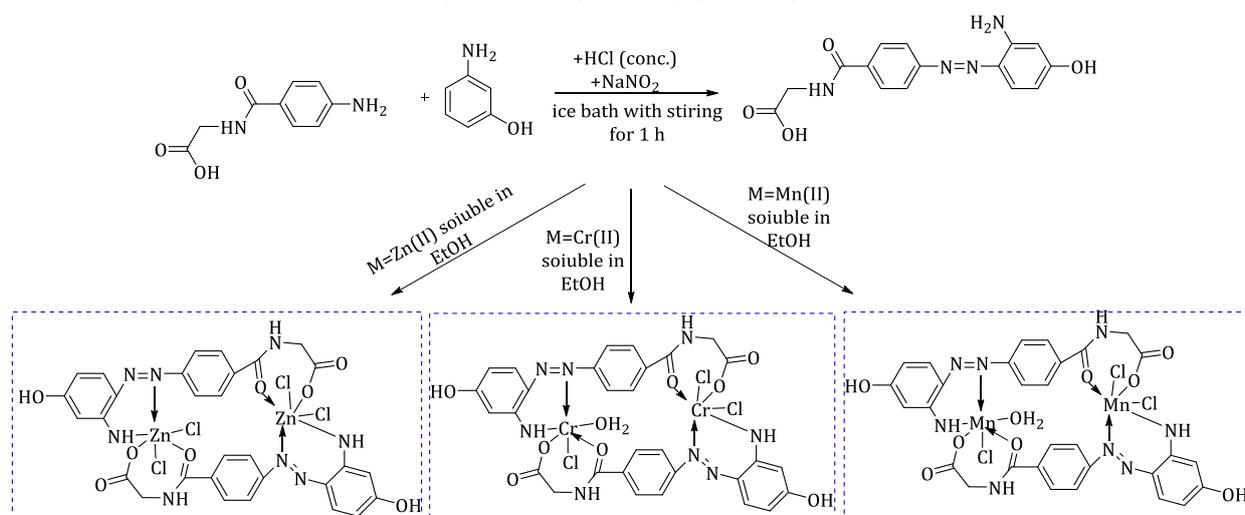
Metal complexes

TGA

ABSTRACT

The researchers wanted to make a novel azo imidazole as a follow-up to their previous work. We focused on the ligand 4-[(2-amino-4-phenylazo)-methyl]-cyclohexane carboxylic acid as a derivative of trans-4-(aminomethyl) cyclohexane carboxylic acid diazonium salt, synthesized a series of its chelate complexes with metal ions, and characterized these compounds using a variety techniques, including elemental analysis, FT-IR, LC-Mass, NMR and UV-Vis spectral process as well TGA, conductivity and magnetic quantifications. Analytical data showed that the Cr(III), Mn(II) and Zn(II) complexes out to 1:1 metal-ligand ratio with octahedral geometry except Mn complex has tetrahedral geometry.

GRAPHICAL ABSTRACT



* Corresponding author: Rasha Khider Hussain Al-Daffay

✉ E-mail: rashak.hussain82@gmail.com

© 2022 by SPC (Sami Publishing Company)

Introduction

Azo dyes represent the largest production volume of dye chemistry today, and their relative importance may even increase in the future. They play a crucial role in the governance of the dye and printing market [1]. Azo dyes are an important class of organic chemicals containing at least one azo chromophore (-N=N-), which gives the color for this famous type of dyes [2]. In general, the chemical structure of an azo dye is represented by a backbone, the auxochrome groups, the chromophoric groups. The color of the azo dyes is determined by the azo bonds and their associated chromophores and auxochromes [1]. It has been estimated that more than 50% of all dyes in common use are azo dyes because of their chemical stability and versatility [3]. Azo dyes do not occur in nature and get synthesized by the reaction of an aryl diazonium salt with an aromatic amine or a phenol [4]. It has also been estimated that more than 50% of all dyes in common use are azo dyes because of their chemical stability and versatility [3]. They constitute more than half of the dyes used today. They differ in the degree of their complexity, according to the number of the azo groups and the number and nature of the oxochrome groups found there [5,6]. The azo group may be bonded to benzene rings, naphthalenes, aromatic heterocycles or to enolizable aliphatic groups. These are essential to give the color of the dye, with their shades of different intensities [1,5].

Materials and Methods

All chemicals and reagents were purchased commercially (Sigma-Aldrich, Merck, and others) and used as-is. To conduct elemental studies (C, H, and N), the single-V Euro vector model EA/3000. 3.0-single was utilized. Using a gravimetric approach, metal ions were calculated as metal oxides. The conductometer WTW was used to measure the molar conductance of the complexes at a temperature of 25°C and a concentration of 1103 M. To dissolve all of the complexes, dimethylformamide (DMF) was utilized. QP50A: DI Analysis on a mass spectrometry (MS) Mass spectra for compounds were obtained using a

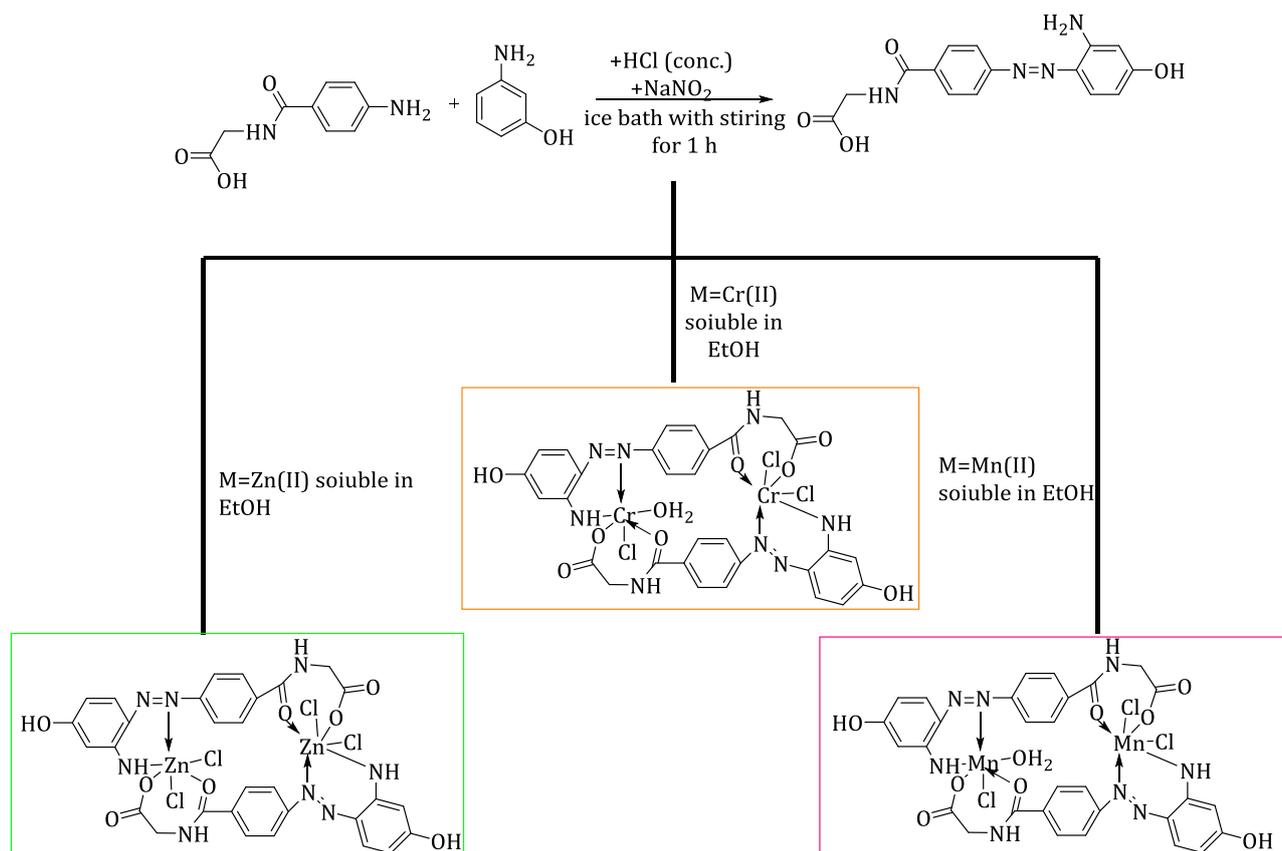
Shimadzu QP-2010-Plus (E170Ev) spectrometer. The UV-Vis spectrophotometer UV-1800 Shimadzu was used to analyze spectra in the ultraviolet-visible (UV-Vis) range, and the proton nuclear magnetic resonance (¹H-NMR) spectrum for ligand in DMSO-d₆ was recorded using a Bruker 400 MHz. The Fourier transform infrared (FTIR) spectra were studied using the IR Prestige-21, and thermo gravimetric investigations were conducted using the Perkin-Elmer Pyris Diamond TGA.

