ORIENTAL JOURNAL OF CHEMISTRY
An International Open Access, Peer Reviewed Research Journal
www.orientjchem.org

ISSN: 0970-020 X
CODEN: OJCHEG
2024, Vol. 40, No.(5):
Pg. 1356-1366

Antibacterial Effects of Mo(VI) Macrocyclic Compounds

SHIKHA KATIYAR[1], SIDDHARAM[2], DEVENDRA PRATAP RAO[3]*
and SHIV GOVIND PRASAD[4]

[1,2,3]Department of Chemistry, Coordination Chemistry Laboratory,
Dayanand Anglo-Vedic (PG) College, Kanpur-208001, U.P., India.
[4]Department of Chemistry, Uttar Pradesh Textile Technology Institute,
Kanpur-208001, India.
*Corresponding author E-mail: devendrapratapraо@yahoo.com

http://dx.doi.org/10.13005/ojc/400518

(Received: June 24, 2024; Accepted: October 08, 2024)

ABSTRACT

Preparing a monomeric [MoO_2(SL)] containing a Schiff base was achieved by condensing furil with 3-bromo-5-(trifluoromethyl) benzene-1,2-diamine, along with preparing 4 different compounds containing [MoO_2(MSL). A study of the interaction between 1,3-diketones and [MoO_2(SL)] is presented in this paper. As part of the study, UV-Vis, magnetic, IR, NMR, and thermal characterization were carried out on five MoO_2(VI) compounds. The coordination number of Mo will be six. The molybdenum octahedral geometry in these compounds consists of 4 N- and 2 O-atoms. When tested against *S. aureus* and *S. typhi*, there was moderate activity in all compounds synthesized. It is based on the chelation hypothesis that antibacterial tasks progress.

Keywords: Molybdenum(VI), Furil, β-diketones, macrocyclic compounds, Schiff base, Chelation presumption, Antibacterial activity.

INTRODUCTION

A macrocyclic compound must contain at least nine atoms, including all heteroatoms. Three donor atoms must be present in this type of compound. The progress of macrocyclic compounds has accelerated over the past decades[1-5]. A significant role is played in coordination chemistry by ligands containing N-atoms and their compounds. The physicochemical and biochemical properties of metal compounds are explored in various research papers[6-11]. The transamination reactions of transitional Schiff bases with vitamin B6 can be catalyzed by a formulation containing transitional Schiff bases with vitamin B6[12,13]. Additionally, Schiff base compounds have antitumor, antifungal, and antiviral properties as well as anti-inflammatory properties[14-20].

In the bioinorganic field, Schiff base compounds can be used to model metal positions in metalloproteins and enzymes[21]. It has been shown that various Schiff bases have greater anticancer activity than isolated ligands[22-29]. Additionally, consumer electronics memory storage devices and chemistry reactions continue to fascinate them.

Different configurations and coordination numbers are found in ligands with extreme density in transition metal compounds[30,31]. It is possible to adapt molybdenum in this aspect because of its multiple oxidation states. There is also a range of coordination numbers from 4 to 8[32]. Molybdenum compounds can be combined with ligands containing heteroatoms to form Schiff base structures, which can be utilized in both homogeneous and heterogeneous reactions. Moreover, MoO_2 compounds possess multiidentate ligands, enabling them to be applied in a range of biological applications[33-39]. Aqueous solutions of Mo(VI) can readily deliver $[MoO_4]^{2-}$. $[MoO_4]^{2-}$ ion concentration can be determined by pH and solution concentration. Oxygen transfer can be accomplished through the $[MoO_4]^{2-}$ ion, which has been shown to exist as a template. Molybdenum oxotransferase is negatively affected by their oxygen transfer properties[40-43]. A number of redox enzymes have been shown to be fully oxidized. These active sites contain cis-dioxomolybdenum moiety.

Human pathogenic microorganisms, animal pathogens, and vegetation pathogens require molybdenum as a biometal[44-48]. A lot of research is currently being conducted on Mo(VI) coordinate chemistry because of its biological properties and catalytic properties[49-52]. Oxomolybdoenzymes are set up by molybdenum molecules[53-55]. Furil may be useful as a chelating agent since it can be used in a variety of ways. Due to its reactive carbonyl groups, diamines and furils may undergo Schiff base condensation. It is essential for the synthesizing of macrocyclic ligands to use furil.

Under certain conditions, the reactions of diamine with furil can synthesize furil's denticity ligands. 1,3-Diketones are formed by the impact of metal templates on synthesized compounds. The proposed structures have been corroborated by various analytical techniques, including TG, molar conductivity, NMR, IR, and UV-Visible spectroscopy.

EXPERIMENTAL

Materials

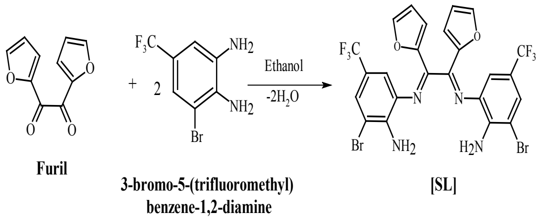
A reagent grade chemical was used by chemists to prepare Schiff bases (ligands) and compounds from business resources. Additionally, we obtained molybdenyl acetylacetonate, trifluoromethyl benzene-1,2-diamine, furil, and 1,3-diketones without further refinement from Aldrich.

Physical Measurements and Analytical Methods

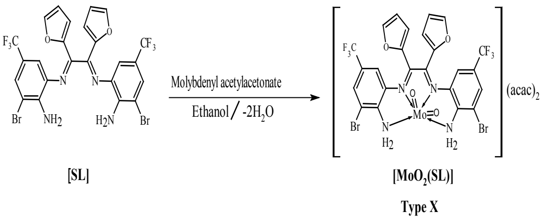
For synthesized compounds, Kjeldahl's method is used to determine nitrogen content. After decaying the compound, molybdenum was measured using a gravimetric method[56]. A method of estimating sulfur was developed for barium sulfate[57]. Sulfuric acid baths were used in addition to general methods for calculating uncorrected melting points. UV spectra were computed using a Labinda-UV 3000+UV/Vis spectrophotometer in ethanol. The Infrared spectra of compounds MoO_2(VI) were recorded using ATR at UPTTI Kanpur. Spectrometer PLN 2-II JMM ECS-400 (JEOL) was employed for ^1H NMR spectrum of MoO_2(VI) compounds. Thermal Analyser USA, SDT Q600 V 20.9 Built 20 was employed to investigate the temperature distributions of MoO_2(SL) in nitrogen gas atmosphere from 50-900°C with a heating rate of 10°C $minute^{-1}$.

