

# Synthesis, Spectroscopic Identification for Mixed-Ligand Complexes and Evaluating Their Biological Effectiveness

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## ARTICLE INFO

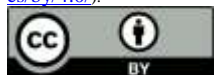
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### Keywords:

Dimidone, 1,2-dibenzothiophene, biological effectiveness, FT-IR, Mix ligand..

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## ABSTRACT

Mix ligand composed of (HL1) Dimidone and (HL2) 1,2-dibenzothiophene were allowed to react with next metal ions: Co (III), Mn (II), Fe (III), Co (II), Ni (II), Cu (II), Zn (II) and Cd (II) individually forming stable metal complexes with different geometries as indicated using various techniques. The formation of the complexes as well as the geometries of the complexes were detected by Fourier-transform-infrared, mass\_spectra, elemental analysis and electronic spectra. Moreover, the solubility of the compounds was tested in various solvents including: CHCl<sub>3</sub>, THF, DMF, DMSO, C<sub>2</sub>H<sub>5</sub>OH and H<sub>2</sub>O. Furthermore, the vital effectiveness was tested toward two types of bacteria gram negative bacteria (*Spuedomonas* & *E.Coli*) and positive bacteria (*Staph. Aureas* & *Bacillus*) and two types of fungi (*Aspergillus niger* & *Fuzaium*) giving different inhibition values (either effective or noneffective) as detailed in the manuscript.

## 1. INTRODUCTION

The mixed ligand complexes derived from the bioactive potent ligands containing N, O donor binding sites with M(II) ions are used in a number of fields like biological, analytical, agricultural industrial and therapeutic applications<sup>(1,2)</sup>. Metal ions are fundamental elements for healthy life to human and higher animals<sup>(3)</sup> particularly the late first row transition metals such as, cobalt, nickel, copper and zinc are biologically relevant metals as they are associated with various biomolecules related to essential physiological activities. Metal complexes of biologically important ligands were sometimes more effective than free ligands<sup>(4)</sup>. It was not surprising; therefore, that many authors have studied the coordination compounds of several central atoms. Mixed ligand complexes had a key role in biological chemistry<sup>(5)</sup> because the mixed chelation occurs commonly in biological fluids as millions of potential ligands were likely to compete for metal ions in-vivo<sup>(6)</sup>.

These create specific structures<sup>(7)</sup> and have been implicated in the storage and transport of active substances through membranes. The transition metal complexes with oxygen donors are applied in various activities such as anticancer, antibiotic, antimicrobial and antifungal agents. Many of the metals such as Cu<sup>2+</sup>, Co<sup>2+</sup> and Ni<sup>2+</sup> have found widespread application in organic synthesis and biology<sup>(8)</sup>. In this recent work, we describe the synthesis of mixed-ligand derived from dimedone and 1,2-dibenzothiophene with next transition metal salts: Co (III), Mn (II), Fe (III), Co (II), Ni (II), Cu (II), Zn (II) and Cd (II). The ligand and its mixed-ligand complexes are diagnosed using elemental\_analysis, fourier transform-infrared, mass\_spectra, magnetic susceptibility measurements, molar conductivity and electronic spectra to elucidate the molecular structure of the ligand transition metal.

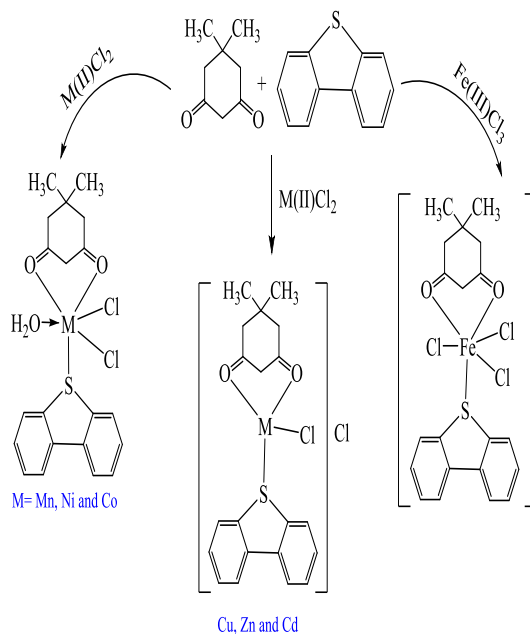
## 2. MATERIALS AND METHODS

### 2.1 Instrumentation & Chemicals:

All the starting materials, chemicals and solvents for the prepared compounds were of analytical grade. Abs. EtOH, MeOH, dimethylsulfoxide and other solvents were of high purity and supplied by Merck Co.,