Synthesis of azo dye ligand: 4-[(2-amino-4-phenylazo)-methyl]-cyclohexane carboxylic acid

P-amino hippuric acid (0.194 g, 1 mmole) melted in a mixture (5ml ethanol, 3ml HCl conc.), and was diazotized at 5°C with 10% solution of NaNO₂. For 3-aminophenol, a diazotized solution was added with stirring to a cooled ethanolic solution at (0.109 g, 1 mmole). Then after mixing directly, a dusky colored mix and azo ligand precipitation was seen. This deposit was filtered, washed a number of ounces for a (1:1) (C₂H₅OH: H₂O) mixture, and then dried. Scheme 1 depicts the reaction.

General method for the preparation of metallic ions complexes

Azo ligand dissolved (0.317 g, 1 mmol) in 10 mL pure ethanol was gradually added in drops wise with stirring a stoichiometric to (0.267 g, 1 mmol) quantity of [2:2] M:L for Cr(III) chloride salt dissolved in 5 mL hot Ethanol and the same amount of ligand was added to (0.198g, 1m.mol) and (137 g, 1 mmol) quantity of [2:2] M:L for Mn(II) and Zn(II) chloride salts, respectively dissolved in 5 mL hot Ethanol. The mixture of all complexes was heated to 65 °C for 2.5 hours, then cooled in an ice bath until precipitated, then left overnight, as depicted in Scheme 1. The solid complexes were separated and rinsed with distilled water and a small amount of heated ethanol to eliminate any unreacted components. Finally, vacuum desiccators were used to dry the complexes. The analytical and physical properties of the ligand and its metal complexes are summarized in Table 1.



Scheme 1: Synthesis of azo dye ligand and its complexes

Result and discussion

Physical and chemical properties of azo dye ligand

This amorphous appearance, which takes the shape of a fine brown powder, distinguishes the

azo dye ligand (LH_2). This synthesis ligand is water and DMSO soluble; however, it is only sparsely soluble in Ethanol. In the presence of air, the metallic ion and azo ligand complexes remained stable.

Table 1: Physical properties & analytical data of ligand & their complexes

Compounds	Chemical Formula M.Wt (g.mol ⁻¹)	Color	m.p. (°C)	Elemental Compositions%					
				C Found	H Found	N Found	O Found	Cl Found	M Found
				C Calc.	H Calc.	N Calc.	O Calc.	Cl Calc.	M Calc.
LH_2	$\text{C}_{15}\text{H}_{14}\text{N}_4\text{O}_4$ 314	Brown	280	56.51	3.41	18.71	21.29	-	-
				57.32	4.46	17.83	20.38	-	-
$[\text{Cr}_2\text{Cl}_2(\text{H}_2\text{O})_2\text{L}_2]$	$\text{C}_{30}\text{H}_{28}\text{Cl}_2\text{N}_8\text{O}_{10}\text{Cr}_2$ 835	Light green	285	44.52	2.21	15.01	18.99	9.38	13.21
				43.11	3.35	13.41	19.16	8.50	12.46
$[\text{Mn}_2\text{L}_2]$	$\text{C}_{30}\text{H}_{24}\text{N}_8\text{O}_8\text{Mn}_2$ 734	Dark green	290	50.50	2.91	16.83	15.80	-	13.78
				49.05	3.27	15.26	17.44	-	14.99
$[\text{Zn}_2\text{Cl}_4\text{L}_2]$	$\text{C}_{30}\text{H}_{24}\text{Cl}_4\text{N}_8\text{O}_8\text{Zn}_2$ 897	Deep Brown	297	39.22	3.71	13.73	12.92	14.01	13.45
				40.13	2.68	12.49	14.27	15.83	14.58

¹H-NMR spectra

¹H-NMR spectra of the ligand's revealed a peak at δ : 1.38 ppm, which was attributed to chemical shifts of $\text{N}=\text{N}-\text{CH}_2$. The multiple signals were observed at δ : 2.69 ppm for ligand; these were referred to CH_2-COO proton in cyclohexane ring.

The NH_2 group appears as singlet at 4.61 ppm. The different peaks at 6.82–7.56 ppm are attributed to the aromatic protons of benzene groups. The proton (OH) of the carboxyl group COOH is responsible for the singlet signal at 11.49 ppm [7,8].

Electronic spectra measurements

Table 2 and Figure 1 show the UV-Vis spectra of the ligand LH₂ and one of its complexes. The n→π* transition of the (N=N) azo group in the free ligand produced a peak with a high intensity band with absorption maxima at (302 nm, 33112.5 cm⁻¹) and two peaks at 330 and 426 ascribed to the n→π* transition of the (N=N) azo group in the free ligand [9]. These peaks were shifted in all metal complex spectra, indicating that the azo group was involved in coordination [10]. Spin transitions at 360, 465, and 651 nm were seen in the electronic spectrum of Cr(III) complex due to ⁴A_{2g} → ⁴T_{1g} (P) (ν₃), ⁴A_{2g} → ⁴T_{1g} (F) (ν₂), and ⁴A_{2g} → ⁴T_{2g} (F) (ν₁), respectively, indicating an octahedral geometry of the complex.

The magnetic moment of the complex was weighed at room temperature to be 3.61 B.M., which is close to the spin alone value, implying an octahedral geometry around the chromium ion [11]. The spectrum of [Mn(LH)₂] complex exhibited bands at; 21505, 25000 and 34722 cm⁻¹ attributed to ⁶A₁→⁴T_{1(G)} and ⁶A₁→⁴T_{2(G)} transitions beside ligand field band, respectively [12,13]. Because d-d transitions are not feasible, electronic spectra did not provide any useful information, and the magnetic susceptibility of the Zn(II) complex showed that it contains diamagnetic moments. In DMSO solution, electronic spectra of the produced azo-dye ligand and its metal complexes in the wavelength range 200–1100 nm (1 × 10⁻³ M) [8,14,15].