Mo(VI) compounds synthesis

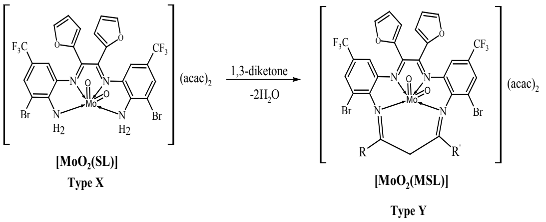
Here are three schemes for synthesizing $[MoO_2(MSL)]$. After dropping 5 mmol of molybdenyl acetylacetonate into ethanol drop-wise, furil (5 mmol) and 3-bromo-5-(trifluoromethyl) benzene-1,2-diamine (10 mmol) into ethanol were added. Two hours after the reaction mixture has been refluxed slightly, the solution has turned brown color. The product was then washed in ethanol and vacuum-isolated using silica gel after filtering. An analysis of the compound's purity was conducted using TLC. Therefore, the yield (Type X) increased to 55%. In Fig. 1 and 2, MoO_2(SL) and Schiff base ligand (SL) are shown as 3D structures.



Scheme 1. Preparation of ligand



Scheme 2. Preparation of $[MoO_2(SL)]$ Scheme



3. Synthetic route to [MoO$_2$(MSL)]

MSL^1: R = CH_3, R' = CH_3; MSL^2: R = C_6H_5, R' = CH_3; MSL_3: R = C_4H_3S, R' = CF_3; MSL_4: R = C_6H_5, R' = C_6H_5

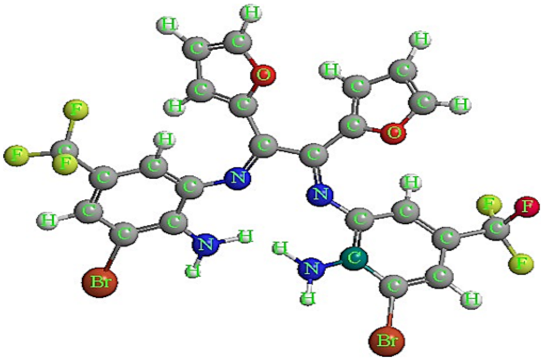


Fig. 1. 3D structure of ligand

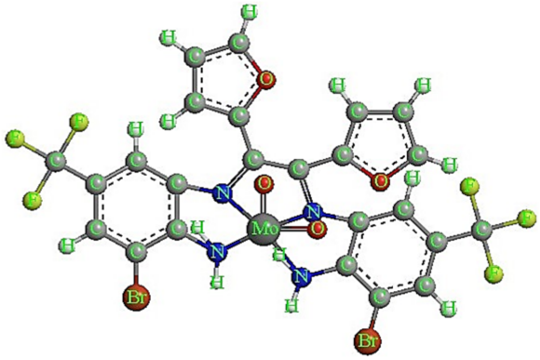


Fig. 2. 3D structure of [MoO$_2$(SL)]

After 3 h the 1,3-diketones were added to Kind X ethyl alcohol solution and a solid product was formed. Pigments of Type Y were isolated as yellow solid macrocyclic stable products from the reaction with 1,3-diketones (0.5 mmol : 0.5 mmol). Macrocyclic compounds are tested for purity by TLC.

Where,

Abbreviations: SL = Schiff base ligand; MSL^1 = compound with ligand and 2,4-pentanedione; MSL^2 = compound with ligand and Benzoylacetone; MSL^3 = compound with ligand and 2-Thenoyltrifluoroacetone; MSL^4 = compound with ligand and Dibenzoylmethane.

Elemental analysis (Table 1) data further supports the fact that they are 1:1 metal: ligand complex.

Antibacterial activity assay

An agar-well diffusion process was used to test resistance to antibacterial agents in several strains of bacteria. Diffusion in agar-wells was conducted[58-60]. A similar level of antibacterial activity was obtained by Doxycycline as well as other antibiotics. A metallic borer was used to drill 6 mm-diameter holes in agar media. We adjusted the density of all bacterial suspensions to $3x10^5$ CFU per mL. Standardized suspensions were used to expand agar. A 1% DMSO solution of 300 g per liter of the produced compounds was used in the investigation. The examined samples were poured into each well. A remainder of the wells contained DMSO (0.05%) and Doxycycline (0.5%). Growth inhibition is determined after 35 h of incubation at 355°C.

Table 1: CHN data of ligand and its compounds

Compound	Yield%	E.F.	F.W.	m.p.(°C)	(%) Calcd./(found)				
					C	S	N	Mo	H
SL	46	$C_{24}H_{14}Br_2F_6N_4O_2$	664.2	130	43.40 (42.5)	--	8.43 (8.35)	--	2.12 (2.10)
[MoO$_2$(SL)]	50	$C_{34}H_{28}Br_2F_6MoN_4O_8$	990.35	135	41.23 (41.15)	--	5.65 (5.60)	9.68 (9.61)	2.84 (2.80)
[MoO$_2$(MSL^1)]	55	$C_{39}H_{32}Br_2F_6MoN_4O_8$	1054.44	128	44.42 (44.35)	--	5.31 (5.24)	9.09 (9.00)	43.05 (42.90)
[MoO$_2$(MSL^2)]	50	$C_{44}H_{34}Br_2F_6MoN_4O_8$	1116.51	140	47.33 (47.27)	--	5.01 (4.95)	8.59 (8.53)	3.06 (3.02)
[MoO$_2$(MSL^3)]	48	$C_{42}H_{32}Br_2F_6MoN_4O_8S$	1122.54	135	44.93 (44.85)	2.85 (2.82)	4.99 (4.93)	8.54 (8.50)	2.87 (2.85)
[MoO^2(MSL$_4$)]	52	$C_{49}H_{36}Br_2F_6MoN_4O_8$	1178.59	130	49.93 (48.90)	--	4.75 (4.71)	8.14 (8.10)	3.07 (3.00)