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Fluka Co. and Sigma-Aldrich Co., Dimedon, 1,2-dibenzothiophene and metal salts [FeCl<sub>3</sub>, ZnCl<sub>2</sub>, CoCl<sub>2</sub>.6H<sub>2</sub>O, MnCl<sub>2</sub>.4H<sub>2</sub>O, NiCl<sub>2</sub>.6H<sub>2</sub>O, CuCl<sub>2</sub>.2H<sub>2</sub>O and CdCl<sub>2</sub>.H<sub>2</sub>O] were supplied by Sigma-Aldrich Co. and BDH Co., The melting point of the prepared ligands and complexes were measured by a Stuart electrothermal melting point apparatus. The elemental (H, N, O, S, C) micro-analysis, to search using the EA 3000 single V.3 model vector device. LC-MSQP50A(E170ev) Shimadzu device. Infrared spectra were measured with a device (Shimadzu-8000S) and the ultraviolet-visible spectra of the ligand and its complexes were recorded using a Shimadzu UV-Visible Spectrophotometer. Molar electrical conductivity measurements were carried out using BC3020 Professional Bench Top Conductivity device.



Scheme 1. Synthesis of complexes

## Complex preparation

### 2.2 Synthesis of Complexes:

(0.237 g, 1mmol.) from CoCl<sub>2</sub>. 6H<sub>2</sub>O dissolved in 10 mL of absolute EtOH placed in round bottomed flask (100 mL in size) with heating to perform the dissolving. Both ligands (HL1) Dimidone (0.140 g, 1mmol.) and (HL2) 1,2-dibenzothiophene (0.184 g, 1mmol.) were dissolved in 20 mL of EtOH and added immediately to cobalt salt solution. After reflux for one hour at 50 °C, the mixture was cooled until precipitates, then filtered, dried and recrystallized using absolute ethanol (1:1:1). Other metal complexes were synthesized in the same approach that followed with cobalt complex using their corresponding chloride metal salt for the next metal ions: Mn(II), Fe(III), Co(II), Ni(II), Cu(II), Zn(II), Cl(II) as detailed in table 1 and illustrated in scheme 1.

Scheme 1. Synthesis of complexes

Table (1) Weights of metal salts and some physical properties of the resulting complexes

Metal Salt	Weight of salt (mmole 1g)	Complex	Yield%	Color	M.P.C Decomposit ion
MnCl <sub>2</sub> .H <sub>2</sub> O	0.197	[MnL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	70	Yellow	212 – 214
FeCl <sub>3</sub>	0.162	[FeL <sub>1</sub> L <sub>2</sub> Cl <sub>3</sub> ]	72	Dark brown	298 – 301
CoCl <sub>2</sub> .6H <sub>2</sub> O	0.237	[CoL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> .H <sub>2</sub> O]	65	Purple	280 – 283
NiCl <sub>2</sub> .6H <sub>2</sub> O	0.237	[NiL <sub>1</sub> L <sub>2</sub> Cl <sub>3</sub> .H <sub>2</sub> O]	49	Yellow	410 – 412

CuCl <sub>2</sub> .2H <sub>2</sub> O	ZnCl <sub>2</sub>	CdCl <sub>2</sub> .H <sub>2</sub> O
0.170	0.136	0.201
[CuL <sub>1</sub> L <sub>2</sub> Cl]Cl	[ZnL <sub>1</sub> L <sub>2</sub> Cl]Cl	[CdL <sub>1</sub> L <sub>2</sub> Cl]Cl
63	47	60
Green	Pale Yellow	Pale Yellow
300 – 303	289 – 291	288 – 290

### 3. RESULTS AND DISCUSSION

#### Spectroscopic studies

**FT-IR Spectroscopy:** According to FT-IR spectroscopy we can indicate about the formation of new complexes depending on the modifications that observed in the spectra of those complexes when compared with the spectra of each ligand individually. Those modifications may include change in the shape or intensities of the main bands or include shift in their wavelengths toward lower or higher wavelengths. In figure 1(a), (HL1) ligand gave the next stretching absorption bands: weak – strong band at 3029 cm<sup>-1</sup> for the vibration of C-H aromatic group, weak band at 2929 cm<sup>-1</sup> belongs to C-H aliphatic group and moderate, sharp band at 1695 cm<sup>-1</sup> for the vibrational mode of carbonyl group and bending absorption band for CH<sub>3</sub> group at 1421 cm<sup>-1</sup>. Figure 1(b) for ligand (HL2) (1,2-dibenzothiophene) demonstrates the next absorption peaks: weak stretching absorption band of C-H aromatic group at 3088 cm<sup>-1</sup>, stretching absorption band of C=C at 1688 cm<sup>-1</sup> <sup>(9,10)</sup>. Figures 2 (a & b) for manganese complex demonstrates the same bands that found in both ligands in addition to the modifications in some bands because of the occurrences of coordination through these groups, those are C=O observed at 1634 cm<sup>-1</sup>. Moreover, new absorption peaks are detected those are aqua water molecule, M-S, M-O and M-Cl as detailed in table 2 <sup>(11)</sup>. Same characterization <sup>(12)</sup> in figures (3, 4, 5,

