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Applications of Polyoxometalates (A Review)

BARKHA RATHEE,[1] MUKHAN WATI[2]* RAVINDER SINDHU,[3] and SUCHITA SINDHU[4]

[1,2]Department of Chemistry, Maharshi Dayanand University, Rohtak-124001, Haryana, India.
[3]Department of Physics, Kurukshetra University Kurukshetra-136119, Haryana, India.
[4]Department of Chemistry, Guru Jambheshwar University of Science& Technology, Hisar-125001, Haryana, India.
*Corresponding author E-mail: mukhandagar88@gmail.com

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ABSTRACT

Polyoxometalates are inorganic clusters having remarkable structure and composition. They function as anti-cancer, anti-bacterial and anti-viral drugs as well. A wholesome outline of polyoxometalates has been attempted encompassing their diverse nature owing to their structure and scope of application.

Keywords: Polyoxometalates, Anti-cancer, Anti-viral, Anti-bacterial drugs.

INTRODUCTION

The purpose of the review is a salute to the heterogenity of polyoxometalates (from now on POMs) chemistry and the innumerable applications in biomedical field as well. Berzelius mentioned about the POMs in 1826 and referred to them as “Molybdenum blues”.[1] These are negatively charged oxide anion clusters of early transition metals namely vanadium, niobium in their highest oxidation states. More precisely they are oligomeric aggregates of metal cations with d(0) configuration: V(V), Nb(V), Ta(V).[2] Today they contribute to development in areas ranging from microelectronics to medical.[3,4] Almost any elements can be incorporated in POMs thus leading to diversity in structures.[5-8] The species is linked with the help of oxide anions which form by self-assembly. These are classically heteropoly anions containing oxygen atoms, hydrogen atoms and at least two atoms of other elements. These complexes have relatively stable thermodynamic arrangement. They retain their identities in aqueous, non-aqueous and even in ionic crystals.

Classification of polyoxometalates

There are 2 comprehensive families of polyoxometalates namely

1. Isopolyoxometalates
2. Heteropolyoxometalates

In isopolyoxometalate, metal and oxide are present. It has only one d(0) metal cation. $[M_mO_Y]^{n-}$ is the general formula.

In heteropolyoxometalate, metal, oxide and a heteroatom like a silicate, phoshate or any other main group oxyanion are present. It contains one or more p, d or f block elements. The general formula for this may be $[M_mO_yX_x]^{m-}$. The heteroatoms in heteropolyoxometalates may be buried or on the surface. As the heteropolyoxometalates are several in count, their structural and electronic properties of these moieties are easier to change compared to isopolyoxometalates.[9,10]

Also, the growing family of POMs can be classified as[11] transition metal substituted POMs and lanthanide substituted POMs. These types of POMs are formed by modification and incorporation of metal ions. In addition to stabilizing high oxidation state, TMSPOMs offer other advantages as well. By varying the cations present, solubility can be adjusted. Also their redox properties are adjustable.[12]

When the heteroatom like P or Si tetrahedrally coordinated, the structure is Keggin and Dawson type. Similarly when the heteroatom like Al is octahedrally coordinated, the structure is Anderson type. Lindqvist structure is adopted by hexametalates $[M_6O_{19}]^{m-}$. There is an octahedral arrangement of six octahedral. Each octahedra shares it's four edges and has a compact structure. The lindqvist structure resembles the ccp arrangement of metal oxide. However, the paramolybdate $[Mo_7O_{24}]^{6-}$ is found to have a bent structure. HeteroPOMs $[XM_6O_{24}]^{m-}$ mostly are present in Anderson type of arrangement. The octahedral is formed by sharing of six edges and forming a planar hexagon arrangement around the central metal atom. The tetrahedrally coordinated heteroatom has the common structure resembling as that of Keggin type $[XM_{12}O_{40}]^{n}$. There are four trimetallic groups arranged tetrahedrally around central metal atom. $[X_2M_{18}O_{62}]^{n-}$ has Dawson structure and is found to be a combination of 2 Keggin ions. In the structure, a trimetallic group is removed on each of the Keggin structure and the fragments which remain are joined. Another important type of structure is lacunary structure. This structure is obtained by selectively removing one or more metal ions by adding alkali. Open coordination sites are available which can be occupied by metal or non-metal atoms. The coordination bonds are formed reversibly and the oxo bridges which are formed are cleaved by base. The products thus formed are called lacunary structures.[13]

Keggin type POM, $[XW_{12}O_{40}]^{n-}$, as a member of the heteropolyoxometalates, was first structurally determined by Keggin in the 1930s using X-ray powder diffraction.