RESULTS AND DISCUSSION

Infrared spectra

The scheme shows the synthesis of dioxomolybdenum(VI) through an in-situ reaction of furil, molybdenum salt, and diamine in a 1:1:2 aqueous ethanol solution. The IR spectra of ligands and compounds exhibit several bands, detailed in Table 2. A macrocyclic species with azomethine N-atoms coordinated to molybdenum shows decreased νC=N absorption frequencies[61-64]. The band positions for isolated ligand >C=N absorbances are 1645-1670 cm^{-1} [61,62], and a Mo-N non-ligand vibration at 510-570 cm^{-1} might cause this[65]. Furil shows >C=N bands around 1660 cm^{-1}, making it a strong chelate ligand for diamines[66,67]. Various ring and C-H vibrations are noted in the IR of MoO_2(VI) compounds and isolated ligands, with asymmetrical and symmetrical (N-H) wide bands at 3435 and 3080 cm^{-1}, respectively. The absence of the NH group indicates that [MoO_2(SL)] and [MoO_2(MSL)] are identical. Mo(VI) compounds are mainly bonded via d-orbitals, typically forming cis-dioxo groups. The C_{2V} symmetry of dioxomolybdenum(VI) compounds reveals both$_{asymmetric}$ and symmetric$_{O=Mo=O}$ vibrations in the IR spectrum[68-76]. The $\nu_{asym(O=Mo=O)}$ vibration is at a lower energy than the $\nu_{sym(O=Mo=O)}$[77,78]. Bands around 1555-1572 cm^{-1} and 1465-1480 cm^{-1} in the outer coordination sphere correspond to C=O and C=C frequencies[79]. A similar spectral pattern can be observed for macrocyclic compounds in the infrared region. The presence of amino groups attached to the carbonyl group in 1,3-diketones eliminates the asymmetric and symmetric stretching vibrations of these functional groups[79,80].

Table 2: IR bands of free ligand and its molybdenum compounds (ν/cm^{-1}) KBr, 4000-400 cm^{-1}

Compound	C=N	Mo-N	C=O (acac)	ν of C=C (acac)	$\nu_{asym(O=Mo=O)}$	$\nu_{sym(O=Mo=O)}$	$\nu_{asym (N-H)}$	ym(N-H)
SL	1670	---	---	---	---	---	3330	3085
[MoO_2(SL)	1645	510	1565	1465	910	975	3435	3080
[MoO_2(MSL^1)]	1664	570	1572	1480	890	968		
[MoO_2(MSL^2)]	1660	535	1560	1472	915	972		
[MoO_2(MSL^3)]	1650	565	1555	1470	904	960		
[MoO_2(MSL^4)]	1655	545	1564	1470	894	972		

^{1}H NMR spectra

In DMSO-D_6, all MoO_2(VI) compounds and their ligands were analyzed by ^{1}H NMR. SL should present a signal because of NH_2 at δ (5.30) as in [MoO_2(SL)] at δ (7.22) but not for other macrocyclic compounds, indicating the presence of 1,3-diketones from which cyclization results[81,82]. All ten protons of the ligand are found in δ (7.43-6.53) multiplets in isolated ligands and molybdenum compounds. Protons on aromatic rings show ~ δ 7.30 peaks. The reason for these shifts was attributed to two types of azomethine used during the preparation of the macrocyclic compound.

^{1}H NMR in DMSO-D_6: SL: N-H (δ = 5.30, 4H), HC-Ar (δ = 7.43, 2H; 7.17, 2H), HC-furan (δ = 6.53, 4H; 7.84, 2H); [MoO_2(SL)]: N-H (δ = 7.22, 4H), HC-Ar (δ = 7.30, 2H; 7.40, 2H), HC-furan (δ = 6.53, 4H; 7.84, 2H); [MoO_2(MSL^1)]: HC-Ar (δ = 7.46, H; 7.63 2H), HC-furan (δ = 6.53, 4H; 7.84, 2H), =C-CH_3 (δ = 0.87, 6H), -CH_2(δ = 1.05, 2H); [MoO_2(MSL^2)]: HC-Ar (δ = 7.46, 2H; 7.63, 2H), HC-furan (δ = 6.50, 4H; 7.45, 2H), -CH_2 (δ = 1.05, 2H); [MoO_2(MSL^3)]: HC-Ar (δ = 7.46, 2H; 7.63, 2H), HC-furan (δ = 6.50, 4H; 7.75, 2H), =C-CH_3 (δ = 0.87, 3H), -CH_2 (δ = 1.05, 2H), HC- thienyl (δ = 7.50, 1H; 7.25, 1H; 7.36, 1H); [MoO_2(MSL_4)]: HC-Ar (δ = 7.46, 2H; 7.63, 2H), HC-furan (δ = 6.45, 4H; 7.65, 2H), -CH_2 (δ = 1.05, 2H).

UV-Visible spectra

Ligand and dixomolybdenum(VI) compounds suggest a strength energy level scheme that is consistent with these spectra in ethanol[83,84]. Dichomolybdenum(VI) compound spectra are similar to those of tetradentate ligands. It is no longer expected that the Mo(VI) ion will exhibit pure d-d absorption bands due to its lack of d- electron. There is a charge transfer between Molybdenum d-orbitals and nitrogen d-orbitals in all molybdenum compounds [$N(\pi)\longrightarrow d(Mo)$]. It exhibits homogeneous UV-Vis spectra when nitrogen donor atoms are present in dioxomolybdenum(VI). These compounds show intense UV-Vis absorption bands at 290 and 315nm attributed to intraligand transitions and $n\longrightarrow\pi^*/\pi\longrightarrow\pi^*$ transitions. It seems to have $N(\pi)\longrightarrow d(Mo)$ in the region of 380–395nm for the band.

Other bands can also accommodate transitions $^2B_2\rightarrow{}^2A_1$ ($d_{xy}\rightarrow d_{x2-y2}$) which are well-suited for mediating charge transfer between LUMO and HOMO. Diagrams of Ballhausen-Gray energy levels have been provided for these compounds. Almost all compounds have octahedral distortions in their electronic spectrums[85-87].

Magnetic properties

Regarding dioxomolybdenum(VI) compounds, diamagnetism does not need to be mentioned when referring to d0 configuration. These electrons are missing in the d-orbitals, so no d-d transitions can be calculated for these compounds. Λ_M of these Mo compounds in DMF at approximately 10^{-3} M show a 1:1 sort electrolyte. These compounds exhibit Λ_M values of 97–115 Ω^{-1} cm^2 mol^{-1}. Molar conductance values suggested tentative shapes for both Type X and Type Y compounds, as predicted by the schemes.