6, 7 and 8) can be applied for the rest of the complexes as detailed in table 2.

Table (2) FT-IR spectral incomes of ligands and their complexes

[FeL <sub>1</sub> L <sub>2</sub> Cl <sub>3</sub> ]	[CoL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> .H <sub>2</sub> O]	[NiL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> .H <sub>2</sub> O]	[MnL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> .H <sub>2</sub> O]	1,2-dibenzothiophene (HL <sub>2</sub> )	Dimedone (HL <sub>1</sub> )	Comp. Symb.
-	3373 b 1597 msh	3365 b 1600 msh	3371 b 1587 msh	--	--	v(H <sub>2</sub> O)
1616 wsh	1621 wsh	1624 wsh	1634 Msh	--	1695 m, sh	v(C=O)
3047 w	3050 w	3029 w	3071 w	3088 w	3029 w	v(C-H) Arom.
2922 Msh	2900 W	2930 W	2937 W	--	2929 w	v(C-H) Alipha.
516, 460 Ws	572, 420 w,w	592, 564 462 w, w, w	529, 472 w, w	--	--	M-O
		380,405 wsh	375,380 wsh	--	--	M-S
		345 msh	350 msh	--	--	M-Cl

[CuL <sub>1</sub> L <sub>2</sub> Cl]Cl	[ZnL <sub>1</sub> L <sub>2</sub> Cl]Cl	[CdL <sub>1</sub> L <sub>2</sub> Cl]Cl
.	.	.
1626 msh	1627 msh	1625 ssh
3055 w	3053 W	3088 b
2920 Wsh	2920 Wsh	2926 W
538, 435 wsh, w	582, 435 w, wsh	495, 424 Wsh
	380 B	380 wsh
	345 W	345 msh

**UV-Vis Spectroscopy:** Ultra violet spectrum of (HL1) ligand dimedone in figure 9, demonstrates moderately broad absorption band at (271 nm, 36900 cm<sup>-1</sup>) belongs to ( $\pi \rightarrow \pi^*$ ) electronic transition, whereas the spectrum of ligand (HL2) (1,2-dibenzothiophene) in figure 10 demonstrates three absorption bands at (272 nm, 36764 cm<sup>-1</sup>) corresponds to ( $\pi \rightarrow \pi^*$ ) electronic transition, (301 nm, 33222 cm<sup>-1</sup>) and (329 nm, 30395 cm<sup>-1</sup>) both corresponding to ( $n \rightarrow \pi^*$ ) electronic transition<sup>(13)</sup> as illustrated in table 3. Figure 11 demonstrates the spectrum of copper complex and the next transitions: ( $\pi \rightarrow \pi^*$  and  $n \rightarrow \pi^*$ ) + C. T M  $\rightarrow$  L at (255 nm, 39215 cm<sup>-1</sup>) and (298 nm, 33557 cm<sup>-1</sup>), the transitions of ligands with some shifting in their wavelengths because of coordination with metal. In addition to d-d transition at visible region (419 nm, 23866 cm<sup>-1</sup>)<sup>(14)</sup>. The UV-Vis spectra of the rest complexes illustrate the same absorption bands that found in ligands at ultra violet region with some modifications including shifting in their absorption bands because of the coordinative binding with metal ion. Moreover, those spectra illustrate new absorption peaks at visible region which in turn belonging to d-d transitions<sup>(14)</sup> as demonstrated in figures (12  $\rightarrow$  17) and table 3.