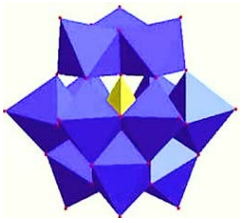

Fig. 1. Keggin structure of POM[13]

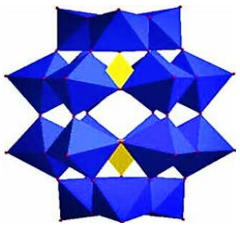

Fig. 2. Wells-Dawson structure of POM[13]

It consists central XO_4 tetrahedron surrounded by four triads at each of its vertices.[14] The triads are linked by corner-sharing or edge-sharing with each other. Geometrically, five isomers have been prepared by Baker and Figgis.[15] The α-isomer has tetrahedral geometry and is known to be the most prominent and thermodynamically stable. Rotation of one of the triads by 600 gives rise to β isomer. The γ, δ and ε isomers are also obtained by successive rotation of triads by 600 each.[16]

Another well known structure is called Wells-Dawson model. It is formed by two tetrahedral XO_4. The β, γ-isomers of Wells-Dawson model can be obtained by rotation of one or two W_3O_{13} groups of α-isomer by 600.[17] Among the six isomers of Dawson structure, 4 have been reported and the α- and β-isomers are the most common. The trivacant anion, α-$[P_2W_{15}O_{56}]^{12-}$, as one of the widely used lacunary POM ligands, is formed by the removal of one W3 "cap" unit from α-$\{P_2W_{18}\}$.[18]

Functionalized POMs

The four subcategories of functionalized POMs

1. Metal containing derivatives of POMs
2. Organometallic derivatives of POMs
3. Organic derivatives of POMs
4. Terminal multiple bonded ligands POMs

Metal containing derivative of lacunary POMs

This subclass contains complexes like $[PW_{11}O_{39}RhCH_2COOH]$ which carry a terminal functional group. Various transition metal derivatives are catalytically used for epoxidation of many oxidising agents.

Organometallic derivative of POMs

This subcategory of POMs causes immobilization of catalytically active POMs and hence facilitates the identification of biological destinations of interest.[19]

Organic derivatives of POMS

Majorly alkoxo, organosilyl and organophoshoryl derivative are prevalent.[20,21] O-alkylation and esterification of POMs can be used to form alkoxo derivatives. Organosilyl derivatives are obtained by reaction of organochlorosilanes on lacunary POMs. Also self-assembly can give the required POMs.[22,23]

Terminal multiple bonded ligands POMs

POMs where the extreme oxo ligands have been replaced by multiple bonded ligands forms the another class of POMs. These can be obtained by performing a reaction analogous to Wittig reaction. Like its other counter parts, this reaction can also take place alternatively by self-assembly.

Overview of POMs

Synthesis

The hydroxo (OH-) and oxo (O^{2-}) ligands proceed towards transition metal and encircle them to form complexes in aqueous solution.[24-26] The higher the charge on metal ion, more easily the protons of ligands dissociate. Thus, cations in their highest oxidation state and fully oxidized form are able to form stable complexes with oxo ligands in aqueous alkaline solutions.

Following this is the acidification of the medium which results in condensation reaction and M-O-M bridges are formed.[27] As this process progresses, expansion of coordination number is witnessed which ends up in formation of condensed structures. The characteristics of the POM so formed depends on various conditions like pH, stoichiometry, type of solvent, ambient temperature, concentration and numerous compounds can be formalized by varying any of the above parameters. For example when the pHs is lowered orthometalates (formed at high pH) protonate and give rise to oxide hydroxide compounds. The species thus formed undergoes condensation through a process called “olation”. The condensation is accompanied by the loss of water and M-O-M linkages are formed. When the acidification is performed in presence of phosphates or silicates then we obtain heteropolyoxometalates.

