

TWO NEW SANDWICH-TYPE COMPOUNDS BASED ON {AsW₉} WITH Pd²⁺ AND Pt⁴⁺ CATIONS – SYNTHESIS, CHARACTERIZATION AND ANTIBACTERIAL ACTIVITY

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Abstract

Following methods described in the literature, two new complexes of [AsW₉O₃₃]⁹⁻ ligand (AsW₉) were synthesized with Pd²⁺ and Pt⁴⁺ cations: Na₁₂[(AsW₉O₃₃)₂Pd₃]*24H₂O (AsW₉Pd); Na₆[(AsW₉O₃₃)₂Pt₃]*46H₂O (AsW₉Pt). The complexes were obtained by direct addition of cation salt solution (PdCl₂/K₂PtCl₆) to AsW₉ sodium salt solution at pH = 8.5, keeping the temperature between 70 - 80°C. After physico-chemical characterization (UV, IR, TGA, conductometry, X-ray), the complexes have been associated to Hervé structures which consist of two AsW₉ units connected by O-Pd/Pt-O bridges. Their biological activity was studied *in vitro* on Gram positive (*Staphylococcus aureus* ATCC 29213) and Gram negative (*Escherichia coli* ATCC 25922) bacterial strains, and showed significant antibacterial activity, inhibiting both *E. coli* and *S. aureus*, with better effect on the Gram negative strain.

Rezumat

După metodele descrise în literatura de specialitate, au fost sintetizați doi complecși noi ai ligandului [AsW₉O₃₃]⁹⁻ (AsW₉) cu cationi de Pd²⁺ și Pt⁴⁺: Na₁₂[(AsW₉O₃₃)₂Pd₃]*24H₂O (AsW₉Pd); Na₆[(AsW₉O₃₃)₂Pt₃]*46H₂O (AsW₉Pt). Complecșii au fost obținuți prin adăugarea directă a soluției cationului (PdCl₂/K₂PtCl₆) la soluția ligandului AsW₉ la pH = 8,5 și temperatura între 70 - 80°C. După caracterizarea fizico-chimică (UV, IR, TGA, conductometrie, raze X), structurile complecșilor au fost asociate cu structura Hervé, structură formată din două unități de AsW₉ conectate prin legături în punte O-Pd/Pt-O. Activitatea lor biologică a fost studiată *in vitro* pe două tulpini bacteriene, una Gram pozitivă (*Staphylococcus aureus* ATCC 29213) și una Gram negativă (*Escherichia coli* ATCC 25922). Cei doi complecși nou sintetizați au prezentat o activitate antibacteriană semnificativă, inhibând atât *S. aureus* cât și *E. coli*, cu un efect mai pronunțat asupra tulpinii Gram negative.

Keywords: *pseudo*-Keggin structure, palladium complexes, platinum complexes, sandwich complexes, antibacterial activity

Introduction

Polyoxometalates (POM) are inorganic complex combinations which have undergone extensive, in-depth development in the last decades. The interest in this class of compounds is growing due to their properties, simple synthesis methods and large variety of possible structures [5]. POM are negatively charged clusters of different transition metals such as tungsten or vanadium with oxygen, formed by metal-oxygen and metal-oxygen-metal bonds. In the interstitial position, there is a large number of lattice water [3].

The aim of this study was the synthesis and characterization of two new complexes of [AsW₉O₃₃]⁹⁻

ligand (AsW₉) with Pd²⁺ and Pt⁴⁺ cations: Na₁₂[(AsW₉O₃₃)₂Pd₃]*24H₂O (AsW₉Pd); Na₆[(AsW₉O₃₃)₂Pt₃]*46H₂O (AsW₉Pt). The trivacant polyanion [AsW₉O₃₃]⁹⁻ is derived from the parent Keggin structure ([AsW₁₂O₄₀]³⁻) by removal of three edge-sharing WO₆ octahedra. The [AsW₉O₃₃]⁹⁻ unit consists of a central AsO₃ tetrahedron surrounded by three vertex-sharing W₃O₁₃ trimers. It is stable at pH = 7 - 9. The heteroatom (As) possesses unshared electron pairs and react with transition metal cations forming complexes with general formula [M₃(AsW₉O₃₃)₂]^{q-} [4, 9, 13]. The lone-pair of electrons at the heteroatom prevents formation of plenary structures such as Keggin ion. AsW₉ can be

considered an inorganic ligand possessing nucleophilic donor oxygens and it has been used as precursor for various POMs [6, 9].