### Magnetic Susceptibility

At a temperature of 25 °C, the Faraday method was used to determine the magnetic sensitivity of the

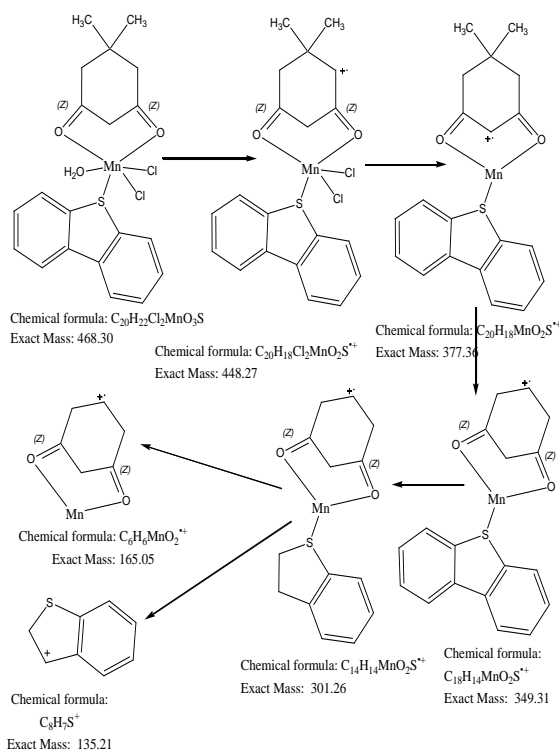
solid states. The oxidation state and electronic configuration of the transition metal atoms are inferred from measurements of the magnetic characteristics. Therefore, whether a compound has low-spin or high-spin is determined by the number of single electrons that make up a transition metal ion<sup>(22,23)</sup>. The magnetic moment for the manganese (II) complex has been measured to be equal to (5.86B.M), whereas the magnetic moment for the iron complex was measured to be (5.80B.M). All complexes have highly twisted octahedral geometries, which are compatible with the magnetic moment of cobalt, which was measured to be (3.96B.M). The lists of magnetic sensitivity values of atoms in organic molecules (Pascal's constants) were used<sup>(24)</sup>, and the values of magnetic moments were fixed in Table (4).

Table (3) UV-Vis incomes of mix ligands and their complexes

Compounds	$\lambda$ nm	ABS	$\epsilon$ (cm <sup>-1</sup> )	$\epsilon$ L.mol <sup>-1</sup> cm <sup>-1</sup>	Assignment	$\Delta m$ (S.cm <sup>2</sup> .Mol <sup>-1</sup> )	Geometry
Dimedone (HL <sub>1</sub> )	271	3.311	36900	3311	$\pi \rightarrow \pi^*$	:	:
1,2-dibenzothiophene (HL <sub>2</sub> )	329 301 272	1.500 1.001 0.489	30395 33222 36764	1500 1001 489	$n \rightarrow \pi^*$ $n \rightarrow \pi^*$ $\pi \rightarrow \pi^*$	:	:
[CuL <sub>1</sub> L <sub>2</sub> Cl]Cl	419 298 255	0.557 2.395 2.663	23866 33557 39215	557 2395 2663	$^2T_2 \rightarrow ^2E$ $n \rightarrow \pi^*$ M $\rightarrow$ L CT $\pi \rightarrow \pi^*$	44	Tetrahedral

[ZnL <sub>1</sub> L <sub>2</sub> Cl]Cl	382 307	0.478 0.329	26178 32573	478 329	n→π*, M→LCT π→π*	41	Tetrahedral
[CdL <sub>1</sub> L <sub>2</sub> Cl]Cl	397 309 269	0.789 1.426 0.675	25188 32362 37174	789 1426 675	M→LCT n→π* π→π*	49	Tetrahedral
[CoL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	778 643 423 291	0.078 0.071 0.801 0.514	12853 15552 23640 34364	780 710 8010 5140	<sup>4</sup> T <sub>1g</sub> → <sup>4</sup> A <sub>2g</sub> <sup>4</sup> T <sub>1g</sub> → <sup>4</sup> T <sub>1g</sub> (P) n→π*, M→LCT π→π*	10	Octahedral
[MnL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	596 582 501 461 301	0.273 0.293 0.286 0.288 0.601	16778 17182 19960 21691 33222	273 293 286 288 601	<sup>6</sup> A <sub>1g</sub> → <sup>6</sup> T <sub>1g</sub> (G) <sup>6</sup> A <sub>1g</sub> → <sup>4</sup> T <sub>1g</sub> (G) <sup>6</sup> A <sub>1g</sub> → <sup>4</sup> A <sub>1g</sub> , <sup>6</sup> E <sub>g</sub> M→LCT π→π*	9	Octahedral
[NiL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	756 596 306	0.657 0.732 2.893	13227 16778 32679	657 732 2893	<sup>3</sup> A <sub>2g</sub> → <sup>3</sup> T <sub>1g</sub> (F) <sup>3</sup> A <sub>2g</sub> → <sup>3</sup> T <sub>1g</sub> (P) M→LCT, n→π*	15	Octahedral
[FeL <sub>1</sub> L <sub>2</sub> Cl <sub>3</sub> ]	768 681 392 301	0.018 0.012 0.653 0.546	13020 14684 25510 33222	180 120 6530 5460	<sup>6</sup> A <sub>1g</sub> → <sup>4</sup> T <sub>1g</sub> (G) <sup>6</sup> A <sub>1g</sub> → <sup>4</sup> T <sub>1g</sub> (G) M→LCT n→π*	16	Octahedral