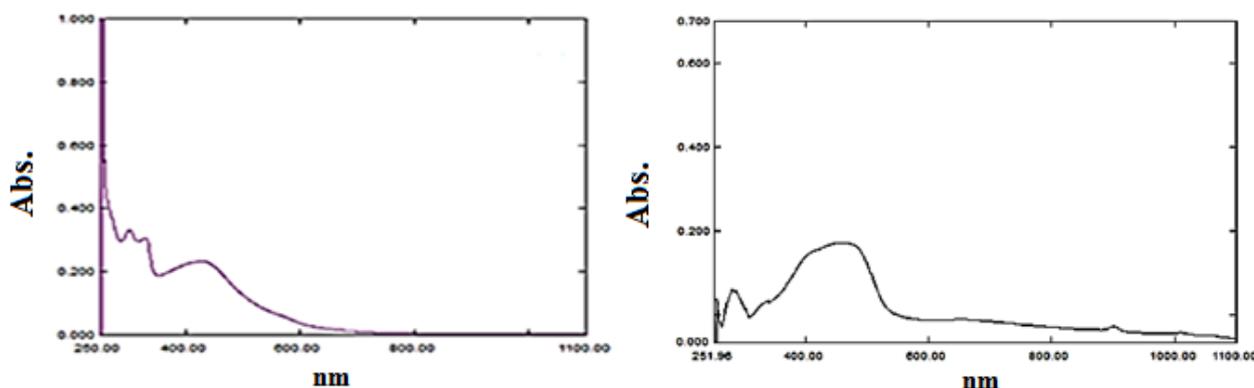


Figure 1: a-Electronic spectra of A-azo ligand b- Electronic spectra of Cr complex

Table 2: Electronic spectral data and molar conductivity of metal complexes with LH₂ ligand in DMSO (1 × 10⁻³ M)

Complexes Geometry	λ _{max} (nm)	ν (cm ⁻¹)	ABS	ε _{max} L (mol ⁻¹ cm ⁻¹)	Assignment	Λ _m cm ² Ω ⁻¹ mol ⁻¹
LH ₂	302	33113	0.248	248	π→π*	-
	330	30303	0.235	235	n→π*	
	426	23474	0.204	204	n→π*	
[Cr ₂ Cl ₂ (H ₂ O) ₂ L ₂] Octahedral	280	35714	0.060	60	π→π*	22
	470	21277	0.170	170	C.T.	
	660	15152	0.025	25	² A _{1g} → ² T _{1g}	
[Mn ₂ L ₂] Tetrahedral	285	35088	0.131	131	π→π*	20
	420	23810	0.198	198	⁶ A ₁ → ⁴ T _{2(G)}	
	480	20833	0.220	220	⁶ A ₁ → ⁴ T _{1(G)}	
[Zn ₂ Cl ₄ L ₂] Octahedral	286	34965	0.120	120	π→π*	17
	342	29240	0.196	196	C.T.	
	495	20202	0.211	211		

Liquid chromatography–mass spectrometry (LC–MS) measurements

The electron impact of fragmentation was used to acquire mass spectra of the novel ligand and metal complexes. In general, high-resolution MS was obtained of the free azo ligand and its complexes,

as well as large fragments associated with breakdown products. Figure 2 depicts the electron impact mass spectrum of the ligand LH₂. This ligand's molecular weight is calculated to be 277g/mol. The spectra showed a peak at 276 m/z, which was ascribed to [M]⁺ and corresponded to a novel azo moiety C₁₄H₁₉N₃O₃. Other distinctive peaks at 137, 84, and 55 m/z could be attributed to different fragments. Their intensity indicates the stability of fragments [16]. Figure 3 depicts the mass spectrum of the Cr(III) complex. A peak at 835 m/z was found in the spectra, which corresponded to the complex moiety [C₃₀H₂₈Cl₂N₈O₁₀Cr₂]. Other distinctive peaks at 299, 269, 149 and 123 m/z could be attributed to

different components. Figure 4 depicts the mass spectrum of the Mn(II) complex. The compound moiety C₃₀H₂₄N₈O₈Mn₂ was identified by a peak at 734 m/z in the spectra. Other distinctive peaks at 278, 251 and 212 m/z could be attributed to different fragments. Figure 5 depicts the electron impact mass spectrum of the Zn(II) complex. The complex moiety C₃₀H₂₄Cl₄N₈O₈Zn₂ had a peak at 897 m/z, which corresponded to this moiety. Other distinctive peaks at 314, 313, 149, and 123 m/z could be attributed to other fragments. Suggested fragmentation routes and structural assignments of fragments are described in Schemes 2–5 [8].

