Research article
International Journal of Heterocyclic Chemistry,
Vol. 7, No. 4, pp. 1-8 (Autumn 2017)
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http://ijhc.iauahvaz.ac.ir

Interaction of Prolin, Leucine and methylurea with inorganic cluster $[(PO_4)M_{12}O_{36}].nH_2O$; (M = Mo, W)

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Recieved:15 September 2017 Revised: 20 November 2017 Accepted: 28 November 2017

Abstract- Three new inorganic-organic hybrid materials based on heteropolyoxometalates, $[L\text{-}C_6H_{14}NO_2]_3[(PO_4)Mo_{12}O_{36}].3H_2O$ (1), $[L\text{-}C_5H_{10}NO_2]_3[(PO_4)W_{12}O_{36}].H_2O$ (2), and $[C_2H_7N_2O]_3[(PO_4)W_{12}O_{36}]. 4H_2O$ (3), where $C_6H_{14}NO_2$, $C_5H_{10}NO_2$, and $C_2H_7N_2O$ are protonated L-leucine, L-proline, and methylurea, respectively, have been synthesized and structurally characterized by some physico-chemical methods. Elemental analyses, IR, Raman, mass, UV, and ^{1}H NMR spectroscopies of the title hybrid materials indicate that there are van der Waals interactions between O atoms of the heteropolyoxometalates and water molecules, as well as the N and O atoms of the amino acids and methyl urea moieties. The molecular structures of synthesized hybrid materials contain discrete entities of L-leucinium, L-prolinium or methyluronium and water molecules that surround every $[(PO_4)M_{12}O_{36}]^{3-}$ anion, over the extended crystalline network. The observed bands in Raman spectra of 2 and 3 demonstrate that $[(PO_4)W_{12}O_{36}]^{3-}$ anion retains its “Keggin structure”. Between pH =7 and pH =4 the characteristic bands of the Keggin anion $[(PO_4)M_{12}O_{36}]^{3-}$(M = Mo, W) appear at 210 and 260 nm in the UV spectra, respectively.

Keywords: Polyoxometalate, L-leucine, L-proline, Methylurea, Inorganic-organic hybrid, IR, Raman, UV, ICP

Introduction

Polyoxometalates (POMs) constitute an interesting class of metal–oxygen cluster hybrids with definite size and shape. These hybrids have been found to be extremely versatile inorganic building blocks in view of their potential applications in catalysis, medicine, materials science, and others. [1-6] In recent decades, POMs associated with organic ligands have generated a group of privileged hybrids. [7-10] They have led to the development of substances with interesting electric, magnetic and/or optical properties. Many POMs have been used as building blocks to construct a variety of organic–inorganic solid-state hybrid materials, following several strategies, namely the use of entities capable of acting as charge compensating cations in the synthesis of salt-like hybrids and the synthesis of organically functionalized POM clusters. Examples of the former are hybrids with POMs and cationic porphyrins, propane sulfonate functionalized organic cations, surfactants, organic radical ions and transition metal or lanthanide complex cations or coordination polymers with organic ligands. Reported association of POMs with aminoacids is a result of either (i) functionalization of the heteropolyanions with the aminoacids or (ii) electrostatic and/or hydrogen bonding interactions. For different purposes, materials have been prepared with the Kegginheteropolyanions ($[XM_{12}O_{40}]_n$, M = Mo, W, X = P, Si, B) and several aminoacids, namely with glycine, tyrosine, ornithine, alanine, histidine, lysine, proline, cysteine and also with aminoacidate copper complexes that only a few had their crystal structure determined. [11] To our knowledge, no other reports with titled Keggin anions and L-leucine, L-proline, and methylurea have been published. The research on amino acid salts of POMs continues to be an interesting subject both in respect to the discovery of new crystalline supramoleculararchitectures (assemblies) and to the study of their properties, and this prompted us to investigate the hybrids resulting from reaction of amino acids and heteropolyacids. Thus, in continuation of our previous works for the synthesis of biologically active hybrids,[12-14] herein, we have carried out the reaction of L-leucine and methyl urea with 12-tungsto and molybdooxoanions. This contribution describes the syntheses and characterization of three novel inorganic-organic hybrid materials based upon heteropolyoxo-metalates: $[L\text{-}C_6H_{14}NO_2]_3[(PO_4)Mo_{12}O_{36}]\cdot 3H_2O$ (**1**), $[L\text{-}C_5H_{10}NO_2]_3[(PO_4)W_{12}O_{36}]\cdot H_2O$ (**2**),$[C_2H_7N_2O]_3\,[(PO_4)W_{12}O_{36}]\cdot 4H_2O$ (**3**).