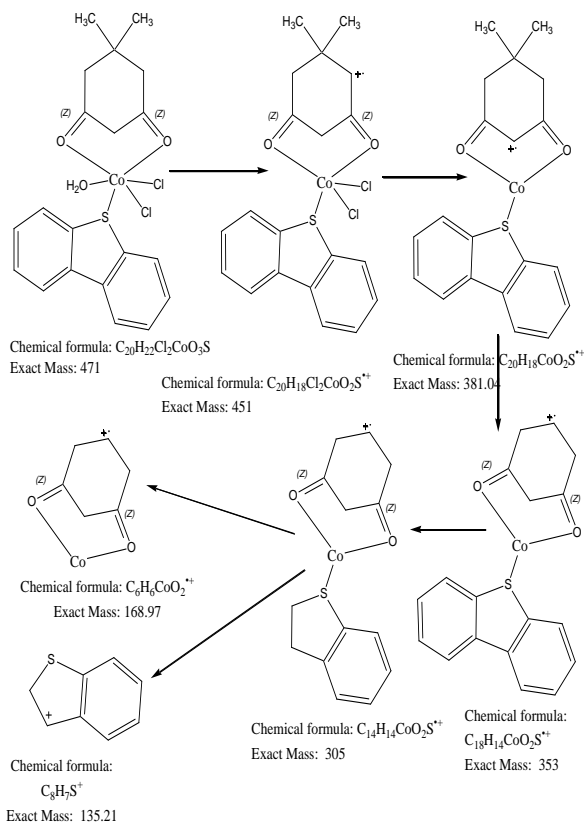
the complex. As for copper complex in Figure 20 and scheme 4 illustrates the molecular ion peak (M+) C<sub>20</sub>H<sub>20</sub>SCl<sub>2</sub>CuO<sub>2</sub> at 422.44 m/z results from the partitioning of the complex. In addition, the spectrum of cadmium complex in Figure 21 and scheme 5 gave the main peak (M+) C<sub>20</sub>H<sub>20</sub>SCl<sub>2</sub>CdO<sub>2</sub> at 472.99 m/z.



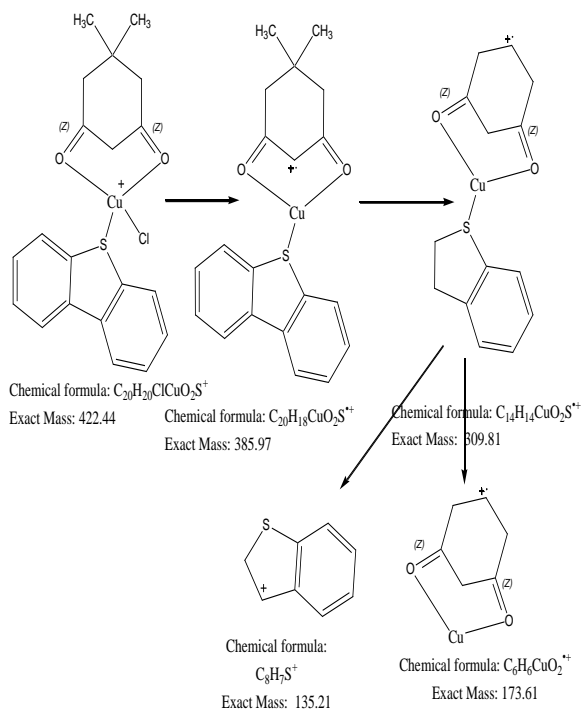
Scheme 2. Fragmentation analogues of manganese complex

