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**VIBRATIONAL SPECTROSCOPIC BEHAVIOR OF
K₇[Ti₂W₁₀PO₄₀] \cdot 6H₂O: AN INTERESTING AND POTENT ANTIVIRAL
POLYOXOMETALATE**

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Resumen

Se preparó el K₇[Ti₂W₁₀PO₄₀] \cdot 6H₂O, conteniendo un hetero-polioxoanión con estructura tipo Keggin y que posee interesantes propiedades farmacológicas. Se registraron los espectros de infrarrojo y Raman del compuesto en fase sólida y se los analizó brevemente, en forma comparativa con los de otros polioxoaniones de estructuras relacionadas.

Abstract

We prepared K₇[Ti₂W₁₀PO₄₀] \cdot 6H₂O, containing a hetero-polyoxoanion with Keggin-type structure, which shows interesting pharmacological properties. The infrared and Raman spectra of the compound in the solid state were recorded and briefly analyzed in comparison with those of other polyoxoanions with related structures.

Palabras clave: K₇[Ti₂W₁₀PO₄₀] \cdot 6H₂O; espectros de IR y Raman; comportamiento vibracional.

Keywords: K₇[Ti₂W₁₀PO₄₀] \cdot 6H₂O; IR and Raman spectra; vibrational behavior.

1. Introduction

Polyoxometalates are anionic metal-oxygen clusters, involving the earlier transition metal cations. More specifically, they are oligomeric aggregates of metallic cations (usually species with d⁰ electronic configuration, such as V(V), Nb(V), Mo(VI) or W (VI)) bridged by oxide anions, generated by auto-assembling processes ^{1,2}. Basically, there are two different families of

polyoxometalates, the isopolyanions or isopolyoxometalates and the heteropolianions or heteropolyoxometalates, which contain one or more “heteroatoms” of elements of the groups p, d or f of the Periodic System. These “heteroatoms” can be located inside or on the surface of the cluster and are, therefore, inaccessible or accessible to solvents, respectively.

One of the most common polyoxoanion structures is the so-called “Keggin structure” schematized in Figure 1. It is constituted by units of three edge-sharing MO_6 - octahedra and four of these units arrange sharing corners between them, generating the $[\text{M}_{12}\text{O}_{40}]^{n-}$ structure. As it can be seen from Figure 1, there is a cavity on the center of the structure with an adequate size to allow the insertion of relatively small ions such as P(V), Si(IV), Ge(IV), Ti(IV), As(V), Zr(IV), etc., which adopt tetrahedral oxygen-coordination. The incorporation of these “heteroatoms” (X) generate a $[\text{XM}_{12}\text{O}_{40}]^{m-}$ stoichiometry. Besides, the “heteroatoms” can also be incorporated in the form of XO_6 octahedra, generating $[\text{X}_n\text{M}_{12-n}\text{O}_{40}]^{m-}$ arrangements.

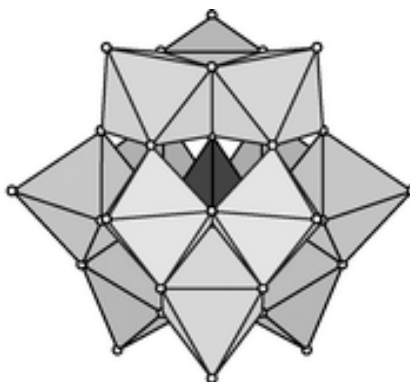


Figure 1. Schematic drawing of the Keggin-type structure.

Some other different structural types, conformed by other forms of octahedral and heteroatomic arrangements, are also known. Two of the most important ones are the “Anderson structure” of type $[\text{XM}_6\text{O}_{24}]^{n-}$, in which six MO_6 -octahedra generate a planar ring by edge sharing, trapping the X-heteroatom in the center of the ring also in octahedral coordination, or the polyoxoanions of formula $[\text{X}_2\text{M}_{18}\text{O}_{62}]^{n-}$ (“Dawson structure”) with a more complex structural ordering ¹.

Many polyoxometalate salts have been shown to be biologically active. Such activity includes highly selective inhibition of enzyme function, as well as *in vitro* and *in vivo* antitumoral, antiviral and antiretroviral activity²⁻⁸.

