

SYNTHESIS, CHARACTERIZATION AND ANTIBACTERIAL ACTIVITY OF MIXED LIGAND DIOXOURANIUM COMPLEXES OF 8-HYDROXYQUINOLINE AND SOME AMINO ACIDS

SUNIL S. PATIL^{1*}, and MANZOOR M. SHAIKH¹

¹Department of Chemistry, Changu Kana Thakur Arts, Commerce and Science College, New Panvel,
Raigad, Maharashtra, India, Pin-410206

Abstract: Mixed ligand complexes of dioxouranium(VI) of the type $[\text{UO}_2(\text{Q})(\text{L})\cdot 2\text{H}_2\text{O}]$ have been synthesized using 8-hydroxyquinoline (HQ) as a primary ligand and N- and/or O- donor amino acids (HL) such as L-lysine, L-aspartic acid and L-cysteine as secondary ligands. The metal complexes have been characterized on the basis of elemental analysis, electrical conductance, room temperature magnetic susceptibility measurements, spectral and thermal studies. The electrical conductance studies of the complexes in DMF in 10^{-3} M concentration indicate their non-electrolytic nature. Room temperature magnetic susceptibility measurements revealed diamagnetic nature of the complexes. Electronic absorption spectra of the complexes show intra-ligand and charge transfer transitions, respectively. Bonding of the metal ion through N- and O- donor atoms of the ligands is revealed by IR studies and the chemical environment of the protons is also confirmed by NMR studies. The thermal analysis data of the complexes indicate the presence of coordinated water molecules. The agar cup and tube dilution methods have been used to study the antibacterial activity of the complexes against the pathogenic bacteria *S. aureus*, *C. diphtheriae*, *S. typhi* and *E. coli*.

Keywords: Mixed ligand dioxouranium complexes; synthesis, characterization and antibacterial study

Numbers of uranium complexes and their mixed chelates have been reported (1, 2). Dioxouranium(VI), UO_2^{2+} , is one of the most studied oxocations for which a large number of complexes with varying geometries are possible (3). The coordination numbers ranging from 7 to 12 for metal chelates of $\text{UO}_2(\text{VI})$ and $\text{Th}(\text{IV})$ have been reported (4, 5). It is well known that mixed ligand complexes, particularly ternary complexes of some metals, play an important role in the activation of enzymes and are used for storage as well as for transport of active materials (6). Mixed ligand complexes are established to be biologically active against pathogenic microorganisms (7, 8), further, metal complexes, which include 8-hydroxyquinoline as primary ligand, exert biological activity (9). Amino acids form complexes with metal atoms and exhibit significant biological and enzymatic activities (10). Ternary complexes containing an amino acid as a secondary ligands have a significance as they are potential models for enzyme metal ion substrate complexes

(11). Recently, it was stated that the $\text{UO}_2(\text{VI})$ complexes show antimicrobial activity (12–14).

This paper reports the synthesis, characterization and antibacterial studies of mixed ligand dioxouranium(VI) complexes prepared with 8-hydroxyquinoline as a primary ligand and amino acids such as L-lysine, L-aspartic acid and L-cysteine as secondary ligands. These complexes have been screened for their antibacterial properties.

EXPERIMENTAL

Materials

Analytical grade uranyl nitrate hexahydrate was used as such without further purification. L-lysine, L-aspartic acid, L-cysteine and 8-hydroxyquinoline were obtained from S.D. Fine Chemicals, Mumbai, India. Solvents like, ethanol and dimethylformamide and laboratory grade chemicals whenever used were distilled and purified according to standard procedures (15, 16).

* Corresponding author: sunilpatil_247@rediffmail.com

Preparation of mixed ligand complexes

Mixed ligand dioxouranium(VI) complexes were prepared from uranyl nitrate hexahydrate, 8-hydroxyquinoline (HQ) as a primary ligand and different amino acids such as, L-lysine, L-aspartic acid and L-cysteine as secondary ligands.

To an aqueous solution (10 cm³) of uranyl nitrate hexahydrate (502 mg, 1 mmol), ethanolic solution (10 cm³) of 8-hydroxyquinoline (145 mg, 1 mmol) was added. The mixture was stirred and kept in a boiling water bath for 10 min. To this hot solution an aqueous solution (10 cm³) of amino acid (1 mmol) was added with constant stirring. The mixture (1:1:1 molar proportion) was again heated in a water bath for 10 min till the temperature reached 50°C. The complexes were precipitated by raising the pH up to 7 of the reaction mixture by adding diluted ammonia solution. The mixture was cooled and solid complex obtained was filtered and washed with water followed by ethanol. The complexes thus prepared were dried under vacuum and were used for further studies.