### LC-Mass spectroscopy:

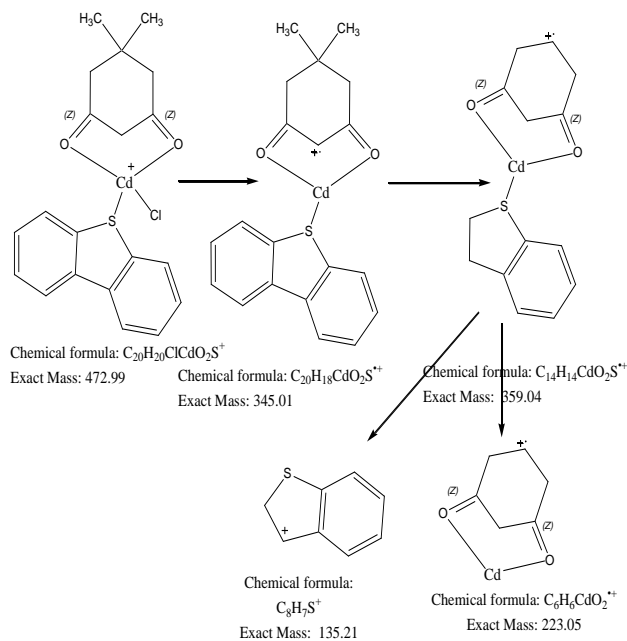
The LC-Mass spectra of the complexes gave compatible results with theoretical results when observe the obtained molecular formulas for each complex and comparing it with the calculated formula. Figure 18 and scheme 2 for manganese complex demonstrates the molecular ion peak (M+) for the formula C<sub>20</sub>H<sub>22</sub>SCl<sub>2</sub>MnO<sub>3</sub> at 468.30 m/z which corresponds to the molecular weight of the complex. Figure 19 and scheme 3 for cobalt complex demonstrates the molecular ion peak (M+) for the formula C<sub>20</sub>H<sub>22</sub>SCl<sub>2</sub>CoO<sub>3</sub> at 471 m/z which corresponds to the molecular weight of