The first polyoxometalate to receive substantial attention as an antiviral and anti-HIV-1 agent was $[\text{NaSb}_9\text{W}_{21}\text{O}_{86}]^{18-}$, the so called HPA-23, and usually employed in the form of its sodium/ammonium salt, $(\text{NH}_4)_{17}\text{Na}[\text{NaSb}_9\text{W}_{21}\text{O}_{86}]\cdot n\text{H}_2\text{O}$. Its crystal structure, which can formally be derived from the Keggin type structure⁸ as well as its spectroscopic and thermal behavior⁹ has been determined. It presents an interesting biological activity⁴ and it has been shown that the reverse transcriptase activity of human immunodeficiency virus (HIV), a causative agent of AIDS, is completely inhibited by HP-23 at a concentration of 60 $\mu\text{g}/\text{mL}$ ^{10,11}.

Notwithstanding, phase I clinical trials indicated that it is too toxic to allow a sufficiently long administration of the drug and in sufficient doses to produce adequate therapeutic efficacy^{4,7}. However, a beneficial consequence of these initial studies with HPA-23 was that it provides a great impetus to investigate polyoxometalates as a new class of antiviral agents with multiple antiviral mechanisms. These studies show that numerous other polyoxometalates present also high antiviral activity and are less toxic than HPA-23⁴.

One of this polyoxometalates is $[\text{Ti}_2\text{W}_{10}\text{PO}_{40}]^{7-}$, which in the form of its hydrated potassium salt, and known as HP-19, was found to be a potent inhibitor of the replication of human immunodeficiency virus (HIV)¹². Additionally, most recently, the potential anti-SARS (severe acute respiratory syndrome) activity of this species has also been explored¹³.

In this paper we present the results of our analysis of the vibrational spectroscopic behavior of this interesting and pharmacologically highly promising polyoxometalate.

2. Materials and Methods

2.1. Synthesis of the compound

The investigated polyoxometalate salt was prepared according to the method described by Domaille and Knoth ¹⁴ as follows: 6 g of NaPO₄H₂ were slowly added to a solution of Na₂WO₄·2H₂O (30 g in 100 mL of water). To this solution 1.8 mL of TiCl₄ was dropwise added under constant stirring. The mixture was then refluxed for 30 min followed by filtration. The clear colorless filtrate was stirred for 10 min with 30 g of KCl to precipitate a white solid salt, which was recrystallized from water to obtain the hydrate of K₇[Ti₂W₁₀PO₄₀].

The water content was determined by heating a known sample amount to a constant weight at 120 °C and determining the loss of weight. These experiences, performed with three independent samples, confirmed the presence of six water molecules. The composition was additionally confirmed performing an analysis of the K-content using the gravimetric method based in the use of sodium tetraphenylborate (Kalignost[®]) as the precipitating agent ^{15,16}. Two independent determinations gave K = 9.12% and 9.08% (theoretical value for K₇[Ti₂W₁₀PO₄₀]·6H₂O = 9.16%).

2.2. Vibrational spectra

The infrared spectra, in the spectral range between 4000 and 400 cm⁻¹, were recorded with a FTIR-Bruker-EQUINOX-55 spectrophotometer, using the KBr pellet technique. Raman spectra were obtained in the same spectral range with a Thermo Scientific DXR Raman microscope, using the 532 nm line of a Thermo Scientific solid-state laser diode pump for excitation.

3. Results and Discussion

3.1. Structural characteristics

The structure of the hydrated $K_7[Ti_2W_{10}PO_{40}]$ has not been directly determined, but the crystal structure of the closely related tetrakis(diethylammonium)sodium dititanium decatungstophosphate undecahydrate, $[(C_2H_5)NH_2]_4Na[H_2Ti_2W_{10}PO_4] \cdot 11H_2O$, was solved by Ozeki and Yamase by single crystal X-ray diffractometry¹⁷. It belongs to the orthorhombic space group $P2_12_12_1$ with $Z = 4$ formulas in the unit cell. The $[H_2Ti_2W_{10}PO_4]^{5-}$ anion has the Keggin structure. The Ti substitution reduces the original T_d symmetry of the W_{12} skeleton to C_2 , as also determined by ^{183}W -NMR spectroscopy¹⁴. These spectroscopic studies also indicate that the $K_7[Ti_2W_{10}PO_{40}]$ samples essentially consist of one isomer (the mentioned C_2 -symmetry species with 1,4 substitutions of the Keggin structure¹⁸) and only very small amounts of other isomers present.