Thermogravimetric analyses

The TG curve of a compound decomposed in one step is illustrated in Fig. 3. Approximately 83.1% of the weight is lost at 279°C due to the decomposition of the Schiff ligands and acetylacetonates, with the calculated weight being around 83%. A residue of 16.3% of MoO_3 remains after heating to 281°C. This weight percent is attributed to MoO_2 at 324°C and is 14.48.

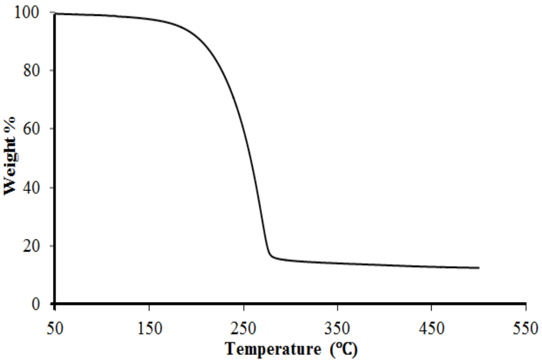


Fig. 3. [MoO$_2$(SL)] TG thermograph

Antibacterial activity

The dioxomolybdenum(VI) compounds in Table 3 possess antimicrobial properties. The results of the formed compounds on various bacteria such as *S. aureus, B. subtilis, E. aerogenes* and *S. typhi* were compared. An explanation for the improved antibacterial properties of Mo(VI) compounds can be found in the chelation presumption[79,80]. most cases, the compounds had a modest or low impact on *B. subtilis*, and *S. typhi*.

By using the positive control, we calculate the percentage inhibition effect using Eq 1.

$$\%\ inhibition\ effect = \frac{extract\ inhibition\ halo\ diameter}{positive\ controlinhibition\ halo\ diameter} X\ 100 \quad (1)$$

Table 3: Data for antibacterial activities exhibited by various bacterial speciesa

Compound	*S. aureus*	*E. aerogenes*	*S. typhi*	*B. subtilis*	*Doxycycline*
[MoO$_2$(SL)]	19	20	15	17	25
[MoO$_2$(MSL^1)]	17	21	16	16	24
[MoO$_2$(MSL^2)]	18	20	19	17	24
[MoO$_2$(MSL^3)]	18	19	16	17	26
[MoO$_2$(MSL^4)]	17	19	16	15	24

[a] DMSO is used to dissolve 300 μg mL^{-1} of material per well in cups and wells. The inhibition zones range from 23-26, 15-18, and 19-22 for strong, moderate, good activity respectively. The antibiotic drug doxycycline is used as a reference drug for the measurement of inhibition zones (mm).

InChI

InChI=1S/C24H14Br2F6N4O2.Mo.2O/c25-13-7-11(23(27,28)29)9-15(19(13)33)35-21(17-3-1-5-37-17)22(18-4-2-6-38-18)36-16-10-12(24(30,31)32)8-14(26)20(16)3

InChI key of parent compound

BVPYRZUCCWATKB-UHFFFAOYSA-N

Smiles notation

FC(F)(F)c1cc(Br)c2[NH2][Mo]34(=O)(=O)[NH2]c5c(Br)cc(cc5[N]3=C(c6occc6)C(=[N]4c2c1)c7occc7)C(F)(F)F

LogP

5.50+/- 0.67

CONCLUSION

As the crystal structures of the respective compounds have not been isolated, crystal structures cannot be provided. Based on the above elemental and spectral studies, [MoO_2(SL)] or [MoO_2(MSL)] can be used to represent all compounds synthesized. These compounds have been tested for their antibacterial activity. This paper presents an analysis of dioxin derivatives derived from molybdenum Schiff bases. Two carbonyl groups, found in furil, proved this by using a flexible chelator. The geometric shape of MoO_2(VI) centers is controlled by macrocyclic products formed by their reaction with 1,3-diketones. Mo is surrounded by a distorted octahedron. Using furil and diamines, Schiff bases are condensed using dioxomolybdenum(VI) cation in an ethanol medium. Nitrogen atoms in azomethine form tetradentate bonds with molybdenum ions in synthesized Schiff bases. An ion of Mo is present in each ligand, based on analytical data.

Funding

This work was supported by the CSJM University, Kanpur, Uttar Pradesh, India under the C.V. Raman Minor Research Project Scheme (letter number CSJMU/P&C/CVR/316/2024, dated 07 March 2021).

ACKNOWLEDGMENT

It would be appreciated if the authors could thank the BoM-Secretary, D.A-V. Post-Graduate College, Kapur for the opportunity to look at the work in a laboratory setting. Fortuitously, UPTTI Kanpur India supplies analytical facilities.

Conflict of Interest

The financial interests of the authors are not in conflict.

REFERENCES

1. Healy, M.D.S.; Rest, A.J. Template reactions., *Advances Inorganic Chemistry and Radiochemistry.,* **1978**, *21*, 1-40, https://doi.org/10.1016/S0065-2792(08)60277-0
2. Sergienko, V.S.; Abramenko, V.L.; Gorbunova, Y.E. Dioxomolybdenum (VI) Complexes with R1-Substituted Salicylidene Allylimines (Hl n): Synthesis and Structure. Crystal Structure of [MoO 2 (L 1) 2](R 1= H)., *Russian Journal of Inorganic Chemistry.,* **2018**, *63*, 28-33, https://doi.org/10.1134/S003602361801014X
3. Melson, G.A. Coordination Chemistry of Macrocyclic Compounds. Plenum Press, NY., **1979**.
4. Lindoy L.F.; Busch, D.H., *Preparative Inorganic Reactions*., **1971**, *6*, 1.
5. Lindoy, L.F.; Busch, D.H. Metal ion-controlled syntheses of novel five-coordinate zinc and cadmium complexes containing a helical coordination geometry and their template reaction to form complexes of a pentadentate macrocyclic ligand., *Inorganic Chemistry.,* **1974**, *13*(10), 2494-2498, https://doi.org/10.1021/ic50140a037
6. Luo, X.F.; Hu, X.; Zhao, X.Y.; Goh, S.H.; Li, X.D. Miscibility and interactions in blends and complexes of poly(4-methyl-5-vinylthiazole) with proton-donating polymers., *Polymer.,* **2003**, *44*(18), 5285-5291, https://doi.org/10.1016/S0032-3861(03)00578-0
7. Murthy, A.S.N.; Reddy, A.R. Electronic absorption spectroscopic studies of enolimine-ketoamine equilibria in Schiff bases., *Journal of Chemical Scences.,* **1981**, *90*(6), 519-526, https://www.ias.ac.in/article/fulltext/jcsc/090/06/0519-0526
8. Razakantoanina, V.; Phung, N.K.P.; Jaureguiberry, G., *Antimalarial activity of new gossypol derivatives, Parasitology Research.,* **2000**, *86*(8), 665-668, https://doi.org/10.1007/pl00008549
9. Royer, R.E.; Deck, L.M.; Vander T.J.; Jagtm, Synthesis and anti-HIV activity of 1,1'-dideoxygossypol and related compounds., *Journal of Medicinal Chemistry.,* **1995**, *38*(13), 2427-2432, https://doi.org/10.1021/jm00013a018
10. Flack, M.R.; Pyle, R. G.; Mullen, N.M. Oral gossypol in the treatment of metastatic adrenal cancer., *Journal of Clinical Endocrinolology Metabolism.,* **1993**, *76,* 1019-1024, https://doi.org/10.1210/jcem.76.4.8473376
11. Baumgrass, R.; Weiwad, M.; Erdmann, F. Reversible inhibition of calcineurin by the polyphenolic aldehyde, gossypol., *The Journal of Biological Chemistry.,* **2001**, *276*(51), 47914-47921, https://doi.org/10.1074/jbc.m103273200
12. Al-Shihri, A.S.M.; Abdel Fattah, H.M. Thermogravimetric and Spectroscopic characterization of trivalent lanthanide chelates with some Schiff base., *Journal of Thermal Analysis Calorimetry.,* **2003**, *71*(2), 643-649, https://doi.org/10.1023/A:1022880615841