Instrumentation

The complexes were analyzed for C, H and N contents on Thermo Finnigan Elemental Analyzer, Model No. FLASH EA 1112 Series at Department of Chemistry, I.I.T., Mumbai, India. Metal content was estimated gravimetrically by standard procedure (17). The molar conductance values were measured in DMF (10⁻³ M) on an Equiptronics Autoranging Conductivity Meter Model No. EQ-667. Room temperature magnetic susceptibilities were measured by a Guoy method using Hg[Co(SCN)₄] as a calibrant at Department of Chemistry, I.I.T., Mumbai. The electronic absorption spectra of all the complexes in DMF solution (10⁻⁴ M) in the ultraviolet and visible region were recorded on Shimadzu UV/VIS-160 spectrophotometer. FT-IR spectra were recorded in KBr discs on a Perkin-Elmer FT-IR spectrophotometer Model 1600 at Department of Chemistry, I.I.T., Mumbai. NMR spectra were recorded on JEOL-300 MHz instrument using TMS as an internal standard at The Institute of Science, Mumbai. Thermal analyses (TG and DTA) were carried out in controlled nitrogen atmosphere on a Perkin-Elmer Diamond TG-DTA Instrument at Department of Chemistry, I.I.T., Mumbai by recording the change in weight of the complexes on increasing temperature up to 900°C at the heating rate of 10°C per min.

Antibacterial screening

Agar cup method

In the agar cup method, a single compound can be tested against number of organisms or a given

organism against different concentrations of the same compound. The method was found suitable for semisolid or liquid samples and was used in the present work. A plate of sterile nutrient agar with the desired test strain was poured to a height of about 5 mm, allowed to solidify and a single cup of about 8 mm diameter was cut from the center of the plate with a sterile cork borer. Thereafter, the cup was filled with the sample solution of known concentration and the plate was incubated at 37°C for 24 h. The extent of inhibition of growth from the edge of the cup was considered as a measure of the activity of the given compound. By using several plates simultaneously, the activities of several samples were quantitatively studied.

Tube dilution method

The test compound (10 mg) was dissolved in suitable solvent (10 cm³) such as dimethyl sulfoxide to prepare a stock solution of concentration 1000 µg/mL. From this stock solution, aliquots of 5 to 250 µg/mL were obtained in test broth.

The test compounds were subjected to *in vitro* screening against *Staphylococcus aureus*, *Corynebacterium diphtheriae*, *Salmonella typhi* and *Escherichia coli* using Muller Hinton broth as the culture medium.

Bacterial inoculums were prepared in sterilized Mueller Hinton broth and incubated for 4 h at 37°C. This was dispersed (5 cm³) in each borosilicate test tube (150 × 20 mm). The test sample solution was added in order to attain a final concentration as 5 to 250 µg/mL. The bacterial inoculums 0.1 cm³ of the desired bacterial strain (*S. aureus*, *C. diphtheriae*, *S. typhi* and *E. coli*) containing 10⁶ bacteria/mL was inoculated in the tube. The tubes were incubated at 37°C for 24 h and then examined for the presence or absence of the growth of the test organisms.

The lowest concentration which showed no visible growth was noted as minimum inhibitory concentration (MIC).

RESULTS AND DISCUSSION

Characterization of metal complexes

The synthesis of mixed ligand uranyl complexes may be represented as follows-

$$\text{UO}_2(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O} + \text{HQ} + \text{HL} \rightarrow [\text{UO}_2(\text{Q})(\text{L}) \cdot 2\text{H}_2\text{O}] + 2\text{HNO}_3 + 4\text{H}_2\text{O}$$

where, HQ is 8-hydroxyquinoline and HL is an amino acid.

All the complexes are colored, non-hygroscopic, thermally stable solids (Tab. 1), indicating a strong metal-ligand bond. The complexes are insol-

uble in common organic solvents such as ethyl alcohol, acetone, chloroform etc., but are partially soluble in DMF and DMSO.