3.2. Spectroscopic Behavior

The infrared and Raman spectra of polyoxoanions adopting the Keggin structure have been systematically investigated much time ago by the group of Rocchiccioli-Deltcheff in France¹⁹⁻²¹ and the main conclusions of these studies can also be applied in the present case.

Following these general criteria one may assume that the PO_4 tetrahedron vibrate almost independently from the rest of the anion. On the other hand, stretching of the different types of W-O bonds can be expected in the following spectral regions: terminal W- O_t bonds at $1000-960\text{ cm}^{-1}$ W- O_b -W bridges (“inter” bridges between corner sharing octahedra) at $890-850\text{ cm}^{-1}$, and W- O_c -W bridges (“intra” bridges between edge-sharing octahedra) at $800-760\text{ cm}^{-1}$. Only the terminal W- O_t stretchings can be considered as pure vibrations; the stretchings involving bridging O-atoms usually present some bend character²².

The FTIR spectrum of $K_7[Ti_2W_{10}PO_{40}] \cdot 6H_2O$ in the full measured range ($4000-400\text{ cm}^{-1}$) is shown in Figure 2 whereas the Raman spectrum, in the most relevant spectral range

(1200-200 cm^{-1}) is presented in Figure 3. The analysis of the vibrational spectra is presented in Table 1 and is briefly commented as follows:

- The stretching vibrations of the water molecules are seen in the infrared spectrum as a very strong and broad band centered at ca. 3500 cm^{-1} . This position suggests the participation of these molecules in the formation of long hydrogen bridges (2.9 - 3.3 Å)^{23,24}. The corresponding deformation mode, $\delta(\text{H}_2\text{O})$, is found as a medium intensity band at 1630 cm^{-1} . In the Raman spectrum these H_2O vibrational modes are only seen as very weak bands.

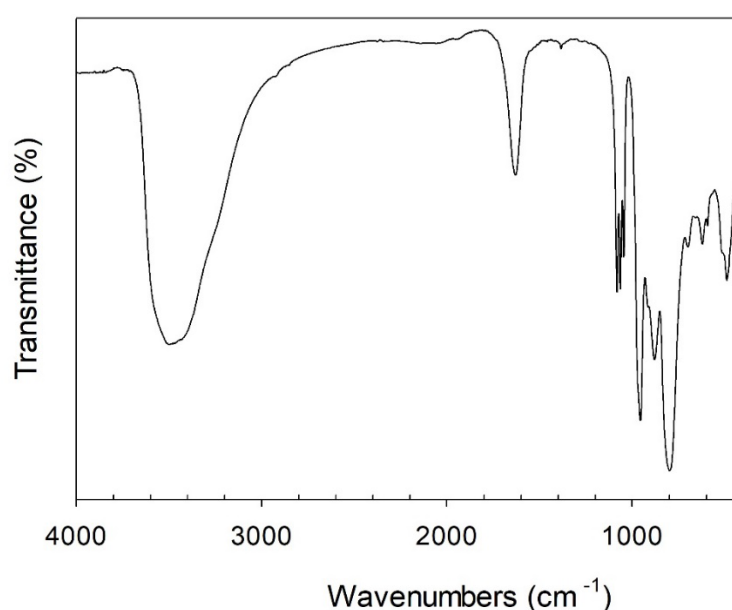


Figure 2. FTIR spectrum of $\text{K}_7[\text{Ti}_2\text{W}_{10}\text{PO}_{40}] \cdot 6\text{H}_2\text{O}$ between 4000 and 400 cm^{-1} .