13. Raman, N.; Sakthivel, A.; Rajasekaran K. Synthesis and spectral characterization of antifungal sensitive Schiff base transition metal complexes., *Mycobiology.,* **2007**, *35*(3), 150-153, https://doi.org/10.4489/MYCO.2007.35.3.150
14. Creaven, B.S.; Czeglédi, E.; Devereux, M.; Enyedy, E.A.; Kia, A.F.A; Karcz, D.; Kellett, A.; McClean, S.; Nagy, N. V.; Noble, A.; Rockenbauer, A.; Szabó-Plánka, T.; Walshab, M. Biological activity and coordination modes of copper(II) complexes of Schiff base-derived coumarin ligands., *Dalton Transactions.,* **2010**, *39*, 10854-10865, https://doi.org/10.1039/c0dt00068j
15. Doctor, V.M.; Oro, J. Mechanism of non-enzymatic transition reaction between histidine and alphaoxoyglutaric acid., *Journal of Biochemistry.,* **1969**, *112*(5), 691-697, https://doi.org/10.1042/bj1120691
16. El-Gammal, O.A.; El-Reash, G.M.A.; Goama, H.E. Mononuclear Cr(III), Mn (II), and Fe(III) complexes derived from new ONO symmetrical flexible hydrazone: synthesis, spectral characterization, optical band gap and DFT computational study., *Letters in Applied Nano Bio Science.,* **2019**, *8*(4), 743-753, https://doi.org/10.33263/LIANBS84.743753
17. Jarrahpour, A.; Khalili, D.; De Clercq, E.; Salmi, C.; Brunel, J.M. Synthesis, antibacterial, antifungal and antiviral activity evaluation of some new bis-Schiff bases of isatin and their derivatives., *Molecules*., **2007**, *12*, 1720-1730, https://doi.org/10.3390/12081720
18. Bharti, S.K.; Patel, S.K.; Nath, G.; Tilak, R.; Singh, S.K. Synthesis, characterization, DNA cleavage and in vitro antimicrobial activities of copper(II) complexes of Schiff bases containing a 2,4-disubstituted thiazole., *Transition Metal Chemistry.,* **2010**, *35*, 917-925, https://doi.org/10.1007/s11243-010-9412-8
19. Manjunatha, M.; Naik, V. H.; Kulkarni, A.D.; Patil, S.A. DNA cleavage, antimicrobial, antiinflammatory anthelmintic activities, and spectroscopic studies of Co(II), Ni(II), and Cu(II) complexes of biologically potential coumarin Schiff bases., *Journal of Coordination Chemistry.,* **2011**, *64*(24), 4264-4275, https://doi.org/10.1080/00958972.2011.621082
20. Amer, S.; El-Wakiel, N.; El-Ghamry, H. Synthesis, spectral, antitumor and antimicrobial studies on Cu(II) complexes of purine and triazole Schiff base derivatives., *Journal of Molecular Structure.,* **2013**, *1049*, 326-335, https://doi.org/10.1016/j.molstruc.2013.06.059
21. Ohashi, M.; Koshiyama, T.; Veno, T.; Yanase, M.; Fujii, H.; Watanabe, Y. Preparation of artificial metalloenzymes by insertion of Chromium(III)Schiff base complexes in to apomyoglobin mutants., *Angewandte Chemie International Edition.,* **2003**, *42*(9), 1005-1008, https://doi.org/10.1002/anie.200390256
22. Dongfang, X.U.; Shuzhi, M.A.; Guangyinng, D.V.; Qizhuang, H.E.; Dazhi, S. Synthesis, characterization and anticancer properties of rare earth complexes with Schiff base and O-phenanthroline., *Journal of Rare Earths.,* **2008**, *26*(5), 643-647, https://doi.org/10.1016/S1002-0721(08)60153-2
23. Uddin, N.; Rashid, F.; Ali S.; Tirmizi S.A.; Ahmad, I.; Zaib, S.;Zubair, M.; Diaconescu, P.L.; Tahir, M.N., Jamshed, I.; Haider, A. Synthesis, characterization, and anticancer activity of Schiff bases., *Journal of Biomolecular Structure and Dynamics.,* **2019**, *38*(11), 3246-3259, https://doi.org/10.1080/07391102.2019.1654924
24. Etain, S.E.H.; Abd El-Aziz, D.M.; Abd El-Zaher, E.H.; Ali, E.A. Synthesis spectral, antimicrobial and antitumor assessment of Schiff base derived from 2-aminobenzothiazol and its transition metal complexes., *Spectro Chim.Acta. Molecular and Biomolecular Spectroscopy*., **A2011**, *79*(5), 1331-1337, https://doi.org/10.1016/j.saa.2011.04.064
25. Cozzi, P.G. Metal-Salen Schiff base complexes in catalysis: practicalaspects., *Chemical Society Reviews.,* **2004**, *33*, 410–421, https://doi.org/10.1039/b307853c
26. Singh, R.K.; Kukrety, A.; Saxena, R.C.; Thakre, G.D.; Atray, N.; Ray, S.S. Novel triazine Schiff base-based cationic gemini surfactants: Synthesis and their evaluation as Antiwear, antifriction, and anticorrosive additives in polyol., *Industrial and Engineering Chemistry Research.,* **2016**, *55*(9), 2520-2526, https://doi.org/10.1021/acs.iecr.5b04242