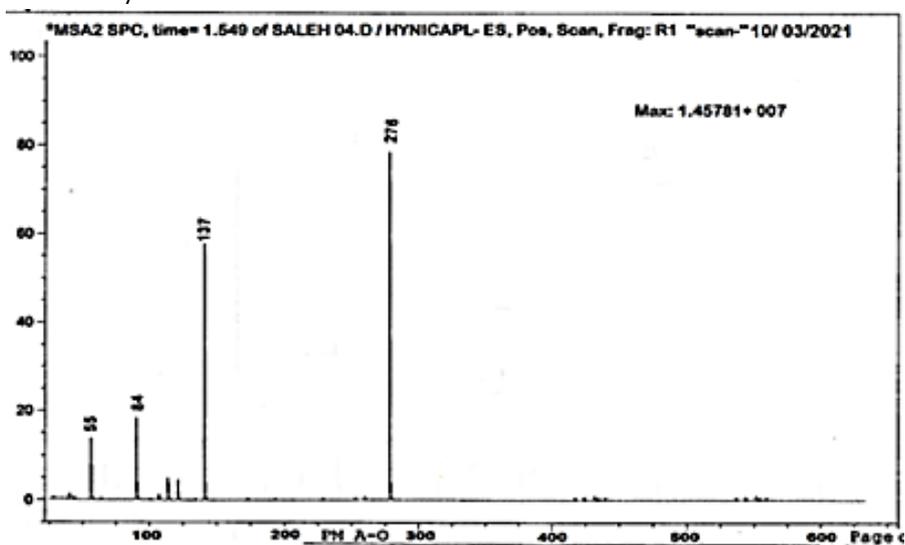


Figure 2: (LC-MS) spectrum of ligand

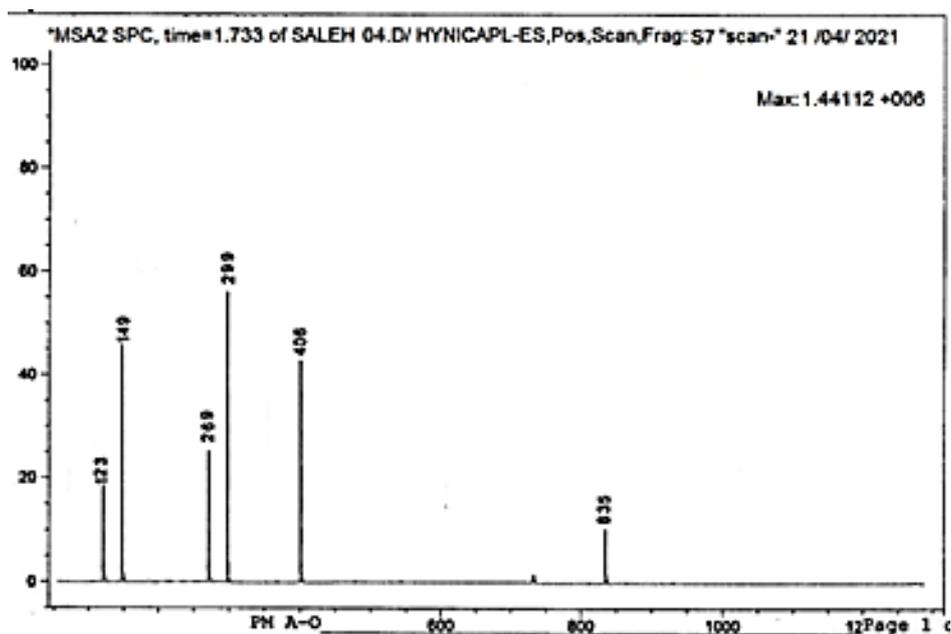


Figure 3: (LC-MS) spectrum of Cr complex

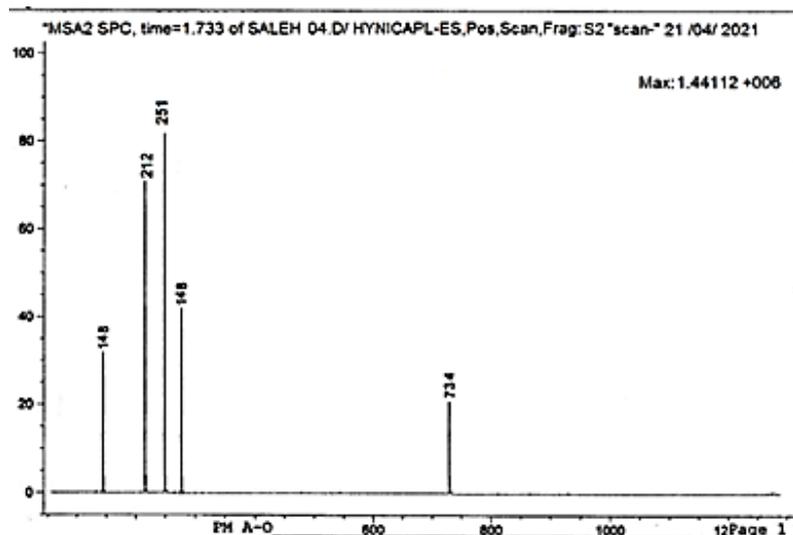


Figure 4: (LC-MS) spectrum of Mn complex

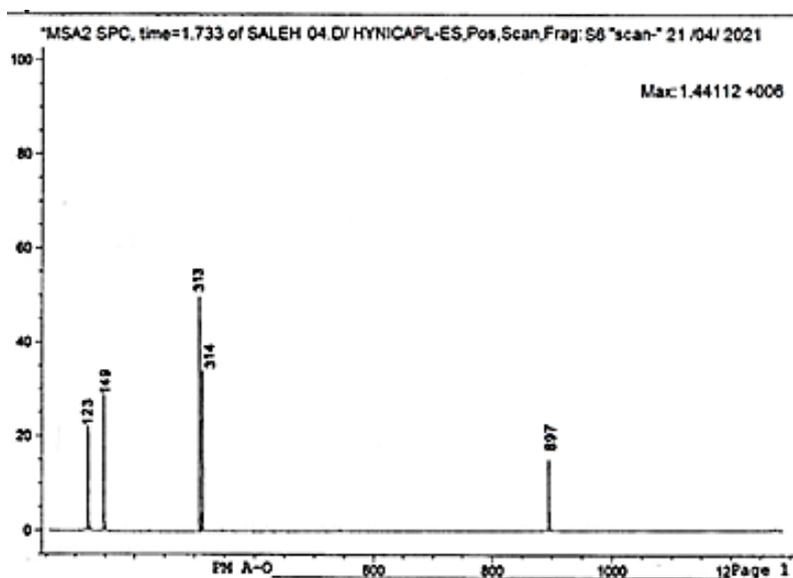
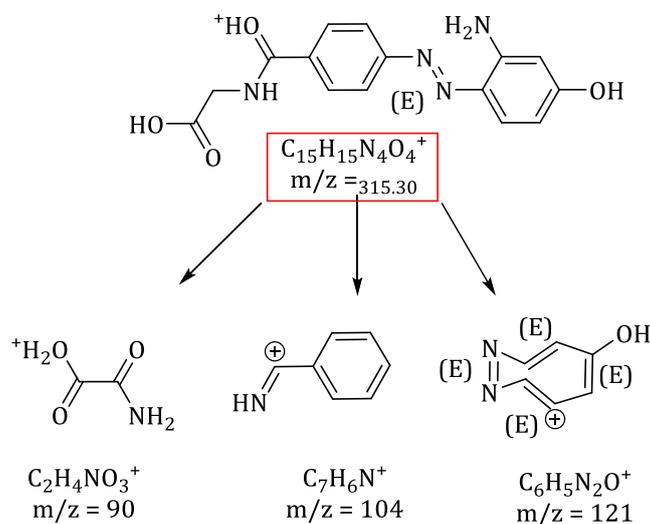
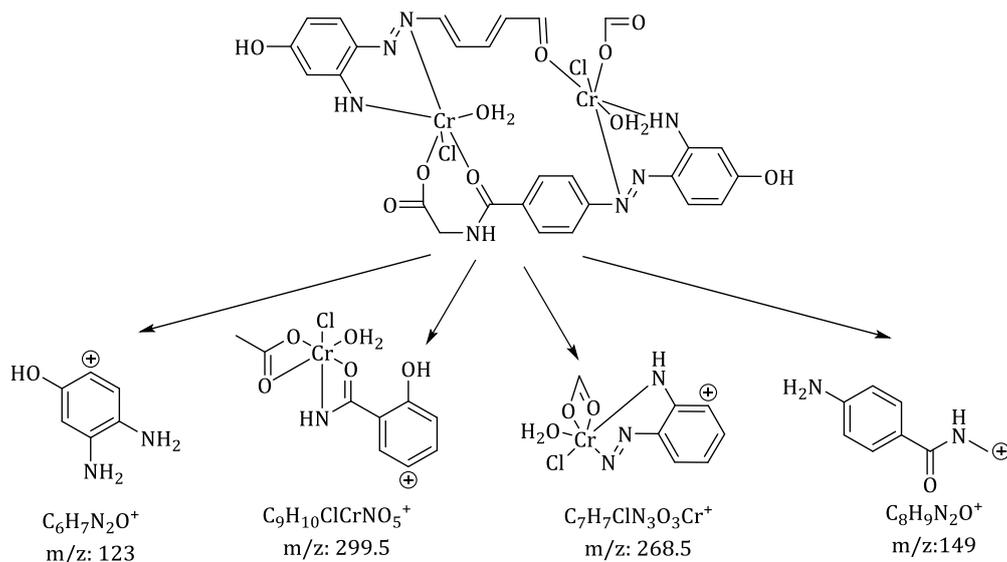