Experimental

α-$H_3[(PO_4)M_{12}O_{36}].nH_2O$ (M = Mo, W) were prepared by the well-known procedures [15]. Other chemicals were commercially available and used without further purification. A Buck-500 scientific spectrometer was employed to record IR spectra using KBr discs. ^1H NMR spectra was recorded on a Bruker BRX-100 Avance spectrometer. Elemental analyses were performed on a Thermo Finnigan Flash-1112EA microanalyzer. Mass spectra were obtained from a Varian CH-7 instrument at 70 eV. The UV spectrum was obtained on an Agilent 8453 single beam photodiode array spectrometer in the range of 190-350 nm. The Raman spectrum was collected employing a 180° back scattering geometry and a Bomem MB-154 Fourier transfer spectrometer which was equipped with a ZnSe beam splitter and TE cooled in GaAs detector. A column containing Dowex 50WX8 in the H^+ form was used to prepare relating heteropolyacid of molybdenum and tungsten. The Mo, W, and P contents were measured by ICP method.

Synthesis of α-$H_3[(PO_4)Mo_{12}O_{36}].21H_2O$

To 100 mL of water at 60˚C $Na_2MoO_4.2H_2O$ (10 g, 41 mmol) was slowly added and then 1mL (0.01 mmol) *ortho*phosphoric acid 85% and 8 mL (0.10 mmol) conc. HCl were added dropwise. The precipitate was dissolved by vigorous stirring and kept overnight. The solution was filtered and precipitate was washed by warm water and dried in a desiccator (Yield: 40% based on Mo).The free acid was prepared by passage of a solution of 10 g of the sodium salt in 20 mL of water through a column (50 × 1 cm) of Dowex 50WX8 in the H^+ form and evaporating the eluate to dryness in vacuo.

Synthesis of α-$H_3[(PO_4)W_{12}O_{36}].19H_2O$

This compound was prepared similarly to above procedure using 100 mL water at 60˚C $Na_2WO_4.2H_2O$ (10 g, 30 mmol), 1mL (0.01 mmol) *ortho*phosphoric acid 85%, and 8 mL (0.10 mmol) conc. HCl

Synthesis of $[L\text{-}C_6H_{14}NO_2]_3[(PO_4)Mo_{12}O_{36}].3H_2O$ (1)

4 ml water, α-$H_3[(PO_4)Mo_{12}O_{36}].21H_2O$ (0.3 g, 0.14 mmol), and L-leucine (0.1 g, 0.76 mmol) were mixed in a small bottle and then the mixture was kept at room temperature under stirring

for two hrs. The contents were then filtered and the resulting yellow precipitate was isolated and air-dried. It was redissolved in a minimum amount of water. Slow evaporation at room temperature for several days yielded large yellow crystals of **1** in about 35% yield based on Mo. Anal. Calc. for **1**: C, 10.01; H, 2.07; N, 1.94; P, 1.43; Mo, 53.33. Found: C, 9.95; H, 2.16; N, 2.03; P, 1.35; Mo, 52.82 %.

Synthesis of $[L\text{-}C_5H_{10}NO_2]_3[(PO_4)W_{12}O_{36}].H_2O$ (2)

4 ml water, (0.5 g, 0.17 mmol) α-H_3 $[(PO_4)W_{12}O_{36}].19H_2O$, and (0.1 g, 0.86 mmol) L-proline were mixed in a small bottle and then the mixture was stirred for 5 hrs. The contents were then filtered and the resulting colorless precipitate was isolated and air-dried. It was redissolved in a minimum amount of DMF. Slow evaporation of the obtained solution at room temperature for 4 weeks gave pure colorless precipitate of **2** in about 30% yield based on W. Attempts to obtain the single crystal were not successful. Anal. Calc. for **2**: C, 5.48; H, 1.09; N, 1.28; P, 0.94; W, 66.84%. Found: C, 5.53; H, 1.01; N, 1.15; P, 0.90; W, 65.42%.

Synthesis of $[C_2H_7N_2O]_3[(PO_4)W_{12}O_{36}].4H_2O$ (3)

The synthesis of **3** was accomplished by dissolving α-$H_3[(PO_4)W_{12}O_{36}].19H_2O$ (0.2 g, 0.07mmol) in 10 mL water. This solution was then added dropwise to a solution containing of methylurea (0.05 g, 0.70 mmol) in 5 mL 2N HCl. The solution was kept at room temperature under stirring for 24 hrs. After adjusting the PH to 2.5 with 2N HCl, the resulting clear solution was left for a week. The white precipitate of **3** was redissolved in water and filtered. The filtrate was kept for several days at ambient conditions. White block crystals of **3** were isolated in about 40% yield based on W (Fig. 1c). Anal. Calc. for **3**: C, 2.27; H, 0.85; N, 2.64; P, 0.97; W, 69.63. Found: C, 2.21; H, 0.80; N, 2.80; P, 0.90; W, 68.45 %.