Scheme 2. Fragmentation analogues of cobalt complex



Scheme 2. Fragmentation analogues of copper complex



Scheme 5. Fragmentation analogues of cadmium complex

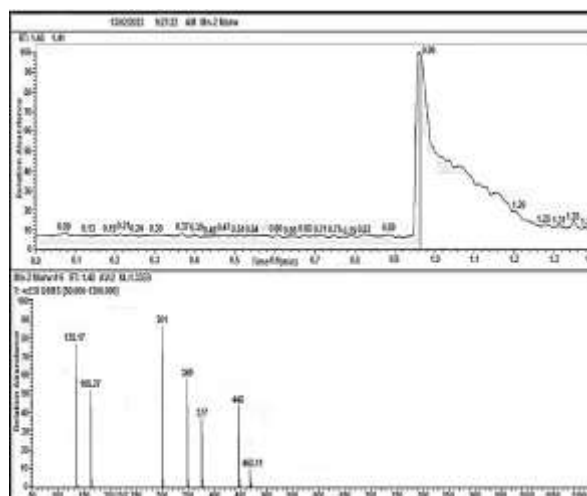


Figure 1. LC-Mas spectrum of manganese complex

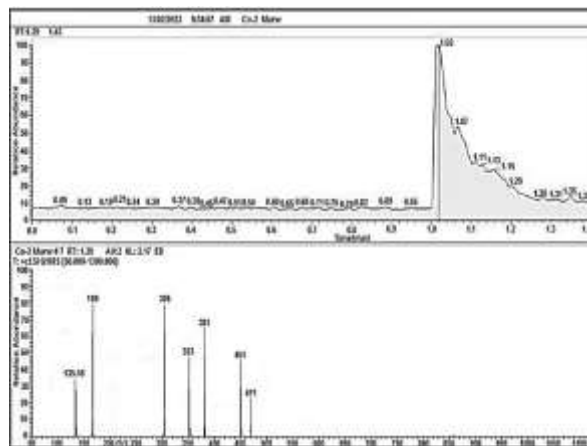


Figure 2. LC-Mas spectrum of cobalt complex

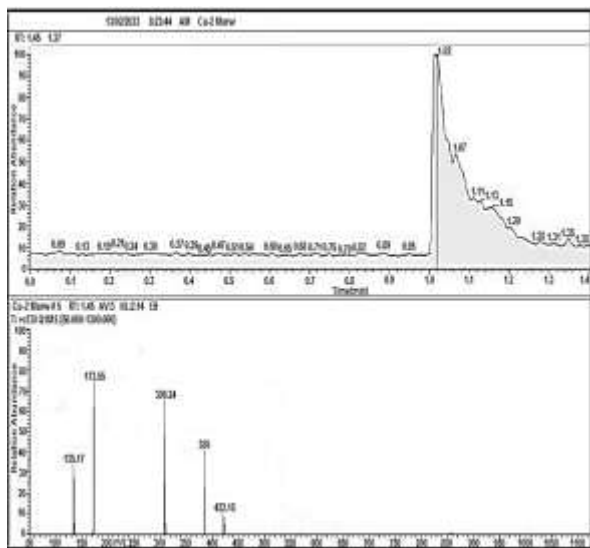


Figure 3. LC-Mas spectrum of copper complex

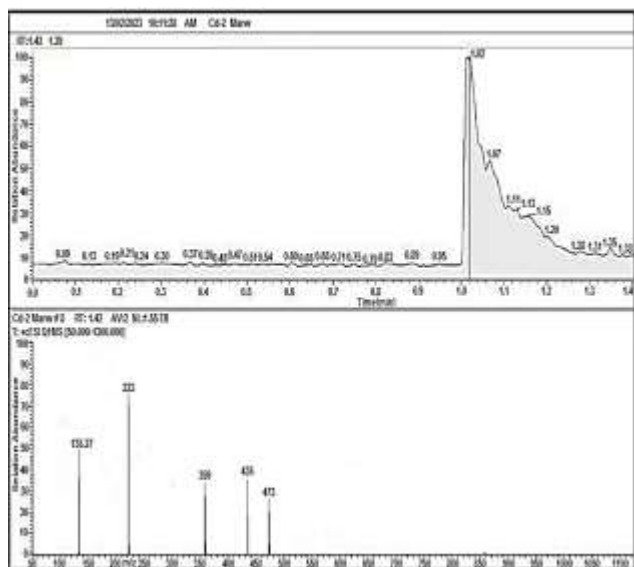


Figure 4. LC-Mas spectrum of cadmium complex

**Elemental-micro-analysis (C. H. N. O. S) diagnosis:**

The percentage for each element in synthesized complexes and also chloride involvement and metal ratio were estimated technically and calculated theoretically, then comparing the results. All estimated results were in good agreement with the theoretical results<sup>(15)</sup> as illustrated in table 4.

**antibacterial activity inhibition:**

The inhibition effectiveness for the compounds in this work were tested against gram negative bacteria (Spuedomonas & E.Coli) and positive bacteria (Staph. Aureas & Bacillus) and two types of fungi (Aspergillus niger & Fuzaium). The samples of the cultivated

complexes showed varying results in terms of the zone of inhibition, and some of them showed ineffectiveness in inhibiting the growth of bacteria or fungi according to the concentrations prepared<sup>(16)</sup> as shown in Tables 5 and 6, the inhibition values of the complexes according to the concentration prepared, as well as Figures 5 show the zones of inhibition for bacteria and fungi.

Table 4. Elemental analysis incomes of the complexes

Compounds (M. wt)	Element micro analysis %, Estimated & (calculated)						
	C	H	N	O	S	Cl	M
$C_{20}H_{22}SCl_2NiO_3$ (472.05)	49.94 (50.89)	3.88 (4.70)	-- --	11.11 (10.17)	7.04 (6.79)	14.72 (15.02)	13.31 (12.43)
$C_{20}H_{22}SCl_2CoO_3$ (472.29)	49.94 (50.86)	3.84 (4.70)	-- --	11.12 (10.16)	5.84 (6.79)	16.00 (15.01)	13.26 (12.48)
$C_{20}H_{20}SCl_2ZnO_2$ (460.73)	51.15 (52.14)	3.52 4.38	-- --	5.99 (6.95)	7.66 (6.96)	16.60 (15.39)	15.08 (14.19)
$C_{20}H_{20}SCl_2CuO_2$ (458.89)	51.58 (52.35)	4.11 (4.39)	-- --	7.08 (6.97)	6.70 (6.99)	16.11 (15.45)	14.42 (13.85)
$C_{20}H_{22}SCl_2MnO_3$ (468.30)	50.49 (51.30)	3.77 (4.74)	-- --	11.04 (10.25)	7.85 (6.85)	14.84 (15.14)	12.01 (11.73)
$C_{20}H_{20}SCl_2CdO_2$ (507.75)	48.01 (47.31)	4.09 (3.97)	-- --	6.89 (6.30)	5.39 (6.32)	14.38 (13.96)	21.24 (22.14)

$C_{20}H_{20}S_2Cl_3FeO_2$ (449.51)	50.11 (49.36)	4.72 (4.14)	-- --	5.73 (6.58)	6.89 (6.59)	20.91 (21.86)	11.64 (11.48)
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Table 5. the bacterial inhibition values of the complexes