Applications of POMs

The polyoxometalates have innumerable applications in various fields of the world today but the most fascinating one is their applications in medicine. Thus there are several studies going on, in fact, have been occurring since past many decades to study the anti-cancer, anti-viral and anti-bacterial properties of POMs.[28,29,30,31]

Anticancer studies of POMs

Polyoxomolybdate PM-8

The investigations have been done for the medical applications of polyoxomolybdates as anticancer drugs. Yamase and coworkers recognized the antitumor activities of Anderson type polyoxomolybdate and heptamolybdate had been acknowledged by Yamase and coworkers.[32,33] They explored PM-8 *in vivo*. $[NH_3Pr^i]_6[Mo_7O_{24}].3H_2O$ is antitumor POM known as PM-8.[34]

It was probed to subdue human colon cancer, breast cancer and lung cancer. MKN-45 gastric cancer had been suppressed in mice by this particular POM; the mice had been implanted with methylcholanthrene induced tumor. PM-8 was administered daily for 9 days after having implanted the tumor cells. Also the inhibition of cell growth of AsPC-1 by PM-8 was observed. Antitumor mechanism of PM-8 resulted from the initiation of programmed cell death pathway. Talking about the properties of PM-8, it is miscible in water, stable complex in aqueous solution in the pH range of 5-7. It can be isolated as ammonium metallic organ metallic salt.[35]

Polyoxomolybdate: Cancer cell chemotherapeutic and tumor growth repression

POMs like PM-8, PM-17, PM-26 showcase antitumor activity against human cancer, MX-1, Co-4 and Meth A mouse sarcoma.[36] The chemical formula for PM-8 is hexakis (isopropylammonium) heptamolybdate (VI). From the chemical formula the

Mo_7O_{24} unit is of utmost importance for antitumor activity.[37] This Anderson type structure is well known to showcase the anticancerous properties at harmless doses *in vivo*. On monitoring the effect of POM named PM-8 on human gastric cancer, it was observed that cancer cell growth repression property of the POM was twice as compared to subgroups when tested on tumor bearing mice. It had no harmfull effects such as weight loss in mice.[38] Talking about the experimental observations, it was revealed that a dose of 100 mg/kg lead to an increase in life span for mice which were implanted with sarcoma tumor cells. On performing a comparative study with approved drugs like 5-fluorouracil it was inferred that PM-8 had more antitumor activity and is less harmful to mice.[39]

The efficacy of PM-8 against small xenografts (MX-1, OAT human cancer) has been evaluated and it was observed experimentally that PM-8 decelerated the cancerous growth of human breast cancer MX-1 and the tumor size that was identified after 46 days of incubation was only 27%. The antitumor activity of PM-8 against the human colon cancer and the human lung cancer is promising. The patients cannot be cured completely of breast, colon and lung cancer by chemotherapy because of the slow growth rate. In such scenario, PM-8 turns out to be very potent and promising. The anticancer activity is directly linked with polyoxomolybdate anion and the cationic portion controls the solubility and hence the digestibility.[40]

On carrying out slight modifications to the original PM-8 structure, mixture of reduced species of $[H_xMo_7O_{24}]^{6-}$ and one or more Mov atoms in aqueous solution, showed anticancer properties against MX-1 xenografts as fully oxidized precursor of PM-8 but the toxicity turned out to be high and led to death of mice during experiment.

Anticancer mechanism of polyoxomolybdate

The mechanism is based on ion redox reaction.

Mechanism:

$$[Mo_7O_{24}]^{6-} + e^- \longrightarrow [Mo_7O_{23}(OH)]^{6-}$$

The POM is altered in such a way

The $[NH_3Pr]$ cationic part is restored by NH_4^+ and K^+. The anion is reinstated by Cl^-. The reduction of $[Mo_7O_{24}]^{6-}$ to $[H_xMo_7O_{24}]^{6-}$ leads to execution of cancer cells. The reaction between $[H_xMo_7O_{24}]^{6-}$ and host cells leads to the formation of $[Mo_7O_{24}]^{6-}$ and hence cytotoxicity. $[Mo_7O_{24}]^{6-}$ thus formed is transmitted to tumor cells and hence they are killed. The structure of this species is thus important for anticancer activity.[41]

EXPERIMENTAL

It was revealed by flow cytometry that apoptotic cells ratio raised in the time while administering PM-8 treatment.[42] Findings showed that tumor cell cytotoxicity mechanisms is apoptosis of tumor cells.