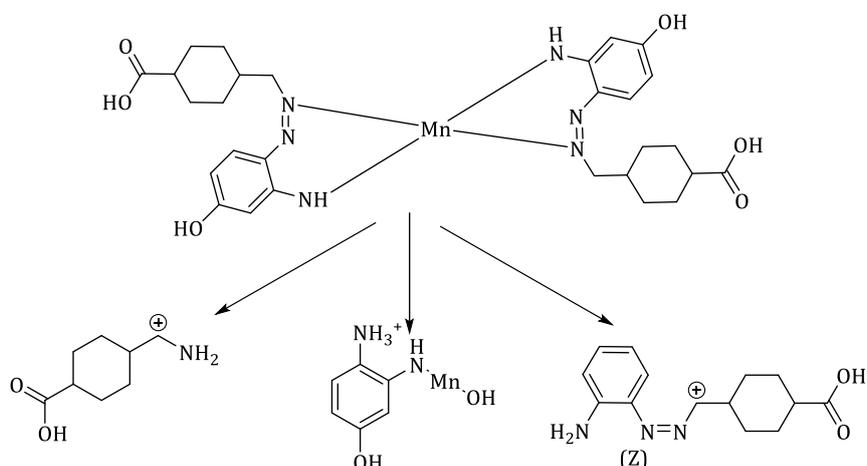
Figure 5: (LC-MS) spectrum of Zn complex



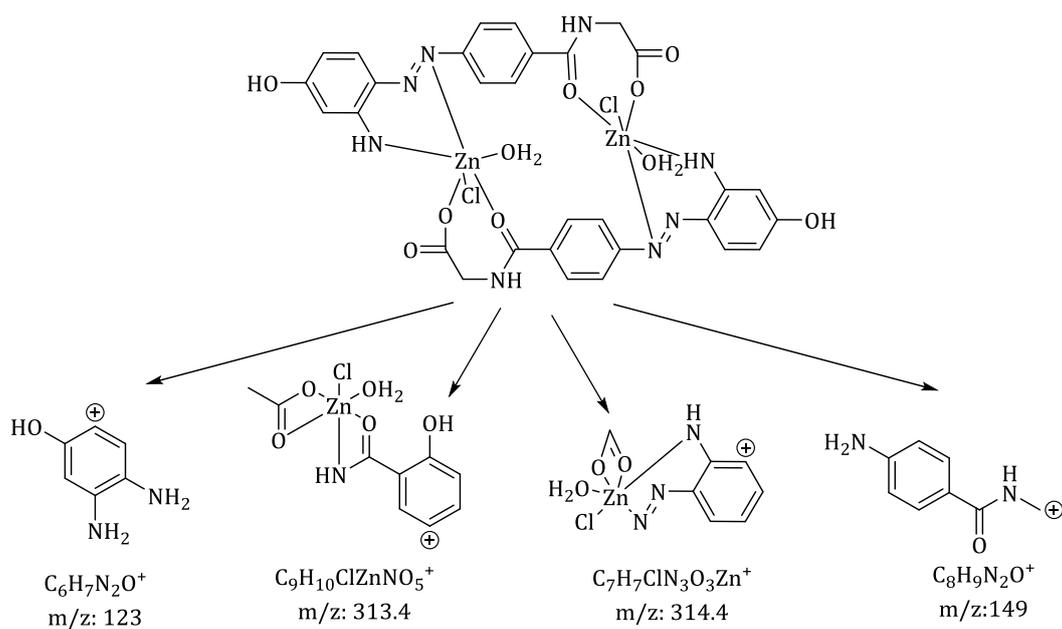
Scheme 2: Fragmentation pattern of ligand



Scheme 3: Fragmentation pattern of Cr complex



Scheme 4: Fragmentation pattern of Mn complex



Scheme 5: Fragmentation pattern of Zn complex

Infrared spectra measurements

FTIR data was used to determine the functional groups in molecules (especially organics), and it can provide indications for the creation of complexes in some cases, where coordination occurs through the changing of functional group frequencies, which have the donating atom. The spectra of azo ligands and their metal chelates complexes with Cr(III), Mn(II) and Zn(II) were gathered and organized in Table 3. Spectrum of the ligand exhibited bands at 3429 and 3275 cm^{-1} , which were assigned to stretching vibration of $\nu(\text{NH}_2)$, at the spectra of all produced compounds these bands, has been removed to lower frequency implying the coordination with metal ion [16]. The (N=N) stretching vibration was given to the band found at 1454 cm^{-1} [17] in the unbound azo ligand (LH_2). This band was discovered in the compounds' spectra around 1477-1495 cm^{-1} . The azo group of the azo ligand shifting confirmed that the azo group was involved in chelation [17,18]. Also, from the previous research it is concluded that the azo-dye nitrogen is always more likely to prefer complexation in the presence of transition metals [19]. Because of the presence of coordinated water molecules in the Cr(III) complex, it was difficult to confirm that this group was involved in chelate formation. The presence of coordinated water molecules in the coordination sphere was attributed to the occurrence of OH bands in the IR spectrum of the Cr(III) complex in the 3381 cm^{-1} , respectively. In addition, stretching vibrations in the range (833, 770 cm^{-1}) were found to correspond to $\nu(\text{M-OH}_2)$. This is strong evidence that water molecules are involved in the coordination. For the unbound ligand, the IR spectra revealed a large stretching vibration band at 3462 cm^{-1} , which could correlate to the phenolic group's OH [20]. This band suffers little displacement because it is not coordinated. When examining the spectra of all complexes by comparison with the free ligand, we found new bands that appeared only in the prepared complexes, which confirmed their successful preparation. Three bands were assigned to $\nu(\text{M-N})$, $\nu(\text{M-O})$ and $\nu(\text{M-Cl})$ in the

Cr(III) and Zn(II) complexes. Two bands were assigned to $\nu(\text{M-N})$ and $\nu(\text{M-O})$ in the Mn(II) complex [17,21,22]. Finally, it is concluded from the IR spectra of all prepared compounds that the azo-dye ligand coordinated to the metal ions through three sites nitrogen site of the azo group, amidic carbonyl and deprotonation of primary amine and oxygen site carboxylic acid group [17,22,23]. Therefore, the ligand behaved as a N,N,O,O tetradentate ligand in the Cr(III), Mn(II) and Zn(II) complexes. The spectrum of the ligand shows sharp absorption band at 1551 cm^{-1} due to $\nu(\text{C=O})$ of carboxylic group. In the produced complexes spectra, it is noticed with a slight modification in form, they moved to higher frequencies 1517-1676 cm^{-1} . These variances point to hydrogen bonding between the carboxylic group's C=O and the orthogonal OH group. The azo group was shifted toward lower frequencies in their complexes spectra, and the primary amine group appeared within the (3377-3145) cm^{-1} region. These findings can be explained by the participation of NH_2 & azo- nitrogen in coordination with metallic ions, as seen in complexes spectra [8, 17-19, 24-28].

