

# Mixed Ligand Complexes of Fe(III), Co(II), Ni(II), and Cu(II) with 3-Acetyl-4-hydroxy-6-methyl-2-pyrone and 1,3,4-Thiadiazole-2,5-dithiol

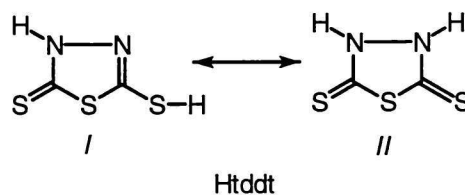
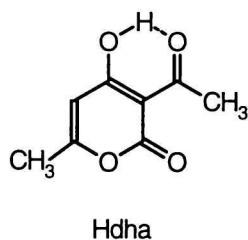
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The binary complexes of Fe(III), Co(II), Ni(II), and Cu(II) with 3-acetyl-4-hydroxy-6-methyl-2-pyrone (Hdha) react readily with 1,3,4-thiadiazole-2,5-dithiol (Htdtd) affording dithiolato mixed ligand complexes of the types  $[\text{Fe}(\text{dha})_2(\text{Htdtd})]$  and  $[\text{M}(\text{dha})(\text{Htdtd})(\text{tdtd})]$ , where M = Co, Ni or Cu, by the substitution of one Hdha molecule by two Htdtd ligands. The prepared complexes were characterized by elemental analysis, electronic and IR spectra as well as TGA and conductivity measurements. Distorted octahedral or square planar geometry was suggested for the mixed ligand complexes. It is observed that some of the thiolato complexes are more potent as bacteriostatic agents than the parent binary complexes.

In the study of transition metal complexes having biological and industrial applications [1, 2], 3-acetyl-4-hydroxy-6-methyl-2-pyrone (dehydroacetic acid, Hdha) appeared as an attractive ligand. Some transition metal complexes derived from Hdha were reported and proved to be valuable as fungistatic agents [3, 4]. On the other hand, a growing interest is being evidenced in the study of mixed ligand complexes which might serve as models for biochemical reactions [5]. Among those it is thought that complexes involving both dha and thiolate ligands could be of interest. Therefore, in the present paper, we used 1,3,4-thiadiazole-2,5-dithiol (Htdtd) as secondary ligand since it is reported that mono- and disubstituted thiadiazoles have pharmacological applications [6–8]. The ligands used have the following structures



## EXPERIMENTAL

The solvents used were of anal. grade. Metal salts  $\text{Fe}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ ,  $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ ,  $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ , and  $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$  were of general purpose reagent grade. Dehydroacetic acid and 1,3,4-thiadiazole-2,5-dithiol were purchased from Sigma and used without further purification.

The electronic spectra were recorded on a Pye—Unicam SP-550 UV VIS spectrophotometer using 1-cm matched silica cells. The IR spectra were obtained as KBr discs using a Pye—Umicam SP3-100 spectrophotometer. Conductivity measurements were carried out using an LF DIGI conductance bridge. Spectroscopy and conductivity measurements were carried out at room temperature ( $\approx 25^\circ\text{C}$ ).

TGA was made using a Mettler TC10A thermal analyzer. Magnetic susceptibility measurements were made at room temperature on the usual Gouy bal-

ance system. Mercury tetrathiocyanatocobaltate(II) was used as the calibrant and diamagnetic corrections were estimated from Pascal's constants.

### Binary Complexes

Bis(dehydroacetato)M(II) complexes, where M = Ni or Cu were prepared according to the literature procedure [3]. Bis(dehydroacetato)diaquocobalt(II) and tris(dehydroacetato)diaquoirron(III) were prepared by mixing the metal salt (2 mmol) dissolved in 50 cm<sup>3</sup> of water—ethanol ( $\varphi_r = 1 : 1$ ) with an ethanolic solution (30 cm<sup>3</sup>) containing two and three equivalents of Hdha for Co(II) and Fe(III) complexes, respectively. To the stirred mixture an aqueous 0.1 M-NH<sub>4</sub>OH solution was added dropwise until pH = 4.5 and pH = 8.2 for both Co(II) and Fe(III) complexes, respectively, whereby a solid was precipitated. This was filtered off, washed with cold ethanol, ether and dried *in vacuo* over P<sub>4</sub>O<sub>10</sub>.