The elemental analysis data (Tab. 2) of uranyl complexes are consistent with their general formulation as 1:1:1, mixed ligand of the type $[\text{UO}_2(\text{Q})(\text{L})\cdot 2\text{H}_2\text{O}]$. The molar conductance values (Tab. 2) of the complexes in DMF at 10^{-3} M concentration are found to be 0.001–0.003 Mhos $\text{cm}^2 \text{mol}^{-1}$ indicating their non-electrolytic nature (18).

Magnetic studies

The magnetic moments of the complexes were calculated from the measured magnetic susceptibilities after employing diamagnetic corrections and revealed their diamagnetic nature (19).

Electronic absorption spectra

The electronic spectra of the metal complexes in DMF were recorded in the UV-visible region (Tab. 3). The spectra show three transitions in the

Table 1. Color, decomposition temperature and pH of the uranyl complexes.

No.	Complex ^a	Color	Decomposition temperature (°C)	pH
1.	$[\text{UO}_2(\text{Q})(\text{Lys})\cdot 2\text{H}_2\text{O}]$	dark brown	250	7.00
2.	$[\text{UO}_2(\text{Q})(\text{Asp})\cdot 2\text{H}_2\text{O}]$	dark brown	260	7.00
3.	$[\text{UO}_2(\text{Q})(\text{Cys})\cdot 2\text{H}_2\text{O}]$	dark brown	230	7.00

^awhere Q represents the deprotonated primary ligand 8-hydroxyquinoline, whereas Lys, Asp and Cys represent deprotonated secondary ligands L-lysine, L-aspartic acid and L-cysteine, respectively.

Table 2. Empirical formula, molecular weight, elemental analysis data and molar conductance of uranyl complexes.

No.	Complex	Empirical formula	Molecular weight	Elemental analysis found (calculated)					Molar conductance Mhos. $\text{cm}^2\text{mol}^{-1}$
				%M	%C	%H	%N	%S	
1.	$[\text{UO}_2(\text{Q})(\text{Lys})\cdot 2\text{H}_2\text{O}]$	$\text{UC}_{15}\text{H}_{23}\text{N}_5\text{O}_7$	595.38	39.94 (39.98)	30.21 (30.23)	3.84 (3.86)	7.04 (7.05)	–	0.003
2.	$[\text{UO}_2(\text{Q})(\text{Asp})\cdot 2\text{H}_2\text{O}]$	$\text{UC}_{13}\text{H}_{16}\text{N}_2\text{O}_9$	582.30	40.87 (40.88)	26.77 (26.79)	2.74 (2.75)	4.80 (4.81)	–	0.001
3.	$[\text{UO}_2(\text{Q})(\text{Cys})\cdot 2\text{H}_2\text{O}]$	$\text{UC}_{12}\text{H}_{16}\text{N}_2\text{O}_7\text{S}$	570.35	41.72 (41.73)	25.23 (25.25)	2.80 (2.81)	4.91 (4.91)	5.60 (5.61)	0.001

Table 3. Electronic spectral data of uranyl complexes.

No.	Complex	λ nm	ν cm^{-1}	Proposed assignments
1.	$[\text{UO}_2(\text{Q})(\text{Lys})\cdot 2\text{H}_2\text{O}]$	271	36900	$\pi \rightarrow \pi^*$
		340	29412	$n \rightarrow \pi^*$
		380	26316	Charge-transfer
2.	$[\text{UO}_2(\text{Q})(\text{Asp})\cdot 2\text{H}_2\text{O}]$	273	36630	$\pi \rightarrow \pi^*$
		334	29940	$n \rightarrow \pi^*$
		387	25840	Charge transfer
3.	$[\text{UO}_2(\text{Q})(\text{Cys})\cdot 2\text{H}_2\text{O}]$	275	36364	$\pi \rightarrow \pi^*$
		330	30303	$n \rightarrow \pi^*$
		390	25641	Charge transfer

Table 4. Infra-red spectral data of uranyl complexes.