Polyoxotungstate $[CoW_{11}TiO_40]^{8-}$

Liu, Pope and coworkers examined the cytostatic valuables of heteropolytungstates against tumor cell *in vivo*.[43-46] Main focus during the experiment was on the organic derivative of heteropolytungstate containing RSn or CpTi. There turned out to be a direct relation between reduction potential and cytotoxicity. Higher the reduction potential, higher is the cytotoxicity. Encapsulation of $[CoW_{11}TiO_40]^{8-}$ in starch nanoparticles leads to enhanced antitumor activity of polyoxotungstate.[47]

By increasing encapsulation, cell penetration of $[CoW_{11}TiO_{40}]^{8-}$ is increased hence the efficiency is increased as higher amount of complex is present inside the cells. It was reported that rare earth containing decatungstate led to growth hampering of tumor in mice. 100 mg per kilogram per day was administered that the weight of tumor for 9 days was found to be only 44%. Hence, $[CoW_{11}TiO_{40}]^{8-}$ *in vivo* activity was similar to that of cyclophosphamide and 5-FU but its toxicity is lower.[48]

Recent advances in anticancer studies of polyoxometalates

Anticancer activity of polyoxometalate-bisphosphonate complex synthesis

Mo_4ZoI_2Mn (III) is one of the most potent drugs against sarcoma cells in mouse.[49]

Molybdenum(VI) complexes with lipophilic-bisphosphonates were formed by the reaction of bisphosphonate predecessors with Molybdenum (VI) ions in aqueous solution.[50] The pH for the reaction was adjusted around 5. The crystals of the mixture

could be obtained by slow evaporation for $Mo_6(ZoIC_6)2.Mo_4ZoI_2Mn$ (II) was synthesized by reducing Mo_4ZoI_2Mn (III) complex. The reduction could not be performed in aqueous solution, hence to a suspension of crystals present in methanol ascorbic acid was added. On doing so a change in color from grey to yellow was observed. The preparation of $Mo_4(ZoIC_8)_2$ Manganese (III) included the reaction between $ZoIC_8$ and $Mn(OAc)_2$ with large amount of Na_2MoO_4 in acetate buffer.

Characterization and structure determination

31P NMR was utilized to examine whether the structures identified in solid state were carried on in solution as well. The 31P NMR spectrum of $Mo_6(ZoIC_6)_2$ showed two singlets, one at 17.1 and the other at 16.8 ppm with relative intensities of 0.63:1.37. The same trend was observed for $Mo_4(ZoIC_8)_2$ with 2 singlets. The presence of another singlet could not be because of free $ZoIC_6$ ligands as their shift value is around 14. The 31P spectra of $Mo_6(ZoIC_6)_2$ showed two peaks indicating the stability of complex in aqueous solution.

X-ray diffraction technique was used to illustrate the structure of $Mo_6(ZoIC_6)_2$. It was found out that there were two independent molecules but each of them had similar inorganic core. In the structure two $\{Mo_3O_8\}$ units are present. Both of the units are linked through a central oxygen atom and in each trimer Mo (VI) ions are present which are linked to pentadentate bisphosphate ligand by C-O-Mo and P-O-Mo bonds. The Mo(VI) ions lie in a plane. The difference in both the complexes are observed in the position of C6 alkyl chain in the imidazole ring. In one of the molecule, it was found that the chain is bent and there are short C-H….O distances (2.33-2.8 A0) while in the other molecule, the chain is extended away from the cluster. From IR elemental analysis and EDX measurements it was known that the Mo_4L_2Mn(III) and Mo_4L_2Mn(II) have structures alike Mo_4L_2Fe, that is, two $\{Mo_2O_6\}$ dimeric units with face shared Mo(VI) octahedral are bound to octahedral Mn ion and the bisphosphate ligands are connected through P-O-M and C-O-M bonds(M=Mo, Mn).[51]