### Mixed Ligand Complexes

**Fe(dha)<sub>2</sub>(Htdtdt) · H<sub>2</sub>O.** To a solution of Fe(dha)<sub>3</sub> · H<sub>2</sub>O (0.5 mmol) in dry benzene, a warm benzene solution of an equimolar amount of Htdtdt was added. The mixture was then stirred at room temperature until the volume was reduced to about its half and a brown precipitate was formed. The precipitate was filtered, washed with dry benzene and stored *in vacuo* over preheated CaCl<sub>2</sub>.

**Co(II) and Ni(II) complexes.** A warm ethanolic solution of the binary complex (0.2 mmol) was mixed with 20 cm<sup>3</sup> of ethanolic solution of Htdtdt (0.2 mmol). The mixture was stirred for half an hour and left to stay at room temperature overnight whereby a

solid complex was separated. This was filtered, washed with ethanol and diethyl ether and dried *in vacuo* over P<sub>4</sub>O<sub>10</sub>.

**Cu(dha)(Htdtdt)<sub>2</sub>.** To a stirred suspension of the binary Cu(II)—dha complex (0.2 mmol) in ethanol (25 cm<sup>3</sup>) an equimolar ethanolic solution of Htdtdt (30 cm<sup>3</sup>) was added dropwise. The stirring was continued until complete dissolution. The resulted intense orange solution was refluxed on a water bath for an hour and concentrated by evaporation to one third of its original volume. An orange solid was separated on cooling to the room temperature. The solid was filtered, washed several times with ethanol and finally with diethyl ether and dried over P<sub>4</sub>O<sub>10</sub>.

### Screening for Antibacterial Activity

The antibacterial activity of the mixed ligand complexes was tested using the usual cup-plate technique [9, 10]. The culture media used are nutrient agar media supplemented by 1 g of yeast per cm<sup>3</sup>. A final content of 10 ppm of the tested compounds was used.

## RESULTS AND DISCUSSION

Elemental analysis and conductivity data indicate that the binary metal complexes are reactive towards the dithiolate ligand affording mixed ligand complexes as formulated in Table 1. The data of Table 1 clearly indicate that an Hdha molecule of the binary chelates is replaced by two Htdtdt ligands. However, the values of molar conductivity of 10<sup>-3</sup> M-DMF solutions of the various complexes fall in the range 4.4—19.8 S cm<sup>2</sup> mol<sup>-1</sup>. Since the reasonable range of 1 : 1 electrolyte in DMF is 65—90 S cm<sup>2</sup> mol<sup>-1</sup> [11], the formed mixed ligand complexes are neutral. This indicates that the

Table 1. Analytical, Magnetic, and Physical Data of the Binary and Mixed Ligand Complexes

Compound	$\mu_{\text{eff}}$ B.M.	Decomp. temperature	Colour	$w_i(\text{calc.})/\%$ $w_i(\text{found})/\%$				$\Lambda$ S cm <sup>2</sup> mol <sup>-1</sup>	M
				C	H	N	S		
I [Fe(dha) <sub>3</sub> ] · H <sub>2</sub> O	5.90	235	Orange	50.1	4.0	—	—	18.0	9.7
II [Fe(dha) <sub>2</sub> (Htdtdt)(H <sub>2</sub> O)]	5.85	>300	Brown	50.0	4.5	—	—	13.3	10.2
				38.8	3.1	5.1	17.3		10
III [Co(dha) <sub>2</sub> (H <sub>2</sub> O) <sub>2</sub> ]	3.80	210	Pink	38.9	3.3	4.8	17.4	5.7	10.5
				44.8	4.2	—	—		13.7
IV [Co(dha)(Htdtdt)(tdtdt)(H <sub>2</sub> O)]	4.30	>300	Brown	45.1	4.0	—	—	19.8	13.1
				25.6	2.5	9.9	34.2		10.8
V [Ni(dha) <sub>2</sub> (H <sub>2</sub> O) <sub>2</sub> ]	3.02	190	Bluish green	25.8	2.7	10.2	34.4	5.1	11.4
				44.8	4.2	—	—		13.6
VI [Ni(dha) <sub>2</sub> (Htdtdt)(tdtdt)(H <sub>2</sub> O) <sub>2</sub> ]	3.24	>300	Dark green	44.5	4.1	—	—	5.55	14.2
				25.	2.5	10.0	34.2		8.0
VII [Cu(dha) <sub>2</sub> ]	1.85	>300	Violet	25.8	2.8	9.6	34.5	4.4	7.7
				48.	3.5	—	—		15.9
VIII [Cu(dha)(Htdtdt)(tdtdt)]	1.90	>300	Brown	48.5	3.3	—	—	10.5	16.2
				27.2	1.9	10.5	36.3		11.9
				26.9	2.1	10.3	36.5		12.4