Sample	mg/ml	Gram positive		Gram negative	
		<i>Staph. aureus</i> Inh. zone cm	<i>Bacillus</i> Inh. zone cm	<i>Spuedomonas</i> Inh. zone cm	<i>E. Coli</i> Inh. zone cm
[ZnL <sub>1</sub> L <sub>2</sub> Cl]Cl	0.033	-ve	-ve	0.8	-ve
[CuL <sub>1</sub> L <sub>2</sub> Cl] Cl	0.02	2	3	3.5	1.7
[MnL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	0.025	-ve	-ve	-ve	-ve
[CoL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	0.019	-ve	-ve	-ve	-ve
[CdL <sub>1</sub> L <sub>2</sub> Cl]Cl	0.0075	3.5	3.5	2.5	2
[FeL <sub>1</sub> L <sub>2</sub> Cl <sub>3</sub> ]	0.0178	-ve	-ve	1	-ve
[NiL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	0.015	-ve	-ve	1.5	-ve

Inh. = inhibition

Table 6. the fungal inhibition values of the complexes

Sample	mg/ml	<i>Aspergillus niger</i>	<i>Fuzaium</i>
		growth cm	growth cm
[CuL <sub>1</sub> L <sub>2</sub> Cl] Cl	0.02	-ve	-ve
[MnL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	0.0 25	-ve	-ve
[CoL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	0.019	-ve	-ve
[CdL <sub>1</sub> L <sub>2</sub> Cl]Cl	0.0048	-ve	-ve
[ZnL <sub>1</sub> L <sub>2</sub> Cl]Cl	0.008	-ve	-ve
[FeL <sub>1</sub> L <sub>2</sub> Cl <sub>3</sub> ]	0.0178	-ve	-ve
[NiL <sub>1</sub> L <sub>2</sub> Cl <sub>2</sub> H <sub>2</sub> O]	0.015	-ve	-ve

### Conclusion:

The synthesis of stable mixed-ligand complexes was carried out successfully using dimedone (HL1) and (HL2) 1,2-dibenzothiophene with next metal salts: Co (III), Mn (II), Fe (III), Co (II), Ni (II), Cu (II), Zn (II) and Cd (II) individually. The interaction of metal ions was carried out through oxygen atoms of (HL1) ligand and sulfur atom of (HL2) ligand. This binding was indicated by FT-IR spectra of the compounds by noticing M-O and M-S bands. Those spectra are also indicated the binding of aqua water molecule and chloride molecules. According to electronic spectra and molar conductivity measurements we could prove the obtained shapes of the complexes either octahedral or tetrahedral. LC-Mass spectra, the fragmentation

analogues of the complexes and also elemental analysis proved the gained molecular formulas. Finally, the inhibitory action of the compounds was tested toward bacteria and fungi giving variable effects as detailed in the manuscript.

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## تحضير وتشخيص معقدات والتحديد الطيفي لخليط المعقدات الليكاند وتقييم فعاليتها البيولوجية

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### الخلاصة:

اتجهت الدراسة المقدمة الى تحضير معقدات جديده بالسماح لخليط الليكاند المكون من (HL1) ديميدون و1,2 (HL2)-ثنائي بنزو ثيوفين بالتفاعل مع أيونات المعادن التالية: (Co (III)، Mn (II)، Fe (III)، Co (II)، Ni (II) و Cu (II) و Zn (II) و Cd (II) يشكلون بشكل فردي مجاميع معدنية مستقرة ذات أشكال هندسية مختلفة كما هو موضح باستخدام تقنيات مختلفة. تم الكشف عن تكوين المجاميع وكذلك الأشكال الهندسية للمعقدات بواسطة تحويل الأشعة تحت الحمراء، أطياف الكتلة، التحليل العنصري والأطياف الإلكترونية. علاوة على ذلك، تم اختبار ذوبان المركبات في مذيبات مختلفة منها: THF، CHCl<sub>3</sub>، DMF، DMSO، C<sub>2</sub>H<sub>5</sub>OH و H<sub>2</sub>O. علاوة على ذلك، تم اختبار الفعالية الحيوية تجاه نوعين من البكتيريا البكتيريا سالبة الجرام (Spuedomonas & E.Coli) والبكتيريا الإيجابية (Staph. Aureas & Bacillus) ونوعين من الفطريات (Aspergillus niger & Fuzaium) تعطي قيم تثبيط مختلفة (سواء كانت فعالة) أو غير فعالة) كما هو موضح في البحث.

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