Thermal measurements

Figures 6, 7 and 8 show the TG and DTG results of heat breakdown of the ligand LH_2 and associated metal complexes. Table 4 contains information on the thermal degradation process. The prepared compounds showed a decomposition in the thermogravimetric decomposition curve, where the ligand's thermal stability was poor at 50°C, similar to the little stability complexes in the range of (135, 100 and 30°C) for Cr(III), Mn(II) and Zn(II) complexes, respectively, indicating the presence of water molecules only in the Cr(II) complex, whether water hydrate or aqua. Table 4 shows the findings of the study. Mn(II) decompose in two stages with an unbroken residue, while the ligand decomposes in three stages with an unbroken residue. The Cr(III) and Zn(II) complexes disintegrate in one stage with an unbroken residue. This is in line with the calculated values and the formula recommended [29-33]

Table 3: The free ligand and its complexes' IR spectrum bands (cm-1)

Comp.	ν OH phenolic	ν (NH)	ν (NH ₂) amine	γ (N=N)	γ co amide	ν CO (COO-) assy.	ν CO (COO-) sym.	$\Delta\nu$	ν (H ₂ O) Coord.	Other bands
LH ₂	3421	-	3393 2937	1454	1622	1551	1397	154	-	-
[Cr ₂ Cl ₂ (H ₂ O) ₂ L ₂]	3420	3377	-	1477	1635	1576	1364	212	3381 833	ν M-N(568,525) ν M-O(474,420) ν M-Cl(376,340)
[Mn ₂ L ₂]	3422	3359	-	1495	1640	1617	1322	295	-	ν M-N(568,544) ν M-O(478,456)
[Zn ₂ L ₂ Cl ₄]	3410	3145	-	1478	1726	1649	1366	283	-	ν M-N(579,540) ν M-O(461,441) ν M-Cl(385,345)