For optimal characterization of the synthesized complexes physico-chemical methods (TGA, conductometry), spectroscopic techniques (UV, IR) and X-ray diffraction were used. Obtained data provided us information about metal ion coordination, the cation influence on the AsW₉ bonds and coordination number of the central ion. Based on these results we propose a formula for the structures and geometry of the molecule, namely: Hervè structure (*pseudo*-Keggin).

Materials and Methods

All chemicals used in this study were of analytical grade from Merck (Germany) and were used without any further purification. All solutions were prepared with ultrapure water obtained with NanoPure Diamond System (Barnstead, USA).

UV spectra were recorded on an Analytik Jena SPECORD 210 spectrophotometer between $\lambda = 190 - 400$ nm in 1 cm quartz cuvettes. The aliquots were obtained by dissolving samples in purified water at a concentration of 10^{-5} M.

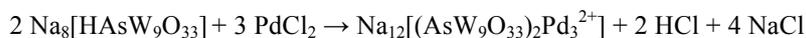
IR spectra were obtained on a Thermo Nicolet380 FTIR spectrophotometer using KBr pressed pellets and the H₂O content was determined by TGA/DSC Mettler Toledo equipment. Thermogravimetric analysis was performed in 50-500°C temperature range, printing a heating rate of 20°C/minute.

Conductometric analysis was performed on an INOLAB 740 multi-parameter apparatus.

X-ray diffraction was conducted on a BRUKER D8 ADVANCE type diffractometer (Cu-K α radiation) with LYNXEYE detector (Bragg-Brentano diffractometer geometry with application in the phase analysis).

Antibacterial activity

The antibacterial activity of the three synthesized compounds (AsW₉, AsW₉Pd, AsW₉Pt) was assessed



The reaction mixture was kept for two hours in the same conditions, while the colour of solution became as milk-coffee. The hot mixture was filtered on a Buchner funnel and the solution was concentrated to 2/3 of initial solution volume. After a few days the complex started to crystallize. The brownish crystals were filtered, redissolved in diluted NaOH solution and recrystallized for purification. The final product was brownish-grey colour. Yield 2.8 g (42.8 %). IR spectrum (KBr pellet, cm⁻¹): 940; 844; 792; 739.2; 499.7. UV (λ_{max} , nm): 251.



In order to avoid synthesis of potassium complex (potassium source from reagent) and drive the

through disk diffusion method. Two bacterial strains were chosen for this study, *Staphylococcus aureus* ATCC 29213, a Gram positive bacteria, and *Escherichia coli* ATCC 25922, a Gram negative bacteria.

The two bacterial strains (DMSO stock maintained at -70°C) were revitalized and repassed with 24 hours before the study on Columbia blood agar. From these fresh cultures, bacterial inoculums were prepared in sterile saline solution (turbidity adjusted 0.5 McFarland). The bacterial inoculums were inoculated by swabbing on three different directions on the surface of Muller Hinton agar medium. The plates were left to dry for 15 minutes at room temperature, afterwards sterile filter paper disks were placed on the surface of the medium (leaving at least 3 cm distance between two disks, and at least 1.5 cm from the edge of the plates). 5 μ L of saturated solution from each compound were placed on the filter disks, and the plates were left again 15 minutes at room temperature, to allow uniform diffusion in the medium. Afterwards, the plates were incubated at 37°C, for 24 hours. The next day, the inhibition zone diameters were measured for each compound.

Synthesis of Na₈[HAsW₉O₃₃]*17H₂O

The trilacunary POM precursor salt Na₈[HAsW₉O₃₃]*17H₂O was synthesized according to published procedures and their purity was confirmed by IR spectroscopy [2, 9]

Synthesis of Na₁₂[(AsW₉O₃₃)₂Pd₃]*24H₂O

The synthesized AsW₉ ligand (10 g; 3.63 mmol) was dissolved in 20 mL hot NaOH diluted solution (pH = 8.5). Cation salt PdCl₂ (0.63 g; 3.6 mmol) was dissolved in 20 mL water:HCl 1:1 (v:v) at 70 - 80°C and the pH was adjusted at 8 with NaOH 3 M. These two solutions were mixed drop-wise, under vigorous stirring, at constant temperature (70 - 80°C) and pH (7 - 8).