27. Sathya, N.; Raja, G.; Padma; Priya, N.; Jayabalakrishnan C. Ruthenium(II) complexes incorporating tridentate schiff base ligands: Synthesis, spectroscopic, redox, catalytic and biological properties., *Applied Organometallic Chemistry.,* **2010**, *24*(5), 366-373, https://doi.org/10.1002/aoc.1621
28. Arun, V.; Sridevi, N.; Robinson, P.P.; Manju, S.; Yusuff, K.K.M. Ni(II) and Ru(II) Schiff base complexes as catalysts for the reduction of benzene., *Journal of Molecular Catalysis A: Chemical.,* **2009**, *304*(1-2), 191-198, https://doi.org/10.1016/j.molcata.2009.02.011
29. Segura, J.L.; Mancheño, M.J.; Zamora, F. Covalent organic frameworks based on Schiff-base chemistry: synthesis, properties and potential applications., *Chemical Society Review.,* **2016**, *45*, 5635-5671, https://doi.org/10.1039/c5cs00878f
30. Yadava, H.D.S.; Sengupta, S.K; Tripathi, S.C. Syntheses and spectroscopic studies on dioxouranium(VI), oxovanadium(IV) and oxozirconium(IV) complexes with tetradentate macrocyclic ligands., *Inorganica Chimica Acta.,* **1987**, *128*, 1-6, https://doi.org/10.1016/S0020-1693(00)84685-X
31. Sergienko, V.S.; Abramenko, V.L.; Surazhskaya, M.D. Intracomplex Dioxomolybdenum (VI) Compounds with Alcoholimines of Aromatic o-Hydroxyaldehydes. Crystal Structure of 2-Hydroxynaphthylidene Monoethanolimine (H_2L) and Solvated Complex [$MoO_2(L)•C_5H_5N$]., *Russian Journal of Inorganic Chemistry.*, **2020**, *65*, 495-501, https://doi.org/10.1134/S0036023620040166
32. Crans, D.C. Fifteen years of dancing with vanadium., *Pure and Applied Chemistry.,* **2005**, *77*(9), 1407-1527, http://dx.doi.org/10.1351/pac200577091497
33. Bagherzadeh, M.; Amini, M.; Parastar, H. Synthesis, X-ray structure and oxidation catalysis of a oxido–peroxido molybdenum(VI) complex with a tridentate Schiff base ligand., *Inorganic Chemistry Communications.,* **2012**, *20*, 86-89, https://doi.org/10.1016/j.inoche.2012.02.023
34. Moradi-Shoeili, Z.; Zare.; M.; Bagherzadeh, M.; Kubicki, M.; Boghaei, D.M. Preparation and structure of zinc complexes containing pincer ligands and their application for Knoevenagel condensation in water., *Journal of Coordination Chemistry.,* **2015**, *68*(2), 548-559, https://doi.org/10.1080/00958972.2014.978308
35. Bagherzadeh, M.; Amini, M.; Parastar, H. Synthesis, X-ray structure and oxidation catalysis of a oxido–peroxido molybdenum(VI) complex with a tridentate Schiff base ligand., *Inorganic Chemistry Communication.,* **2012**, *20*, 86-89, https://doi.org/10.1016/j.inoche.2012.02.023
36. Aziz, A.A.A. Synthesis, spectroscopic characterization, thermal studies, catalytic epoxidation and biological activity of chromium and molybdenum hexacarbonyl bound to a novel N_2O_2 Schiff base., *Journal of Molecular Structure.,* **2010**, *979*(1-3), 77-85, https://doi.org/10.1016/j.molstruc.2010.06.004
37. Chakravarthy, R.D.; Suresh, K.; Ramkumar, V.; Chand, D.K. New chiral molybdenum complex catalyzed sulfide oxidation with hydrogen peroxide., *Inorganica Chimica Acta.,* **2011**, *376*(1), 57-63, https://doi.org/10.1016/j.ica.2011.05.033
38. Rayati, S.; Rafiee, N.; Wojtczak, A. cis-Dioxo-molybdenum(VI) Schiff base complexes: Synthesis, crystal structure and catalytic performance for homogeneous oxidation of olefins., *Inorganica Chimica Acta.,* **2012**, *386*, 27-35, https://doi.org/10.1016/j.ica.2012.02.005
39. Rao, D.P. A review on versatile applications of novel Schiff bases and their metal complexes., *Letters in Applied NanoBioScience.,* **2019**, *8*(4), 675-681. https://doi.org/10.33263/LIANBS84.675681
40. Pushie, M.J.; George, G.N. Spectroscopic studies of molybdenum and tungsten enzymes., *Coordination Chemistry Review.,* **2011**, *255*(9-10), 1055-1084, https://doi.org/10.1016/j.ccr.2011.01.056
41. Gautam, R. K.; Singh, C. P.; Prasad S. P.; Saxena, R.; Rao, D.P. Synthesis and antibacterial activity of novel molybdenum complexes with macrocyclic Schiff base derived from furanylethanedione., *Asian Journal of Chemistry.,* **2019**, *31*, 2607-2612, https://doi.org/10.14233/ajchem.2019.22242