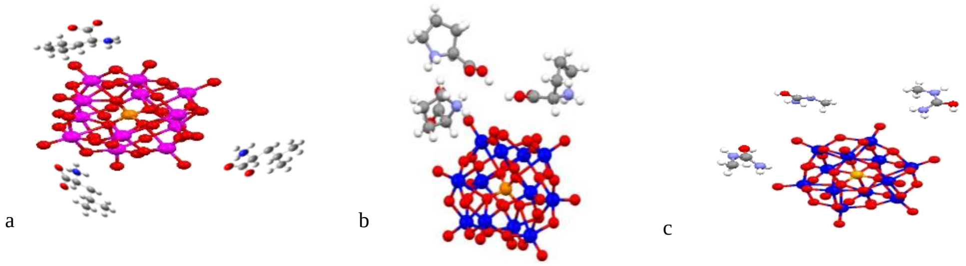

Fig. 1—Schematic representation of proposed structures for **1-3.[** Colour codes: phosphorus, orange; oxygen, red; carbon, gray; hydrogen, white (a: molybdenum, pink; nitrogen, blue; b and c: tungsten, blue; nitrogen, light blue)].

Results and discussion

The structural assignments of hybrids **1**to **3** were based on the spectral and microanalytical data.Generally, there are four types of oxygen atoms in any Keggin unit. Four X–$O_a$oxygens are bonded to a heteroatom (e.g., phosphorus) in the central tetrahedron. Twelve M–O_b–M oxygen atoms are in a corner-sharing arrangement between the MO_6 octahedrons. Twelve M–O_c–M oxygens exist in an edge-sharing arrangement between the neighboring MO_6 octahedrons. Finally, there are twelve M=O_d terminal oxygen atoms[1]. Characteristic IR bands of L-leucine remain unchanged. IR bands arising from the POM anions, on the other hand, are altered in intensity and position, compared to those of the free α-$H_3[(PO_4)M_{12}O_{36}].nH_2O$ (M = Mo, W)[15]. In hybrid **1** the vibrational bands of the P–O_a, and Mo=O_d show red-shift from 1067 and 963 cm^{-1} to 1061 and 958 cm^{-1} respectively. The Mo-O_b-Mo and Mo–O_c–Mo bands of **1** are blue shifted from 870 and 785 cm^{-1} to 879 and 788 cm^{-1}, respectively. The apparent weakening of the two bonds and strengthening of the other two bonds in **1** is likely to be due to different hydrogen bonding interactions between POM oxygens and the hydrogen atoms of L-leucine nitrogen and, to a lesser extent, the hydrogen atoms of L-leucine carbons. Characteristic peaks of L-leucine are as expected. For example, the 1460 cm^{-1} band is typical of N–H vibration, the one at 1734 cm^{-1} is characteristic of the carbonyl group and the featured 2953 cm^{-1} band is attributed to CH_2 groups. In hybrid **2**, characteristic IR bands of L-proline remain unchanged. IR bands arising from the POM cation, on the other hand, are altered in intensity and position compared to those of the uncombinedheteropoly acids with the exception of vibrational bands of P–O_a and W=O_d which are 1080 and 982 cm^{-1}, respectively. In fact these oxygens do not have any role in the van der Waals interactions between POMs and amino acid. The W–O_c–W: red shifted from 810 cm^{-1} to 804 cm^{-1} and W–O_b–W band is blue shifted from 890 cm^{-1} to 895 cm^{-1}. The apparent weakening of one bond and strengthening of another in the title hybrid is likely to be due to different hydrogen bonding interactions between POM oxygens and the hydrogen atoms of nitrogen in L-proline, and to a lesser extent, the hydrogen atoms of carbons in L-proline. Characteristic peaks of L-proline are as expected. For example, the 1460 cm^{-1} band is typical of N–H vibration, the one at 1728 cm^{-1} is characteristic of the carbonyl group and the featured 2950-2970 cm^{-1} band is attributed to CH_2 andCH groups. In hybrid **3**, the $W{=}O_d$ bond has blue shifted from 982 to 984 cm^{-1} and the $W–O_b–W$ bond has red-shifted from 890 to 885 cm^{-1}, while the other bonds, namely, the $P–O_a$and $W–O_c–W$ bonds, are unchanged. Also, the characteristic peaks of methyl urea molecules are observed. For example the peaks at 1336-1730 and 2916-2943 cm^{-1} are characteristic of methyl urea molecules. The 1453 cm^{-1} feature is characteristic of N–H vibration, 1711 cm^{-1} is characteristic of the C=O group and the feature at 2953 cm^{-1} is attributed to the methyl group. This seems contradictory, because one would expect to observe some changes in the wave numbers (absorption energy) due to the POM-methyluronium interaction. However, the "contradiction" may be rationalized by the fact that we are looking at the literature values for the vibrational frequencies of methylurea and not methyluronium. Furthermore, our observed wave numbers are obtained from a crystal lattice that exerts its unique influence, not present in the uncombined "ligand", *i.e.*, methylurea. The ^1H NMR shifts for hybrid **1** are 4.0 (t, 1H, C_1H); 1.8 (q, 4H, C2, 3H); 0.9 (t, 6H, C4, 5H). Hybrid **2**: 4.30(t,1H,C_2H); 3.40(t, 2H, C_5H); 2.03(m, 4H, C_3H, C_4H). These shifts and patterns are consistent with the seven hydrogen atoms that are covalently bonded to the carbon atoms of the L-proline. The ^1H NMR spectrum of **3** reveals the signal of protons of the methyl group at δ2.5. The peaks for NH_2 and NH protons are masked by the solvent resonance absorptions. According to the above data, it is concluded that van der Waals interactions reduce electron density around the C-H groups. Hence, these protons appear at lower magnetic field. The peaks for NH_2 protons are masked by the solvent resonance absorptions. The UV spectra of the title hybrids measured in aqueous solution, is similar to that of α-$H_3[(PO_4)M_{12}O_{36}].nH_2O$ (M = Mo, W) in the same solutions. Between pH = 4-7, these spectra exhibit two absorption bands at 210 and 260 nm, ascribed to $p_\pi(O_d)\rightarrow d_{\pi*}(W)$ transitions in the W=O bonds and transitions d_π-p_π-d_π between the energetic levels of the W–O–W tricentric bonds. These results indicate that the polyanions in the title hybrid materials still retain the basic Keggin structure, but are distorted due to the effect of hydrogen bonding interactions.