No.	Complex	ν (O-H) H ₂ O	ν (N-H) asym. (A. a.)	ν (N-H) sym. (A. a.)	ν (C-O) (A. a.)	ν (C-O) (A. a.)	ν (C=N) (HQ)	ν (C=O) (HQ)	ν (M-O)	ν (M=N)	ν (O=U=O)	ν (S-H)	
1.	[UO ₂ (Q)(L-lys)·2H ₂ O]	3460 (b)	3140 (w)	3050 (w)	1572 (s)	1378 (s)	1602 (w)	1499 (s)	1103 (s)	608 (w)	485 (w)	900 (s) 819 (m)	–
2.	[UO ₂ (Q)(Asp)·2H ₂ O]	3431 (b)	3140 (w)	3050 (w)	1572 (s)	1378 (s)	1601 (w)	1499 (s)	1104 (s)	605 (w)	485 (w)	899 (s) 819 (m)	–
3	[UO ₂ (Q)(Cys)·2H ₂ O]	3431 (b)	3140 (w)	3050 (w)	1572 (s)	1378 (s)	1602 (w)	1499 (s)	1104 (s)	608 (w)	485 (w)	899 (s) 820 (m)	2600 (w)

range 36364–36900 cm⁻¹, 29412–30303 cm⁻¹ and 25641–26316 cm⁻¹ ascribed to $\pi \rightarrow \pi^*$, $n \rightarrow \pi^*$ and the charge transfer transitions from the ligands to the metal, respectively.

Infrared spectra

The FT-IR spectra of the metal complexes were recorded for KBr discs over the range 4000–400 cm⁻¹. On the basis of the reported infrared spectra of amino acids, 8-hydroxyquinoline and their metal complexes (20–22), some of the important bands have been assigned (Tab. 4).

A broad band observed in the region between 3460–3431 cm⁻¹ is due to asymmetric and symmetric O–H stretching modes and a band in the range 1602–1601 cm⁻¹ is due to H–O–H bending vibrations indicating presence of a coordinated water molecules further confirmed by thermal studies.

The ν (CO) band is observed at ~1120 cm⁻¹. The position of this band undergoes variation depending on metal complex under study (23). A strong ν (CO) band observed in the range between 1104–1103 cm⁻¹ indicates the presence of oxine moiety in the complexes coordinated through its nitrogen and oxygen atoms as uninegative bidentate ligand (24). The ν (C=N) mode observed at 1580 cm⁻¹ in the spectra of free HQ ligand is found to be shifted to lower wave number 1499 cm⁻¹ in the spectra of complexes. A negative shift in this vibrational mode on complexation indicates the coordination through ternary nitrogen donor of HQ. The in plane and out of plane ring deformation modes observed at 509 cm⁻¹ and 781 cm⁻¹, respectively, confirm coordination through nitrogen atom of HQ with the metal.

Broad bands at 3040 and 2960 cm⁻¹ due to N-H (asymmetric) and N-H (symmetric) vibrations of free amino acid moiety are shifted to higher wave numbers 3140 cm⁻¹ and 3050 cm⁻¹, respectively in the spectra of metal complexes, suggesting coordination of the amino group through nitrogen with the metal ion.

The $\nu_{\text{asymmetric}}(\text{COO}^-)$ band of the free amino acid, i.e., 1610–1590 cm⁻¹, is shifted to lower wave number – 1572 cm⁻¹ and the $\nu_{\text{symmetric}}(\text{COO}^-)$ mode observed at ~1400 cm⁻¹ in the spectra of free amino acids is found to be shifted to lower wave number – 1378 cm⁻¹, in the spectra of complexes indicating the coordination of the carboxylic acid group *via* oxygen with the metal ion (20).

An important feature of the infrared spectra of metal complexes with 8HQ is the absence of band ~3440 cm⁻¹ due to the O-H stretching vibration of the free O-H group of HQ (22). This observation leads to the conclusion that complex formation takes

Table 5. ¹H NMR spectral data of uranyl complexes.

No.	Complex	Chemical shifts, (δ, ppm)
1.	[UO ₂ (Q)(Lys)·2H ₂ O]	1.32–1.35 (m, 2H, -CH ₂), 1.54–1.57 (m, 4H, 2-CH ₂), 2.60 (t, 2H, -CH ₂), 2.80 (s, 2H, -NH ₂), 2.90 (t, 1H, -CH), 3.50 (s, 2H, H ₂ O), 5.20 (s, 2H, -NH ₂), 6.6–7.8 (m, 6H, Ar-H).
2.	[UO ₂ (Q)(Asp)·2H ₂ O]	2.62 (d, 2H, -CH ₂), 2.80 (s, 2H, -NH ₂), 2.95 (t, 1H, -CH), 3.50 (s, 2H, H ₂ O), 6.6–7.8 (m, 6H, Ar-H), 11.10 (s, 1H, -COOH).
3.	[UO ₂ (Q)(Cys)·2H ₂ O]	2.14 (s, 1H, -SH), 2.56 (d, 2H, -CH ₂), 2.80 (s, 2H, -NH ₂), 2.88 (t, 1H, -CH), 3.50 (s, 2H, H ₂ O), 6.6–7.8 (m, 6H, Ar-H).