**Table 2.** Some IR Frequencies (in  $\text{cm}^{-1}$ ) of Binary and Mixed Ligand Complexes

Compound	$\nu(\text{C}=\text{O})$	$\nu(\text{CNS} + \text{CS})$	$\nu(\text{C}-\text{S})$	$\nu(\text{C}=\text{S})$	$\delta(\text{SH})$
<i>I</i>	1710	—	—	—	—
<i>II</i>	1720	1270	1080	730	830
<i>III</i>	1680	—	—	—	—
<i>IV</i>	1690	1260	1060	720	840
<i>V</i>	1680	—	—	—	—
<i>VI</i>	1710	1270	1055	715	—
<i>VII</i>	1700	—	—	—	—
<i>VIII</i>	1720	1290	1070	715	840

thiadiazole-dithiol molecule behaves as a univalent and monodentate ligand. This can be explained on the basis of the structural characteristics of the secondary ligand (Htdtdt) which can exist in the given tautomeric forms.

The X-ray diffraction studies indicated that it exists mainly as 1,3,4-thiadiazole-2-thiol-5-thione (*II*) in the solid state, whereas in solution it exists in a tautomeric equilibrium [12] of the two forms *I* and *II*. Such a formulation can provide many possibilities in the formed mixed ligand complexes and/or a mixture of them. However, elemental analysis and conductivity data reveal that in the obtained neutral mixed ligand complexes a univalent anion of *II* and a molecule of *I* are coordinated to the metal ion. The possibility of formation of a mixture is ruled out from the observation that these complexes start decomposition at a definite temperature as given in Table 1. A support to the elemental analysis and conductivity data could be achieved from TGA electronic and IR spectra as given hereafter.

In infrared spectra (Table 2) the mixed ligand complexes display a strong band due to (NCS + CS) stretching frequency [13] in the region 1265–1290  $\text{cm}^{-1}$  and a strong band due to  $\nu(\text{C}=\text{S})$  [14] in the 715–730  $\text{cm}^{-1}$  range. The former band was found to be located at higher frequency, whereas the latter one was shifted to a lower frequency relative to their position in the IR spectrum of the free Htdtdt molecule (1260  $\text{cm}^{-1}$  and 750  $\text{cm}^{-1}$ , respectively). These shifts are considered as evidence for the coordination of this ligand through its sulfur atom. Also, bands due to  $\nu(\text{NH})$  and  $\delta(\text{NH})$  are observed in the range 3060–3180 and at 1450  $\text{cm}^{-1}$ , respectively, in the spectrum of free Htdtdt. These two bands were found to remain practically unchanged upon complexation. This rules out coordination of the NH groups of the ligand [15] and can be considered as an evidence for the coordination of Htdtdt in both the thiol and thione forms. Furthermore, the aforementioned increase in the frequency of the  $\nu(\text{CNS} + \text{CS})$  band upon complexation is in agreement with the electronic shift  $\text{HN} - \text{C}=\text{S} \rightarrow \text{M}$  due to the coordination of the ligand through its thiocarbonyl sulfur atom [15].

In thermal studies the presence of coordinated or hydration water as well as the absence of water

molecules in the prepared complexes could be verified by TGA. The binary Fe(III)—dha complex (compound *I*) and its mixed ligand complex *II* were found to possess a mass loss corresponding to one water molecule at  $\approx 105^\circ\text{C}$  indicating that these complexes are six-coordinated and the attached water molecule exists as hydration water. Compounds *VII* and *VIII* did not possess any loss of mass up to their decomposition temperature confirming their anhydrous nature as the elemental analysis data revealed (Table 1). The TGA curves of compounds *III*–*VI* showed a mass loss of two water molecules in the temperature range 180–200  $^\circ\text{C}$ . This indicates that the two water molecules are coordinately bonded to the metal ion in these complexes.

The different electronic spectral bands displayed by the binary and mixed ligand complex solutions (in DMF), in the range of the instrument used, are listed in Table 3. The binary Co(II) complex displayed a broad  $d-d$  band covering the range of both  ${}^4T_{1g} \rightarrow {}^4A_{2g}$ ,  $\nu_2$ , and  ${}^4T_{1g} \rightarrow {}^4T_{1g}(P)$ ,  $\nu_3$  with a lower energy side being as broad as that it is difficult to detect, precisely, the maximum corresponding to  $\nu_2$ , but a definite maximum could be ascertained at 19 200  $\text{cm}^{-1}$  due to the  $\nu_3$  transition. In the mixed ligand Co(II) complex, the low energy band is that more pronounced with a maximum at 15 400  $\text{cm}^{-1}$  whereas that of higher energy seems to be hidden by the neighbouring intense broad CT band. It is to be noted that although transition to the  ${}^4A_{2g}$  state ( $\nu_2$ ) is very weak in high-spin octahedral complexes, it may be intensified in the present mixed ligand complex by low symmetry and mixing with the spin-forbidden transitions. Spin-orbit coupling, however, is known to be obscured at ambient temperatures, therefore it is assumed that the symmetry of the octahedral Co(II) mixed ligand complex is reduced upon substitution of an Hdha ligand by the dithiolate one. The measured magnetic moments ( $\mu = 3.8$ – $4.3$  BM, Table 1) are in the range of high-spin Co(II) complexes.