42. Rao, C.P.; Sreedhara, A.; Rao, P.V.; Verghese, M.B.; Rissanen, K.; Kolehmainen, E.; Lokanath, N.K.; Sridhar, M.A.; Prasad, J.S. Syntheses, structure, reactivity and species recognition studies of oxo-vanadium(V) and -molybdenum(VI) complexes., *Journal of the Chemical Society*., **1998**, *14*, 2383-2394, https://doi.org/10.1039/A801226A
43. Hahn, R.; Herrmann, W.A.; Artens, G.R.J. Kleine, M. Biologically relevant metal coordination compounds: $MoVIO_2$ and nickel(II) complexes with tridentate aromatic Schiff bases., *Polyhedron.,* **1995**, *14*(20-21), 2953-2960, https://doi.org/10.1016/0277-5387(95)00133-D
44. Mendel, R.R. Molybdenum: biological activity and metabolism., *Dalton Transaction.,* **2005**, *21*, 3404-3409, https://doi.org/10.1039/B505527J
45. Sigel, A.; Sigel, H. Metal Ions in Biological Systems, Molybdenum and Tungsten: Their Roles in Biological Processes, Marcel Dekker, NY. 39, **2002**.
46. Maurya, R.C.; Shukla, B.; Pandey, A. Synthesis, magnetic and spectral studies of some cis-dioxomolybdenum(VI) complexes derived from N, O- and N2O2- type Schiff bases., *Indian Journal of Chemistry.,* **2002**, *41*A(3), 554-559,URI: http://hdl.handle.net/123456789/29016
47. Rousso, I.; Friedman, N.; Sheves, M.; Ottolenghi, M. pKa of the protonated Schiff base and aspartic 85 in the bacteriorhodopsin binding site is controlled by a specific geometry between the two residues., *Biochemistry.,* **1995**, *34*, 12059-12065, https://doi.org/10.1021/bi00037a049
48. Bassov, T.; Sheves, M. Alteration of pKa of the bacteriorhodopsin protonated Schiff base. A study with model compounds., *Biochemistry.,* **1980**, *25*(18), 5249-5258, https://doi.org/10.1021/bi00366a040
49. Mimoum, H.; Roch, I.S.D.; Sajus, L. Epoxydation des olefines par les complexes peroxydiques covalents du molybdene-VI., *Tetrahedron.,* **1970**, *26*(1), 37-50, https://doi.org/10.1016/0040-4020(70)85005-0
50. Conte, V.; Furia, F.D. Catalytic oxidations with hydrogen peroxide as oxidant, Kluwer Academic Publisher, Berlin., **1992**.
51. Mimoum, H.; Saussine, L.; Daire, E.; Postel, M.; Fisher, J.; Weiss, R. Vanadium(V) peroxy complexes. New versatile biomimetic reagents for epoxidation of olefins and hydroxylation of alkanes and aromatic hydrocarbons., *Journal of American Chemistry Society.,* **1983**, *105*(10), 3101-3110, https://doi.org/10.1021/ja00348a025
52. Nair, M.L.H.; Thankamani, D. Synthesis and characterization of oxomolybdenum (V) and dioxomolybdenum (VI) complexes with schiff base derived from isonicotinoylhydrazide., *Indian Journal of Chemistry.,* **2009**, *48A*(9), 1212-1218, URI: http://hdl.handle.net/123456789/6010
53. Garner, G.D. Molybdenum, special topics in Comprehensive Coordination Chemistry. Wilkinson G, Ed., Pergamon press, Oxford. **1987**, *6*, 1421.
54. Niasari, M.S.; Davar, F.; Bazarganipour, M. Synthesis, characterization and catalyticoxidation of para-xylene by a manganese(III) Schiff base complex on functionalized multi-wall carbon nanotubes (MWNTs)., *Dalton Transactions.,* **2010**, *39*, 7330-7337, https://doi.org/10.1039/B923416K
55. Ambroziak, K.; Beleck, R.M.; He, Y.; Saha, B.; Sherrington, D.C. Investigation of batch alkene epoxidations catalyzed by polymer-supported Mo(VI) complexes., *Industrial and Engineering Chemistry Research.,* **2009**, *48*(7), 3293-3302, https://doi.org/10.1021/ie801171s
56. Vogel, A.I. A Text book of quantitative Inorganic analysis 4th ed., Longmans Green Co. Ltd., London., **1978**.
57. Vogel, A.I. A Text book of practical organic chemistry 4th ed., Longmans Green Co. Ltd., London., **1978**.
58. Simmons, A. Practical medical microbiology 14th ed, Churchill Livingston, Edinberg., **1996,** *11*, 163.
59. Collee, J.G..; Duguid, J.P.; Frase, A.G.; Marmion, B.D. Practical medical microbiology, Churchill Livingstone, New York., **1989**.
60. Nag, P.; Sharma, D. Synthesis, characterization and anticandidal activity of dioxomolybdenum (VI) complexes of the type $[MoO_2\{ON{=}C(CH_3)Ar\}_2]$ and $[MoO_2\{OC(R)CHC(R'){=}NC_6H_5\}_2]$. Heliyon., **2019**, *5*(5), E01729, https://doi.org/10.1016/j.heliyon.2019.e01729