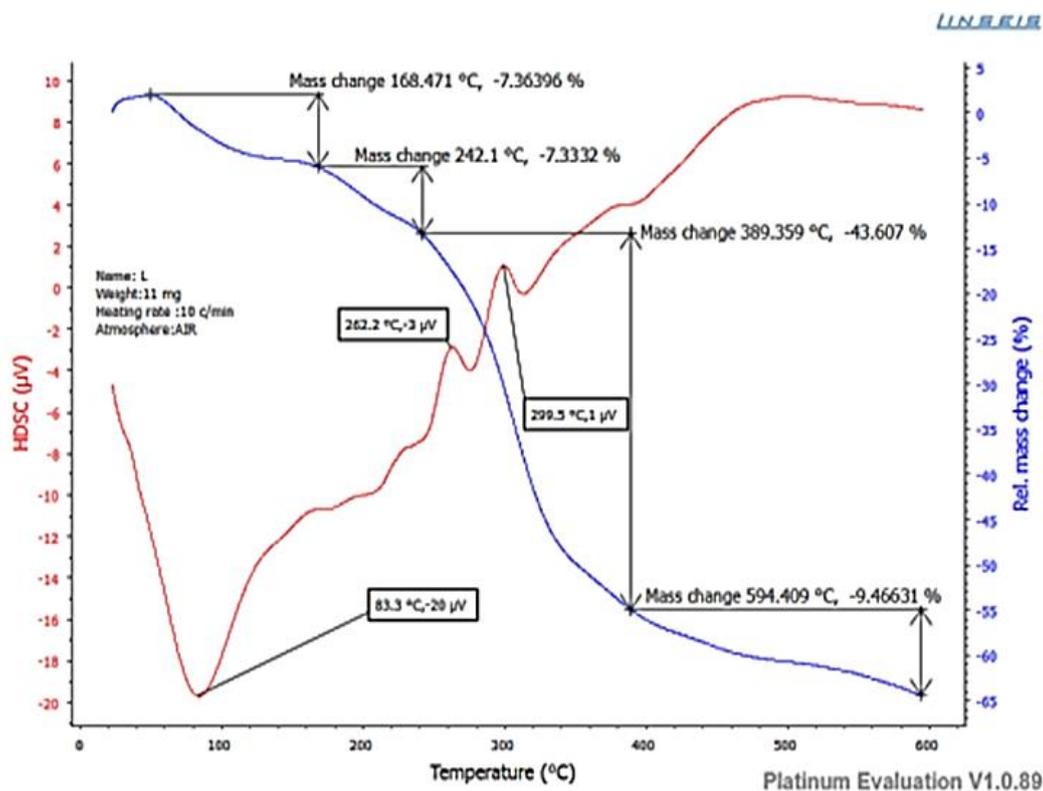


Figure 6: Thermogravimetry of Ligand

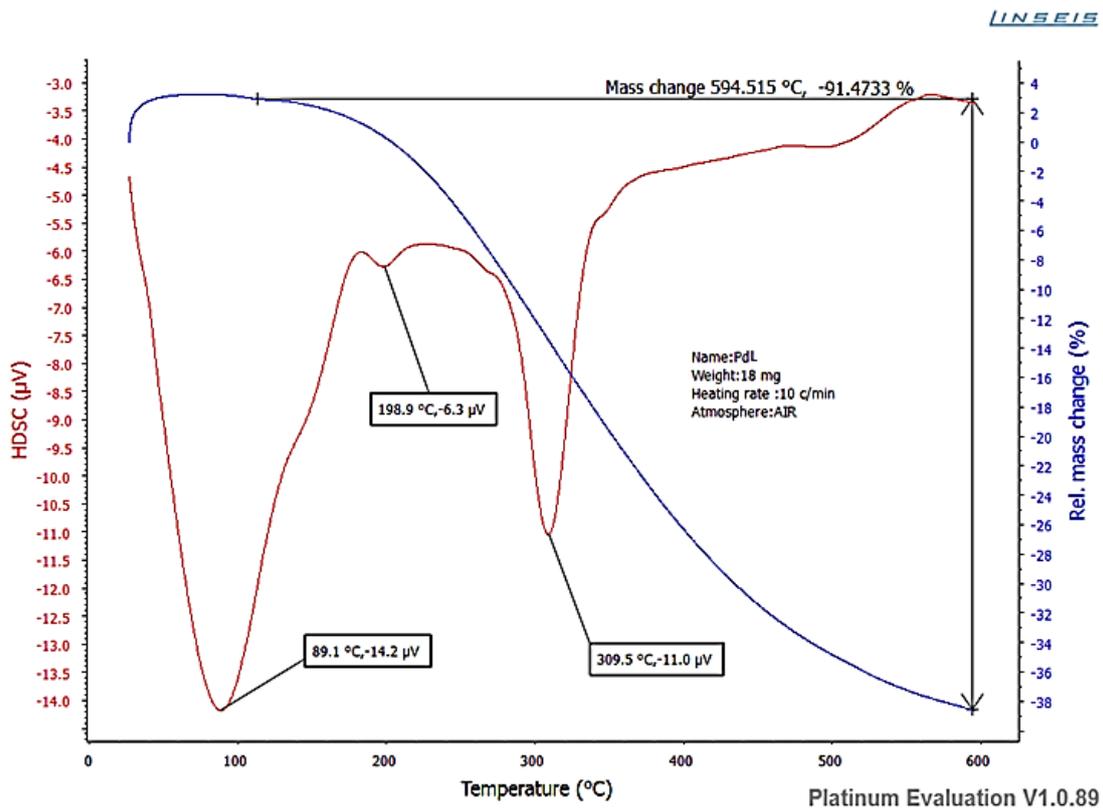


Figure 7: Thermogravimetry of Cr complex

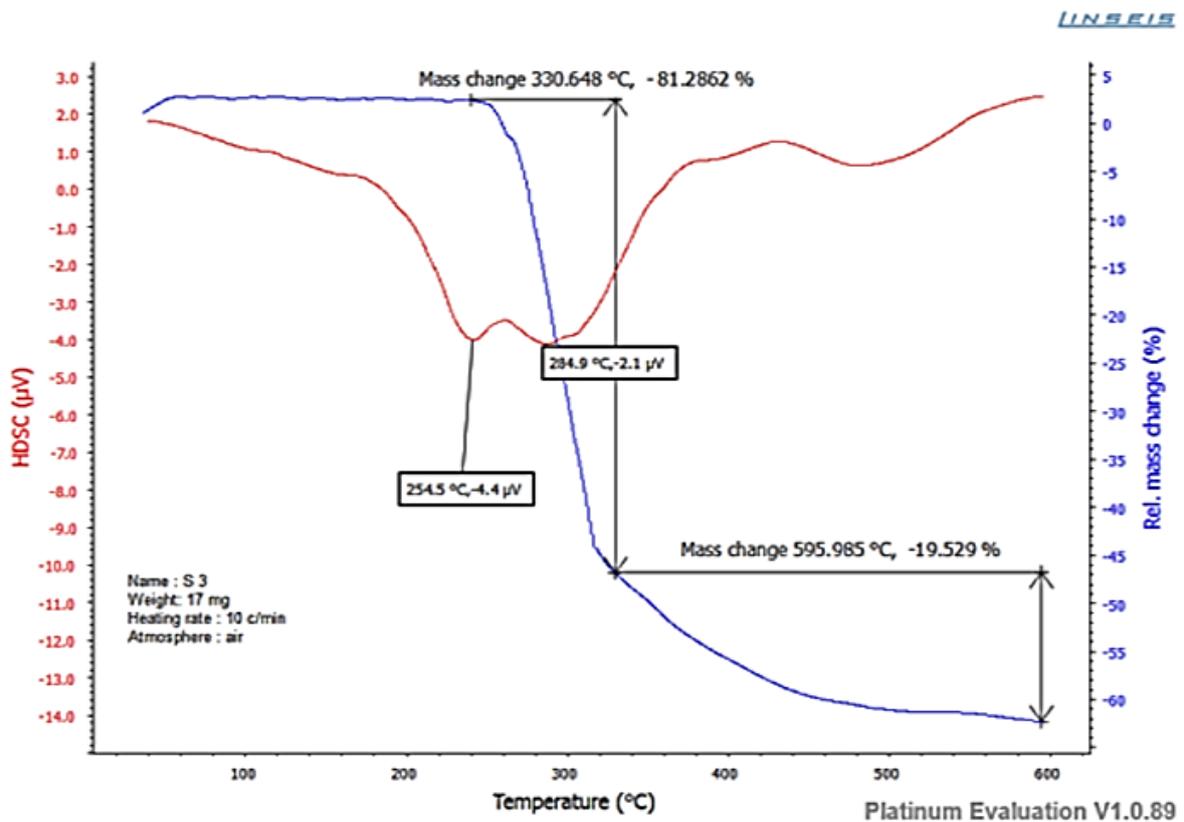


Figure 8: Thermogravimetry of Mn complex

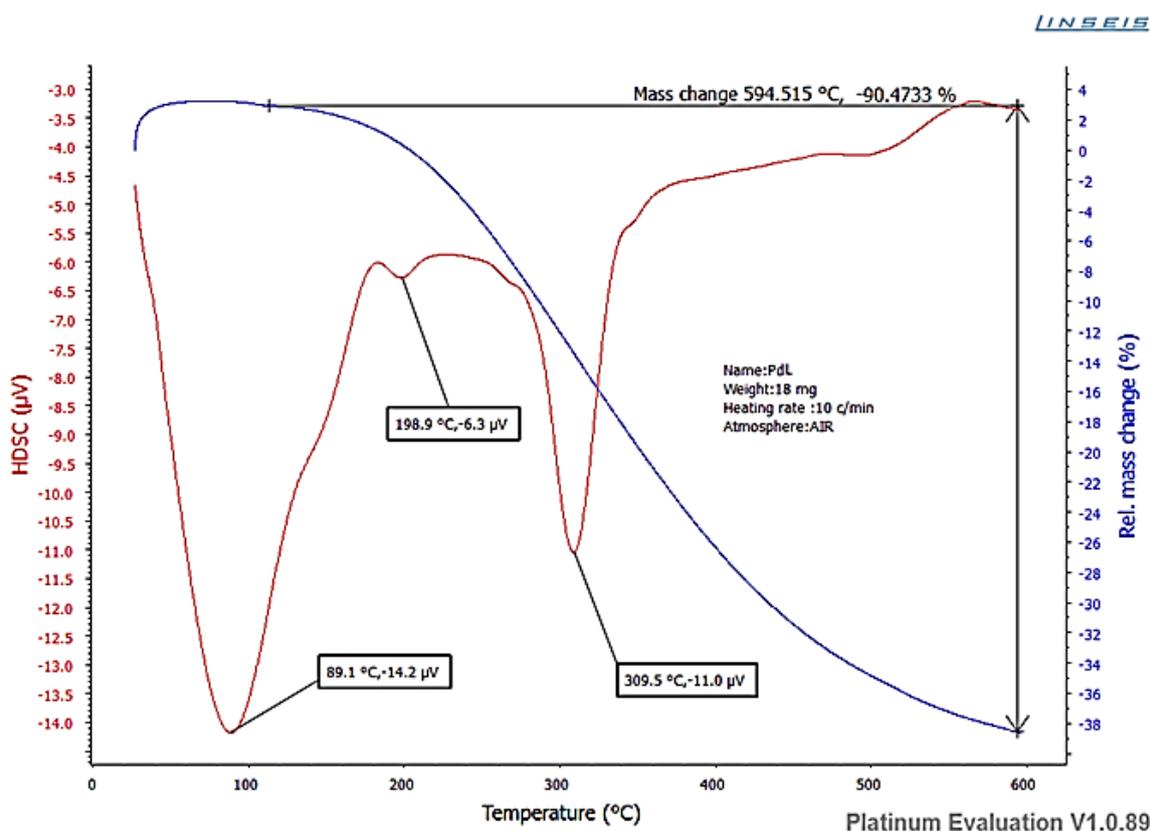


Figure 9: Thermogravimetry of Zn complex

Table 4: Thermal decomposition of Ligand and its complexes

Compound	Thermogravimetric range °C	DSC max °C	% Estimated (calculated)		Assignment
			Mass loss	Total mass loss	
(Li)	50-170 170-241 241-389 389-600	83.3(Endo) 262.2(Exo) 299.5(Exo) 390(Endo) 500(Exo)	7.3(6.5) 7.33(5.8) 43.6(45.8) 9.5(9.7) 32.13 (32.22)	92.53 (93.52)	-H ₂ O -NH ₂ -C ₇ H ₁₁ O ₂ -CHN
[Cr ₂ Cl ₂ (H ₂ O) ₂ L ₂]	30-120 120-595	89.1(Endo) 198.9(Endo) 309.5(Endo) 560(Exo)	91.47(91.86) 8.53(8.14)	91.47 (91.86)	-2H ₂ O+C ₃₀ H ₂₀ N ₈ O ₅ Cr -CrO
[Mn ₂ L ₂]	100-330 330-438 438-593	254.5(Endo) 284.9(Endo) 438(Exo)	81.29(80.65) 19.53(19.35)	100.8 (100)	-C ₃₀ H ₂₄ N ₈ O ₆ -2MnO
[Zn ₂ Cl ₄ L ₂]	30-595	209.9(Endo) 309.5(Endo) 473.0(Exo) 560.0(Exo)	86.98(86.39) 13.02(13.61)	86.98 (86.39)	- C ₃₀ H ₂₄ Cl ₄ N ₈ O ₆ (0.5ZnO) -1.5ZnO

Conclusion

Many researchers have been interested in preparing these compounds and studying their properties and effectiveness, particularly the

differences between the aromatic rings attached to the nitrogen atoms of the azo group, which may be acidic, basic, or both, and the distribution of compensated groups at different sites in the

aromatic ring relative to the azo group, such as the hydroxyl group if attached at the ortho site, which has more importance due to the azo group. Orthohydroxy azo chemicals fall into this category. We were attempting to synthesize a new azo ligand that contains numerous consistency sites and three new chelates complexes with some metallic ions, as well as characterize the ligand and its complexes using various approaches. In this study, which focused on the production of new azo compounds, fourier transform infrared (FT-IR), ¹H-NMR spectrum characterization, and CHN elemental analysis were used to validate all of the synthesized azo compounds.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

All authors contributed toward data analysis, drafting, and revising the paper and agreed to be responsible for all the aspects of this work.