Binary and mixed ligand six-coordinated Ni(II) complexes display a  $d-d$  band at 14 700  $\text{cm}^{-1}$  due to the spin allowing the  ${}^3A_{2g} \rightarrow {}^3T_{1g}$  transition. This band was observed to be a doublet one indicating that the spin-forbidden  ${}^1E_g$  state is close enough to the  ${}^3T_{1g}$  state. These findings indicate that the six-

**Table 3.** Electronic Spectral Data of the Binary and Ternary Complexes ( $\bar{\nu}/\text{cm}^{-1}$ )

Compound	Intraligand	$\sigma_{S \rightarrow M}$	$\pi_{S \rightarrow M}$	$d-d$
I	36 400 (1 500)	-	-	-
	33 300 (1 400)			
II	37 000 (1 360)	23 800 (220)	18 800 (100)	-
	33 700 (1 110)			
III	37 000 (1 630)	-	-	19 200 (210)
	33 300 (1 450)			
IV	37 000 (1 870)	28 600 (1 400)	23 800 (1 040)	15 400 (180)
	33 300 (1 600)			
V	37 000 (4 100)	-	-	14 700 (1 000)
	32 800 (2 300)			
VI	37 000 (3 200)	28 200 (1 400)	-	14 700 (285)
	32 200 (2 400)			
VII	37 000 (3 800)	-	-	14 700 (1 000)
	32 600 (2 300)			
VIII	35 700 (4 000)	-	18 500 (1 000)	15 200 (900)

**Table 4.** Antibacterial Activity (Inhibition Zone, mm) of the Binary and Mixed Ligand Complexes

Compound	<i>Bacillus cereus</i>	<i>Micrococcus luteus</i>	<i>Serratia</i>	<i>Pseudomonas fluorescens</i>
I	-	-	-	-
II	6.0	-	8.0	10.0
III	-	-	-	10.0
IV	8.0	7.0	10.0	12.0
V	-	-	-	-
VI	10.0	8.0	12.0	14.0
VII	8.0	-	8.0	6.0
VIII	10.0	8.0	12.0	10.0

coordinate Ni(II) complexes assume a distorted octahedral geometry [16]. These complexes were found to be paramagnetic ( $\mu = 3.02-3.25$  BM), which suggests octahedral geometry.

Binary and mixed ligand copper(II) complexes exhibit a broad structured  $d-d$  band in the 14 700–15 200  $\text{cm}^{-1}$  range. This range is acceptable for four-coordinate Cu(II) complexes of  $D_{2h}$  symmetry, which indicates that these complexes possess a square planar geometry that is strongly favoured for  $d^9$  configuration [6, 17] (transition from  $xz, yz$  to  $x^2 - y^2$ ). The magnetic moment of Cu(II) complexes lies in the range 1.85–1.9 BM, which is in harmony with the proposed geometry.

On the other hand, mixed ligand complexes displayed rather stronger one or two bands at higher energies than those of the  $d-d$  bands. These bands were missing in the spectra of the binary complexes; therefore they can easily be assigned to charge-transfer transitions (LMCT), mainly  $S \rightarrow MCT$ . These bands are, based on relative energy considerations, divisible into two types, namely  $\sigma S \rightarrow M$ ,  $\pi S \rightarrow M$ . The CT bands of a relatively lower energy are assignable to  $\pi S \rightarrow MCT$  and those of higher energy to  $\sigma S \rightarrow MCT$  [18, 19]. Assignment of the different bands is given in Table 4.

The data of antibacterial activity in Table 4 indicate that where the free ligands (Hdha, Htdtdt) do not possess antibacterial activity at the used concentration, binary and mixed ligand complexes exhibit an ambient bacteriostatic activity. The complexes showed a special potency against *Bacillus cereus* (g + ve) and *Pseudomonas fluorescens* (g - ve).

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