The synthesized POMs were tested against human non small cell lung cancer cell line and the most active compound had IC_{50} values around 4-5 μM which turns out to be 6X more potent than Zoledronate. One of the most active compounds was tested against sarcoma cells in mouse xenograft system and the results indicated that there was 5-fold decrease in tumor cell volume as compared to Zoledronate after 28 days treatment period. The results are incredibly interesting as for the first time POM/bisphosphate/Mn complexes have potent in vivo activity. Thus by incorporating bisphosphates into POM it is possible to target Ras as well as EGFR-driven cancers.[53]

Antiviral studies of POMs

As early as 1970, the inhibitory effect of "silicotungstic acid supernatants" was observed by a group of scientists in Paris.[54] It was a cell culture which was procured during an experimental procedure in which silicotungstic acid was used. It was subsequently inferred that the prohibitive effect is due to the silicotungstate ion and this led to the study of antiviral activities of polyanions. With the advent to AIDS, the search for antiviral has increased and the use of POMs in this respect has also been encouraged. The anti-HIV property has been reported by almost 50 polyoxometalates.[55] Polytungtates such as $[NMe_3H_7][CH_3C_5H_4TiP_2W_{17}O_{61}]$ are active as anti-viral agents. POMs show activity against both DNA and RNA viruses like HIV (human immunodeficiency syndrome) and SARS (severe acute respiratory syndrome), influenza RNA virus and herpes DNA simplex virus (HSV).

Cell penetration

The extent of cell penetration alters the mechanism in which the POM performs viral inhibition. POMs are active inside the cytoplasm as well as on the surface of the cell. It is already known that these are negatively charged species and their size in nanometer range. This small size and surface charge hinder the penetration of POMs into the cells. But several evidences have been derived from various techniques and numerous types of experiment which indicate that POMs penetrate into the cell membrane. As an illustration Raman laser spectroscopy was evidently used to provide corroboration for HPA-23 entering C3HBi fibroblast cells. HPA-23: polytungstoantimoniate that was used extensively during early antiviral research on POMs. HPA acronym used for "heteropoly acid" and the molecular weight for the same is 23.

***In vitro* antimyxovirus and anti-human immuno -deficiency virus activities of POMs**

There are POMs which have shown their ability to stop the duplication of retro-paramyxo and herpses viruses. The kind of mechanism adopted by HIV-1 inhibition follows is obstruction by polyoxometalates. They inhibit the binding the viruses to cells. HS-058, the Keggin sandwich type of compound $K_{10}Fe_4(H_2O)_2(PW_9O_{34})2.H_2O$ was investigated to have inhibitory action against parainfluenza virus 2 influenza viruses A and B, measles virus and respiratory virus. However, HS-058 did not show any effect on mumps virus or parainfluenza virus 3.[56]

Table 1: Chemical formulae andclass of antiviral polyoxometalates[56]