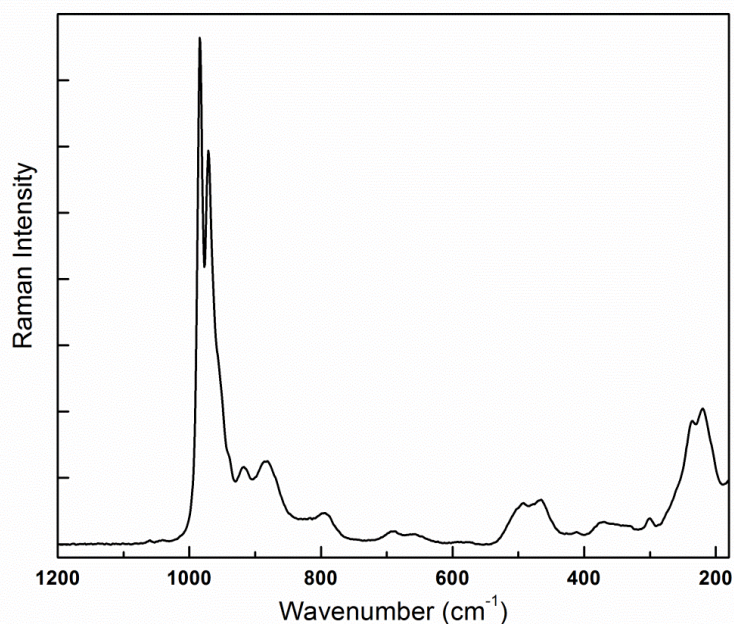


Figure 3. Raman spectrum of $K_7[Ti_2W_{10}PO_{40}] \cdot 6H_2O$ between 1200 and 200 cm^{-1} .

Table 1. Assignments of the FTIR and FT-Raman spectra of $K_7[Ti_2W_{10}PO_{40}] \cdot 6H_2O$ (Band positions in cm^{-1}).

Infrared	Raman	Assignments
3497 vs, br	3470 vw, br	$\nu(H_2O)$
1630 m	1628 vw	$\delta(H_2O)$
1083 s, 1064 s, 1046 m	1060 vw, 1045 vw	$\nu_3(PO_4)$
	983 vs	$\nu(W-O_t)$
	971 vs	$\nu_1(PO_4)$
956 s		$\nu(W-O_t)$
925 sh, 880 m	917 w, 881 w	$\nu(W-O_b-W)$
799 vs	794 w	$\nu(W-O_c-W)$
699 vw	688 w, 657 sh	MO_6 -deformations
622 w, 594 vw		$\nu_4(PO_4)$
515 sh, 490 m	578 vw	MO_6 -deformations
	492 w, 465 w	$\nu_2(PO_4)$
	370 w, 300 w	MO_6 -deformations
	235 w, 220 m	External modes

vs, very strong; s, strong; m, medium; w, weak; vw, very weak; sh, shoulder; br, broad.

- The behavior of the PO_4^{3-} vibrations is very interesting. If one admits that this ion is located at a C_1 crystallographic site¹⁷ the complete removal of all degeneracies and the activation of all vibrational modes of the formally tetrahedral unit are expected. In the infrared spectrum, the antisymmetric vibration (ν_3) is clearly seen as the expected triplet of bands, generated from the initially triple degenerated F_2 mode. Notwithstanding, the corresponding symmetric vibration (ν_1), apparently attains not enough intensity to become visible in the IR although it may be

accidentally overlapped by the next, relatively strong, IR band. In the Raman spectrum only two of the three expected ν_3 -components could be identified as very weak bands, whereas ν_1 appears, as expected²⁵, as one of the two strongest Raman signals. Regarding the deformational modes of this anion, the antisymmetric deformation, (ν_4), was identified as a doublet in the IR spectrum, whereas the corresponding symmetric mode, (ν_2), was found only in the Raman spectrum, as expected on the basis of known intensity criteria^{25,26}.

- The Keggin-skeleton presents characteristic bands for the terminal W-O_t bonds at 956 cm⁻¹ (IR) and 983 cm⁻¹ (Raman), and two groups of bands at lower energies related to the “inter” and “intra” W-O-W bridges, whereas some deformational vibrations were found below 700 cm⁻¹ in both spectra.

- A comparison with the solution IR and Raman spectra of the [W₁₂PO₄₀]³⁻ anion¹⁹ shows the expected similarities, although band displacements to lower energies in the present case are evident. This effect may be related to the presence of Ti in two of the MO₆-octahedra and of the water molecules in the lattice, which usually causes a decrease of frequency in the M-O vibrations²⁰.

4. Conclusions

The polyoxometallate salt K₇[Ti₂W₁₀PO₄₀].6H₂O was prepared using a known synthetic procedure. Their FTIR and Raman spectra were measured in the solid state and an assignment was proposed on the basis of known spectroscopic data for other related compounds belonging to the same structural type. The results are of interest as they allow a rapid and straightforward characterization of a chemical species with interesting pharmacological properties.

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