Table 6. Thermal data of uranyl complexes.

No.	Complex	Decomp. temp. (°C)	Temp. range (°C)	% weight loss		Decomposition product
				found	calcd.	
1.	[UO ₂ (Q)(Lys)·2H ₂ O]	250	110–190	06.00	06.04	[UO ₂ (Q)(Lys)]
			250–360	24.20	24.35	[UO ₂ (Q)]
			425–550	24.10	24.19	[UO ₂]
2.	[UO ₂ (Q)(Asp)·2H ₂ O]	260	110–190	06.00	06.18	[UO ₂ (Q)(Asp)]
			260–360	22.52	22.67	[UO ₂ (Q)]
			430–520	24.51	24.73	[UO ₂]
3.	[UO ₂ (Q)(Cys)·2H ₂ O]	230	110–160	06.31	06.31	[UO ₂ (Q)(Cys)]
			230–380	21.02	21.04	[UO ₂ (Q)]
			460–585	25.00	25.25	[UO ₂]

place by deprotonation of the hydroxyl group of HQ moiety.

The FT-IR spectra of the uranyl complexes show no absorption bands near 1352 cm⁻¹ where ionic nitrate is known to absorb (25), indicating absence of ionic nitrate. Other bands observed at ~1468, ~1278, ~1035 and ~734 cm⁻¹ corresponding to ν₁, ν₄, ν₂ and ν₃ vibrations agree with frequencies reported for bidentate nitrate group (26, 27).

The bands at 900–899 cm⁻¹ and 820–819 cm⁻¹ are assigned to ν_{asymmetric}(O-U-O) and ν_{symmetric}(O-U-O) vibrational modes of linear O=U=O moiety (28, 29). The weak band observed at 2600 cm⁻¹ in the spectra of the complex with L-cysteine may be ascribed to the S-H vibration.

Some new bands of weak intensity observed in the regions around 608–605 cm⁻¹ and 485 cm⁻¹ may be ascribed to the M-O and M-N vibrations, respectively (30). It may be noted that these vibrational bands are absent in the infra-red spectra of HQ as well as amino acids.

NMR spectra

¹H NMR spectra of complexes in DMSO exhibit a singlet at δ 2.8 ppm due to amino group protons and broad multiplet in the region δ 6.6–7.8

ppm due to the aromatic ring protons. The presence of water molecules in the complexes is confirmed by the appearance of a new signal around δ 3.5 ppm, attributed to H₂O protons (31).

The complex with L-lysine shows multiplet at δ 1.32–1.35 ppm for two protons of methylene group, another multiplet at δ 1.54–1.57 ppm for four protons of two methylene groups, two triplets at δ 2.60 and 2.90 ppm for two protons of methylene group and one proton of -CH group, respectively, and a broad singlet at δ 5.20 ppm for two protons of other amino group which was D₂O exchangeable.

The complex with L-aspartic acid shows doublet at δ 2.62 ppm for two protons of methylene, triplet at δ 2.95 ppm for one proton of -CH and singlet at δ 11.10 ppm for one proton of carboxylic acid group.

The complex with L-cysteine shows doublet at δ 2.56 ppm for two protons of methylene group, triplet at δ 2.88 ppm for one proton of -CH group and singlet at δ 2.14 ppm for one proton of another -SH group (Table 5).

Thermal studies

The TG and DTA studies of the uranyl complexes have been recorded in the nitrogen atmos-

Table 7. Antibacterial activity (mm) of uranyl complexes by agar cup method.

No.	Complex	Test			
		<i>S. aureus</i>	<i>C. diphtheriae</i>	<i>S. typhi</i>	<i>E. coli</i>
1.	[UO ₂ (Q)(Lys)·2H ₂ O]	14	13	22	22
2.	[UO ₂ (Q)(Asp)·2H ₂ O]	12	13	25	25
3.	[UO ₂ (Q)(Cys)·2H ₂ O]	14	12	22	24

Table 8. MIC data of uranyl complexes.