Code No	Formulae	Class
HS-005	$(NH_4)_{17}Na[NaSb_9W_{21}O_{86}]$	Inorganic cryptate Keggin
HS-008	β-$H_4SiW_{12}O_{40}$	Wells-Dawson
HS-010	α-$(NH_4)_6P_2W_{18}O_{62}$	Preyssier
HS-026	$(NH_4)_{14}[NaP_5W_{30}O_{110}]$	Lacunary
HS-042	$Na_{12}P_2W_{15}O_{56}.18H_2O$	Wells-Dawson sandwich
HS-052	$Na_{16}Ni_4(H_2O)_2(P_2W_{15}O_{56})_2.nH_2O$	
HS-053	$Na_{16}Mn_4(H_2O)_2(P_2W_{15}O_{56})_2.nH_2O$	Wells-Dawson sandwich
HS-054	$Na_{16}Fe_4(H_2O)_2(P_2W_{15}O_{56})_2.nH_2O$	Wells-Dawson sandwich
HS-055	$K_{10}Zn_4(H_2O)_2(PW_9O_{34})_2.nH_2O$	Keggin sandwich
HS-056	$K_{10}Ni_4(H_2O)_2(PW_9O_{34})_2.nH_2O$	Keggin sandwich
HS-057	$K_{10}Mn_4(H_2O)_2(PW_9O_{34})_2.nH_2O$	Keggin sandwich
HS-058	$K_{10}Fe_4(H_2O)_2(PW_9O_{34})_2.nH_2O$	Keggin sandwich
HS-083	$\{(CH_3)_4N)_4SiW_{11}O_{39}O\text{-}(SiCH_2CH_2CH_2CH_2CH_2CH_3)_2$	Organic derivatized
HS-089	$\{(CH_3)_4N)_4SiW_{11}O_{39}O\text{-}(SiCH_2CH_2COOCH_3)_2$	Organic derivatized
HS-091	$K_8Mn(II)P_2W_{17}O_{61}.nH_2O$	Transition Metal Substituted polyoxometalate
HS-105	$(Me_3NH)_7SiW_9Nb_3O_{40}.nH_2O$	Keggin
HS-106	$(Me_3NH)_8Si_2W_{18}Nb_6O_{77}.nH_2O$	Dimerized Keggin
HS-131	$(Me_3NH)_5(NbO_2)SiW_{11}O_{39}$	Keggin peroxo
HS-132	$(Me_3NH)_5NbSiW_{11}O_{40}$	Keggin
HS-133	$(Me_3NH)_5(TaO_2)SiW_{11}O_{39}$	Keggin peroxo
HS-136	$(Me_3NH)_7(NbO_2)_2SiW_9O_{37}$	Keggin peroxo
HS-146	$K_7NbP_2W_{17}O_{62}$	Wells-Dawson
HS-157	$K_{12}(NbO_2)_6P_2W_{12}O_{56}$	Wells-Dawson peroxo
HS-158	$K_{12}Nb_6P_2W_{12}O_{62}$	Wells-Dawson

DISCUSSION

It was inferred that POMs have a broad spectrum of antiviral activity. Since the agents responsible for the cause of viral respiratory infections are not identifiable at clinical level hence it becomes imperative to use broad spectrum antiviral drug to prevent the progress of the infection. Hence HS-058 which is a powerful antiviral drug against the FluV-A, FluV-B, and other viruses is a very promising antiviral. During the examination various POMs were investigated and among them HS-054 turned out to have higher antiviral activity and lesser toxicity than its counterparts. The observation was also made that several polyoxometalates that had anti-HIV 1 activity were also influential against FluV-A virus.[57]

Antibacterial studies of POMs

β-lactam antibiotics such as penicillin can stop the construction of cell wall in bacteria hence hindering the growth of bacterial culture and thus acting as antibacterial agents. But the resistance which the bacteria are developing against these drugs is posing a huge health issue. Over time some bacteria have evolved to produce β-lactamases which hydrolyses the β-lactam ring which is present in antibiotics hence rendering them ineffective. Even bacteria have developed resistance against penicillin by changing their penicillin-binding-proteins (PBP) and such penicillin resistant bacteria are a huge threat.

Tajima[58] described about the effectiveness of an aged mixture of phosphate and tungstate. It was in amalgamation with β-lactam antibiotics. He invented a "T" factor and according to him this factor highly increased the antibacterial effect of drug in MRSA strains. He studied about the mechanism of factor T and inferred that it lowered the amount of PBP-2 and stimulated strains to β-lactams. Factor T was afterwards recognized as lacunary

Keggin polyoxotungstate and the discovery was further extended on about 70 POMs in combination with β-lactam antibiotics.[59] Polyoxomolybdate, vanadate, metavanadate are adsorbed less by cells than polyoxotungstates. The collaborative power of polyoxotungstates is lowered in presence of polycations say, for example, polylysine as they have a tendency to form ion pairs with negatively charged complexes. Decatungstates which have Anderson type structures are found to have lesser synergistic effect than Keggin species. The lacunary Keggin type species has more potency than the parent saturated $[PW_{12}O_{40}]^{3-}$. The polyoxotungtate $[CoSiW_{11}O_{39}]^{6-}$ is an appropriate example of balance between toxicity and sensitizing effect. The existence of mini cations increases the stimulating effect of the polyoxotungstate. Keggin ion $[PTi_2W_{10}O_{40}]^{7-}$ stops the formation of PBP-2 and lowers the production of β-lactamases which also contributes to the cooperative effects with β-lactam antibiotics. Yamase mentioned about the antibacterial effect of polyoxovanadate against 6 strains of penicillin resistant pneumonia.[60]