61. Rana, V.B.; Singh, P.; Singh, D.P.; Teotia, M.P. Trivalent chromium, manganese, iron and cobalt chelates of a tetradentate N6 macrocyclie ligand., *Transition Metal Chemistry.,* **1982**, *7*, 174-177, https://doi.org/10.1007/BF01035836
62. Chandra, S.; Sharma, K.K. Synthesis and characterization of copper(II) complexes of a macrocyclic ligand., *Transition Metal Chemistry.,* **1983**, *8*, 1-3, https://doi.org/10.1007/BF00618784
63. Malik, W.U.; Bembi, R.; Singh, R. Preparation and characterisation of some new 12- and 14-membered dibenzotetraaza macrocyclic complexes of iron(III)., *Inorganica Chimica Acta.,* **1983**, *68*, 223-228, https://doi.org/10.1016/S0020-1693(00)88965-3
64. Głowiak, T.; Jerzykiewicz, L.; Sobczak, J.M.; Ziółkowski, J.J. New insights into the chemistry of oxomolybdenum(VI) complexes with N-salicylidene-2-aminoethanol., *Inorganica Chimica Acta.,* **2003**, *356*, 387-392, https://doi.org/10.1016/S0020-1693(03)00301-3
65. Ferraro, J.R. Low frequency vibrations of inorganic and coordination compounds. Plenum, New York., **1971**.
66. Dyer, J.R. Applications of absorption spectroscopy of organic compounds. Prentice-Hall, Inc., Englewood Cliffs, NJ, **1965**.
67. Singh, S.; Yadav, H.S.; Yadava, A.K.; Rao, D.P. Synthesis and characterization of oxovanadium(IV) complexes with tetradentate Schiff base ligands having thenil as precursor molecule., *Current Research in Chemistry.,* **2011**, *3*, 106-113, https://doi.org/10.3923/crc.2011.106.113
68. Willis, L.J.; Loehr, T.M.; Miller, K.F.; Bruce, A.E.; Stiefel, E.I. Raman and infrared spectroscopic studies of dioxomolybdenum(VI) complexes with cysteamine chelates., *Inorganic Chemistry.,* **1986**, *25*, 4289-4293, https://doi.org/10.1021/ic00243a045
69. Ceylan, B.I.; Kurt, Y.D.; Ulkuseven, B. Synthesis and characterization of new dioxomolybdenum(VI) complexes derived from benzophenone-thiosemicarbazone (H_2L). Crystal structure of [MoO_2L(PrOH)]., *Journal of Coordination Chemistry.,* **2009**, *62*, 757-766, https://doi.org/10.1080/00958970802339669
70. S.N. Rao, K.N. Munshi, N.N. Rao, M.M. Bhadbhade, E. Suresh. Synthesis, spectral and X-ray structural characterization of [cis-MoO_2(L)(solv)](L = salicylidene salicyloyl hydrazine) and its use as catalytic oxidant., *Polyhedron.,* **1999**, *18*, 2491-2497, https://doi.org/10.1016/S0277-5387(99)00139-4
71. El-Medani, S. M.; Aboaly, M.M.; Abdalla, H.H.; Ramadan, R.M. Reactions of Group 6 Metal Carbonyls with Salicylaldehyde Hydrazone., *Spectroscopy Letter.,* **2004**, *37*(6), 619-632, https://doi.org/10.1081/SL-200037610
72. Zhu, X.W. Synthesis, crystal structures and catalytic property of dioxomolybdenum(VI) complexes derived from tridentate Schiff bases., *Acta Chimica Slovenica.,* **2018**, *65*, 939-945, https://doi.org/10.17344/acsi. 2018.4607
73. Maurya, R.C.; Chourasia, J.; Martin, M.H.; Roy, S.; Sharma, A.K.; Vishwakarma, P. Dioxomolybdenum(VI) chelates of bioinorganic, catalytic, and medicinal relevance: Studies on some cis-dioxomolybdenum(VI) complexes involving O, N-donor 4-oximino-2-pyrazoline-5-one derivatives., *Arabian Journal of Chemistry.,* **2015**, *8*(3), 293-306, https://doi.org/10.1016/j.arabjc.2011.01.010
74. Wang, X.; Zhang, X.M.; Liu, H.X. Synthesis, characterization and crystal structure of cis-dioxomolybdenum(VI) complexes of the Schiff base Girard reagent (T) salt., *Journal of Coordination Chemistry.,* **1994**, *33*, 223-228, https://doi.org/10.1080/00958979408024280
75. Mahmoudi, H.; Bagherzadeh, M.; Ataie, S.; Kia, R.; Heydar Moravej, S.; Zare, M.; Raithby, P.R.; Ferlin, F.; Vaccaro, L. Synthesis and X-ray crystal structure of a molybdenum(VI) Schiff base complex: Design of a new catalytic system for sustainable olefin epoxidation., *Inorganica Chimica Acta.,* **2020**, *511*, 119775, https://doi.org/10.1016/j.ica.2020.119775
76. Rao, D.P.; Yadav, H.S.; Yadava, A.K.; Singh, S.; Yadav, U.S. Syntheses and spectroscopic studies on macrocyclic complexes of dioxomolybdenum(VI) with furil as precursor., *E-Journal of Chemistry.,* **2012**, *9*, 497-503, https://doi.org/10.1155/2012/205123
77. Cotton, F.A.; Wilkinson, G.; Murillo, C.A.; Bochmann, M. Advanced Inorganic Chemistry., 6th ed., Wiley, New York., **1999**, *18*, 944-947.

78. Nakamoto, K. Infrared and Raman Spectra of inorganic and co-ordination compounds. New York: Wiley, **1978**, https://doi.org/10.1002/0470027320.s4104
79. Gehrke, H.; Veal, J. Acetylacetonate complexes of molybdenum(V) and molybdenum(VI)., *Inorganica Chimica Acta.,* **1969**, *3*, 623-627, https://doi.org/10.1016/S0020-1693(00)92563-5
80. Yadav, H.S. Synthesis of spectroscopic studies of oxovanadium(IV) complexes with 16- and 18-membered macrocyclic ligands., *Polyhedron.,* **1993**, *12*, 313-317, https://doi.org/10.1016/S0277-5387(00)81729-5
81. Garg, R.; Saini, M.K.; Fahmi, N.; Singh, R.V. Spectroscopic and biochemical studies of some manganese(II), oxovanadium(V) and dioxovanadium(VI) complexes S/O and N donor agents synthesized under microwave conditions., *Transition Metal Chemistry.,* **2006**, *31*, 362-367, https://doi.org/10.1007/s11243-005-0001-1
82. Kahroic, E.; Molcanov, K.; Tusek-Bozic, L.; Kojic-Prodic, B. New complexes of Mo(V) with Schiff bases: Crystal structure of butylammonium di-μ-oxo-μ-acetato-bis[(N-butylsalicylideniminato-N,O) oxomolybdenum(V)] benzene, acetic acid solvate., *Polyhedron.,* **2006**, *25*(12), 2459-2464, https://doi.org/10.1016/j.poly.2006.02.008
83. Rao, D.P.; Yadav, H.S.; Yadava, A.K.; Singh, S.; Yadav, U.S. In-situ preparation of macrocyclic complexes of dioxomolybdenum(VI) involving a heterocyclic precursor., *Journal of Coordination Chemistry.,* **2011**, *64*, 293-299, https://doi.org/10.1080/00958972.2010.544037
84. Sakata, K.; Kuroda, M.; Yanagida, S.; Hashimoto, M. Preparation and spectroscopic properties of oxovanadium(IV) and dioxomolybdenum(VI) complexes with tetraaza[14] annulenes containing pyridine rings., *Inorganica Chimica Acta.,* **1989**, *156*, 107-112, https://doi.org/10.1016/S0020-1693(00)90375-X
85. Gautam, R.K.; Singh, C.P.; Kumar, D.; Rao, D.P. New Insights into the Chemistry of cis-Dioxomolybdenum(VI) Schiff base complexes with macrocyclic ligands., *Chemical Science Transactions.,* **2019**, *8*(4), 467-476, https://doi.org/10.7598/cst2019.1594
86. Gautam, R.K.; Singh, C.P.; Saxena, R.; Rao, D.P. Synthesis and studies of some cis-MoO_2(VI) complexes with nitrogen donor macrocyclic ligands., *European Chemical Bulletin*., **2019**, *8*, 387-393, http://dx.doi.org/10.17628/ecb.2019.8.387-393
87. Ballhausen, C.J.; Gray, H.B. The electronic structure of the vanadyl ion., *Inorganic Chemistry.,* **1962**, *1*, 111-122, https://doi.org/10.1021/ic50001a022