Conflict of Interest

We have no conflicts of interest to disclose.

ORCID:

Rasha Khider Hussain Al-Daffay

<https://www.orcid.org/0000-0002-7708-3436>

Abbas Ali Salih Al-Hamdani

<https://orcid.org/0000-0002-2506-986X>

References

- [1]. Benkhaya S., M'rabet S., El Harfi A., *Heliyon*, 2020, **6**:e03271 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [2]. Mohammed H.S., *Bull. Chem. Soc. Ethiop.*, 2020, **34**:523 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [3]. Papić S., Peternel I., Krevzelj Ž., Kušić H., Koprivanac N., *Environ. Eng. Manag. J.*, 2014, **13**:2561 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [4]. Lomax S.Q., Lomax J.F., *Herit. Sci.*, 2019, **7**:101 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [5]. Kawther A., Asmaa S., Amira R., El-Hennawi H., *Biointerf. Res. Appl. Chem.*, 2021, **11**:11713 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [6]. Khuzaie M.G.A., Al-Majidi S.M.H., *J. Phys.: Conf. Ser.*, 2020, **2290**:030011 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [7]. Mohamed Wannas N., Al-Hamdani A.A.S., Al-Zoubi W., *J. Phys. Org. Chem.*, 2020, **33**:e4099 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [8]. Al Zoubi W., Jirjees V., Suleman V., Al-Hamdani A.A.S., Ahmed S.D., Kim Y.G., Ko Y.G., *J. Phys. Org. Chem.*, 2019, **32**:e4004 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [9]. Dahi M.A., Jarad A.J., *J. Phys.: Conf. Ser.*, 2020, **1664**:012090 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [10]. Deghadi R.G., Mahmoud W.H., Mohamed G.G., *Appl. Organomet. Chem.*, 2020, **34**:e5883 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [11]. Moamen S.R., Altalhi T., Safyah B.B., Ghaferah H.A., Kehkashan A., *Russ. J. Gen. Chem.*, 2021, **91**:890 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [12]. Alzahrani R., Althagafi I., Alsoliemy A., Abou-Melha K.S., Alrefaei A.F., Mersal G.A., El-Metwaly N., *J. Mol. Struct.*, 2021, **1243**:130855 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [13]. Karim L.K.A., Jaafar W.A., *Baghdad Sci. J.*, 2017, **14**:390 [[Google Scholar](#)], [[Publisher](#)]
- [14]. Kuate M., Conde M.A., Nchimi K.N., Paboudam A.G., Ntum S.J.E., Ndifon P.T., *Int. J. Org. Chem.*, 2018, **8**:298 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [15]. Jirjees V.Y., Suleman V.T., Al-Hamdani A.A., Ahmed S.D., *Chem. Asian J.*, 2019, **31**:2430 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [16]. Suleman V.T., Al-Hamdani A.A.S., Ahmed S.D., Jirjees V.Y., Khan M.E., Dib A., Al Zoubi W., Ko Y.G., *Appl. Organomet. Chem.*, 2020, **34**:e5546 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [17]. Nakamoto K., *Infrared and Raman Spectra of Inorganic and Coordination Compounds*, Wiley-Inter Science: New York. 1997 [[Google Scholar](#)], [[Publisher](#)]
- [18]. Kareem M.J., Al-Hamdani A.A.S., Ko Y.G., Al Zoubi W., Mohammed S.G., *J. Mol. Struct.*, 2021, **1231**:129669 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

- [19]. Obaid S.M.H., Sultan J.S., Al-Hamdani AAS. *Indones. J. Chem.*, 2020, **20**:1311 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [20]. Al-Hamdani A.A.S., Al Zoubi W., *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, 2015, **137**:75 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [21]. Al-Hamdani A.A.S., Hasan Z.A.A., *Baghdad Sci. J.*, 2016, **13**:511 [[Google Scholar](#)], [[Publisher](#)]
- [22]. Al Zoubi W., Al-Hamdani A.A.S., Ahmed S.D., Basheer H.M., Al-Luhaibi R.S., Dib A., Ko Y.G., *J. Phys. Org. Chem.*, 2018, **32**:e3916 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [23]. Lever A.B.P., *Inorganic Electronic Spectroscopy*, Elsevier Publishing Company: Amsterdam, London, 1968, p. 121, edn6 [[Google Scholar](#)], [[Publisher](#)]
- [24]. Al Zoubi W., Kim M.J., Salih Al-Hamdani A.A., Kim Y.G., Ko Y., G., *Appl. Organomet. Chem.*, 2019, **33**:e5210 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [25]. Jirjees V.Y., Al-Hamdani A.A.S., Wannas N.M., Faeqad A.R., Dib A., Al Zoubi W., *J. Phys. Org. Chem.*, 2020, **34**:e4169 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [26]. Bal S., Bal S.S., *Adv. Chem.*, 2014, **2014**: 1-12 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [27]. Samy M.E., Moamen S.R., Fawziah A.A., Reham Z.H., *Int. J. Environ. Res. Public Health.*, 2021, **18**:8030 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [28]. Kirill V.Y., Aleksandr S.S., Werner K., Sergey A.G., *Molecules*, 2020, **25**:768 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [29]. Kareem M.J., Al-Hamdani A.A.S., Jirjees V.Y., Khan M.E., Allaf A.W., Al Zoubi W., *J. Phys. Org. Chem.*, 2020, **34**:e4156 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [30]. Zoubi W.A., Al-Hamdani A.A.S., Ko Y.G., *Sep. Sci. Technol.*, 2017, **52**:1052 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [31]. Ahmadi R.A., Amani S., *Molecules*, 2012, **17**:6434 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [32]. Deghadi R.G., Mahmoud W.H., Mohamed G.G., *Appl. Organomet. Chem.*, 2020, **34**:e5883 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [33]. Al-Hamdani A.A.S., Hamoodah R.G., *Baghdad Sci. J.*, 2016, **13**:770 [[Google Scholar](#)], [[Publisher](#)]

HOW TO CITE THIS ARTICLE

Rasha Khider Hussain Al-Daffay, Abbas Ali Salih Al-Hamdani. Synthesis, Characterization and Thermal Analysis of Cr(III), Mn(II) and Zn(II) Complexes of a New Acidicazo Ligand. *Chem. Methodol.*, 2022, 6(7) 507-521
<https://doi.org/10.22034/CHEMM.2022.335777.1467>
URL: http://www.chemmethod.com/article_149179.html