No.	Complex	MIC (µg/mL)			
		<i>S. aureus</i>	<i>C. diphtheriae</i>	<i>S. typhi</i>	<i>E. coli</i>
1.	[UO ₂ (Q)(Lys)·2H ₂ O]	20	25	10	10
2.	[UO ₂ (Q)(Asp)·2H ₂ O]	10	25	10	20
3.	[UO ₂ (Q)(Cys)·2H ₂ O]	10	25	10	10
4.	UO ₂ (NO ₃) ₂ ·6H ₂ O	50	50	100	100
5.	8-Hydroxyquinoline	50	50	110	100
6.	Tetracycline	1.5	2.0	1.5	2.5

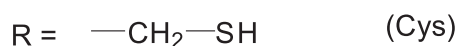
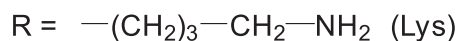
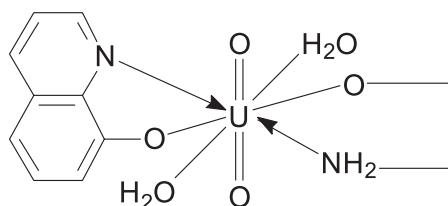


Figure 1. Proposed structures and bonding for the uranyl complexes

phere at the constant heating rate of 10°C per min. The TG of the uranyl complexes show that they are thermally quite stable to varying degree. The complexes show gradual loss in weight due to decomposition by fragmentation with increasing temperature as presented in Table 6. All the complexes show similar behavior in TG and DTA studies. The thermogram of these complexes show the loss in weight corresponding to two water molecules in the temperature range 110–190°C, followed by weight loss due to amino acid moiety in the range 230–380°C. The final step of the decomposition observed in the range 425–585°C corresponds to the weight loss of HQ moiety present in the complexes.

The DTA of the complexes display an endothermic peak in the range 110–190°C, which indicates the presence of coordinated water molecules. As the temperature is raised, the DTA curve shows a small exotherm in the range 230–380°C and a broad exotherm in the range 530–620°C attributed to decomposition of amino acid and 8-hydroxyquinoline moieties present in the complexes, respectively. The formation of a broad exotherm is possibly due to simultaneous decomposition of ligand moieties and their subsequent oxidation to gaseous products like CO₂ and H₂O etc. (19).

Like most of the metal organic complexes, these complexes also decompose to a fine powder of metal oxide i.e., UO₂. The constant weight plateau in TG after 600°C indicates completion of the reaction. The UO₂ form was confirmed by X-ray diffraction pattern of the decomposed product (19).

Antibacterial studies

All the metal complexes were screened against *Staphylococcus aureus*, *Corynebacterium diphtheriae*, *Salmonella typhi* and *Escherichia coli*.

The studies based on agar cup method revealed that the complexes are sensitive against *S. typhi* and *E. coli* and less sensitive against *S. aureus* and *C. diphtheriae* (Tab. 7).

The minimum inhibitory concentration (MIC) of ligand and the metal salts ranges between 50–110 µg/mL while that of metal complexes ranges between 10–25 µg/mL (Tab. 8). The complexes are found to be more active against *S. typhi* and *E. coli*

as compared to *S. aureus* and *C. diphtheriae*. As compared to standard antibacterial compound, tetracycline, the complexes show moderate activity against selected strains of microorganisms (32).

The results show that, as compared to the activity of metal salts and free ligand, the metal complexes show higher activity. The activity of metal complexes is enhanced due to chelation. The chelation reduces considerably the polarity of the metal ions in the complexes, which in turn increases the hydrophobic character of the chelate and thus enables its permeation through the lipid layer of microorganisms (33).

On the basis of the physico-chemical studies, the bonding and structure for the uranyl complexes may be represented as shown in Figure 1.

CONCLUSIONS

Based on the above results the following conclusions may be drawn. The higher decomposition temperatures of the complexes indicate a strong metal-ligand bond and electrical conductance studies show non-electrolytic nature of the complexes, respectively. Magnetic studies indicate diamagnetic nature of the complexes. Electronic absorption spectra of the complexes show intra-ligand and charge transfer transitions, respectively. IR spectra show bonding of the metal ion through N- and O- donor atoms of the two ligands. ¹H NMR study reveals the chemical environment of protons and the presence of water molecules in the complexes. Thermal analysis confirms the presence of coordinated water molecules.

On the basis of above results, coordination number eight is proposed for uranyl complexes.

The antibacterial study shows that complexes are found to be more active against *S. typhi* and *E. coli* as compared to *S. aureus* and *C. diphtheriae*.

Compared to standard antibacterial compound, tetracycline, the complexes show moderate activity against the selected strains of microorganisms.

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