Recent advances in the antibacterial studies of polyoxometalates: $[Tl_2\{B\text{-}\beta\text{-}SiW_8O_{30}(OH)\}_2]$

The first distinct thallium containing POM has been synthesized and characterized which showed anti-bacterial properties as well. The POM is $[Tl_2\{B\text{-}\beta\text{-}SiW_8O_{30}(OH)\}_2]$ and this has been characterized in solid state and it is stable in solution as well. Various techniques like 203 Tl and 205 Tl NMR, mass spectrometry, electrospray ionization, and electrochemical studies made the characterization possible. It has been reported that Tl containing metal oxides having extended structure.[61] The structure of hexagonal tungsten bronze $AXWO_3$, first described by Magneli in 1953.[62] In 1980, Towene's group described a Tl subdue Keggin ion based on elemental analysis.[63] Tl^{3+} undergoes hydrolysis in aqueous solution and formed thallium hydroxo complexes begins at pH 0.5.[64] 203 Tl and 205 Tl NMR spectroscopy depicting spin-spin coupling between thallium atoms is a powerful tool to study structure. In the structure, two Tl^{3+} ions present are octahedrally coordinated and are sandwiched between the 2 lacunary Keggin type structures.[65]

Characterization

In solid state, IR spectroscopy was and done by KBr pellet method. Using X-ray diffraction, it was found out that POM crystallizes in monoclinic system with C_{2h} symmetry. 2 Tl^{3+} ions were present and 2 $\{B\text{-}\beta\text{-}SiW_8O_{30}(OH)\}_2]$ units.[66] In 2005, the first POM was discovered that contained [$B\text{-}\beta\text{-}SiW_8O_{31}$].[67] There are 2 Tl^{3+} ions present which are octahedrally coordinated and each Tl ion is coordinated to 2 [$B\text{-}\beta\text{-}SiW_8O_{31}$] fragments through 4 terminal O atoms of 2 complete tungsten oxo triads and 2 terminal O atoms of two $\{SiO_4\}$ hetero groups. Tl-O bond length was found to be 2.156-2.238 A^0 and distance between two Tl atoms was found to be 3.338 A^0. BVS (bond valence sum) calculations revealed that the oxidation state of Tl is +3. Elemental analysis revealed that the POM is diprotonated and BVS calculations suggested 2 μ_3-O atoms.[68] From 203 Tl AND 205 Tl NMR spectroscopy, spectra appeared pseudotriplets due to spin-spin coupling between two sterically similar Tl atoms and the central peaks were obtained due to 205 Tl-205 Tl or 203 Tl-203 Tl atoms coupling. In the similar way, satellite peals were obtained by 205 Tl-203 Tl heteronuclear coupling. ^1H couplings had no role to play because of fast exchange.

Antibacterial activity

Minimum inhibitory concentration (MIC) of the antibacterial POM was found to be comparable to the $Tl(NO_3)_2$ and $Tl(OOCCH_3)_3$ and the latter is known as inorganic antibacterial against *Gram-negative* bacteria. Both Tl salts were found to have similar activity in phosphate buffer. Tl^{3+} salt are insoluble while POM is. POM showed high antibacterial activity against *Gram-positive* bacteria, exhibiting 32-fold increased activity comparatively to plain Tl^{3+} or Tl^{2+} ions.

CONCLUSION

The study revealed that the polyoxometalates has evolved present days because the study of anionic POMs and it reactivity still continues to fascinate the researchers till date owing to the magnificent properties and vast area of application of polyoxometalates. The polyoxometalates have immense potential to act as drugs which are economical and more powerful as well as effective than prevalent organic drugs in market today. An exchange between chemistry and biology will assist in development of bio-medical applications of POMs. Which gives rise to afresh

and promising feasibilities in molecular biology and in the detection and treatment of diseases. In near future, it is likely that, with the advances in research in applications of Polyoxometalates in medicine, they will be available for curing diseases and giving intensive competition to comparatively expensive organic drugs.

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Conflict of interest

There is no conflict of interest.

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