Raman spectra of **2** and **3** were recorded in the range of 1050-200 cm^{-1}. There are three prominent bands at 1007, 987 and 217 cm^{-1} for **3** that can be attributed to $\nu_s(W{=}O_d)$, $\nu_{as}(W{=}O_d)$, and $\nu_s(W–O_a)$, respectively. These bands demonstrate that $[(PO_4)W_{12}O_{36}]^{-3}$ anion retains its "Keggin structure"[15]. Raman bands for methyl urea molecules have low intensity and could not be assigned unambiguously.

Obtained results from ^{1}H NMR spectra and elemental analyses are in good agreement with mass spectroscopy data. M^+ ions at m/z = 130, 115,and 73 indicate the presence of $C_6H_{12}NO_2$, $C_5H_8NO_2$, and $C_2H_5N_2O$ molecular formulas and suggest the loss of one hydrogen atom. Further,m/z = 114, 99, and 57 suggest the loss of NH_2 (M-16), which is confirmed by neutral loss mass spectroscopy and indicate the presence of N-H bond in the title hybrid materials. Schematic representation of proposed structures for **1-3** is rendered in Fig. 1. In the present study, combination of the POM cluster and the organic substrate resulted in hybrids **1-3**, which have been fully characterized by elemental analyses, IR, Raman, ^{1}H NMR spectroscopies, Mass, and UV techniques. According to the molecular structural analyses, these materials contain infinite planes of inorganic moiety. The arrangement of these planes with respect to each other makes the specific space for the entering of organic molecules. Indeed, the presence of Van Der Waals interactions holds the organic moieties in the vacancies in the POM crystalline network. The synthesis and characterization of these new organic–inorganic hybrid hybrids, is an important continuous step to incorporate organic molecules of biological significance into the network of inorganic cluster-hybrids. A combination of electrostatic forces and hydrogen bonding keeps this “adduct” stable in the solid state. The fact that in the solution phase the hybrid is also stable makes it a viable candidate for applications as homogeneous catalysis. There may be potential pharmaceutical benefits that are yet to be explored. Our future efforts will be devoted to the growth of large crystals and related X-ray studies and biological activity tests on these hybrids.

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