Synthesis of Na₆[(AsW₉O₃₃)₂Pt₃]*46H₂O

This complex was synthesized analogously as above, using the same quantities of AsW₉ in the same conditions of temperature and pH, except that PdCl₂ was replaced with K₂PtCl₆ (1.72 g; 3.5 mmol) which was dissolved in 140 mL hot purified water. After adding cation solution in ligand solution drop-by-drop, the mix was maintained in constant conditions of temperature (70 - 80°C) and pH (7 - 8) for two hours.

reaction to sodium complex instead, powdered NaCl was added to the mixture; the solution became

dark-brown. The solution was filtered on Buchner funnel and then concentrated to 2/3 of initial volume. When the complex crystallized, it was separated and redissolved in diluted NaOH solution for purification. The final crystals were grey. Yield 3.17 g (44.4 %). IR spectrum (KBr pellet, cm^{-1}): 941.2; 841.6; 805; 746.4; 511.5. UV (λ_{max} , nm): 248.

Results and Discussion

Synthesis

Even if the compounds could be synthesized directly from Na_2WO_4 , NaAsO_2 and cations (one-pot reaction) the complexes were obtained in two steps, by adding cations solutions to AsW_9 ligand solution [8]. This method was chosen to ensure AsW_9 identity by UV, IR, TGA analysis. Regardless of the chosen method the pH value, the reaction temperature and the molar ratio are the essentials factors in this work: pH = 7 - 8, temperature range 70 - 80°C, ligand:cation molar ratio = 2:3.

All obtained compounds (AsW_9 , AsW_9Pd , AsW_9Pt) were analysed by UV, IR spectrophotometry and X-ray diffraction. The number of water molecules in these structures was determined by TGA analysis and the ligand:cation molar ratio in complexes was established by conductometric titration of AsW_9 with metallic salts (K_2PtCl_6 in the case of platinum and PdCl_2 for palladium). The ratio was obtained from the inflexion points of the curves when molar ratio was plotted *versus* conductivity (Figure 1).

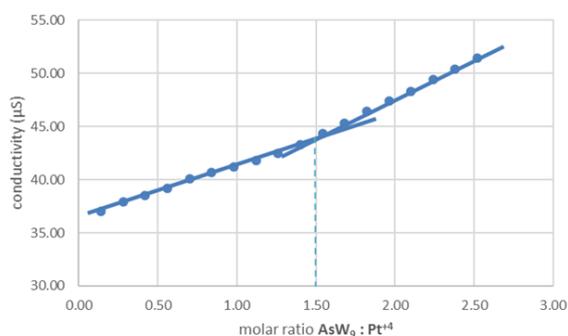


Figure 1.

Conductivity of AsW_9 solution dependent on the added K_2PtCl_6 solution

From the plotted data the same ligand:cation combination ratio can be noticed for both complexes (2 ligand:3 cation/complex) even if the coordination capacity is different (Pd^{2+} with coordination number 4, Pt^{4+} with coordination number 6). These results make it possible to associate the synthesized complexes as having Hervé structures: two trivalent $[\text{AsW}_9\text{O}_{33}]^{9-}$ subunits connected by O-Pd-O/O-Pt-O bridges. Each metallic cation is coordinated by four oxygen atoms from four WO_6 groups of two different AsW_9 units (Figure 2).

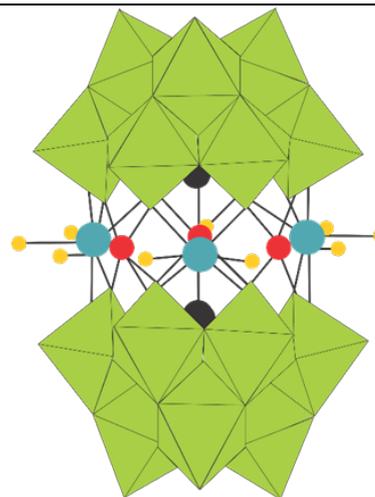


Figure 2.

Hervé structure complexes (green octahedra = WO_6 ; black sphere = As; red sphere = Pd/Pt; blue sphere = Na; little yellow sphere = O)

All four valences of Pd^{2+} are involved with oxygen, while in Pt^{4+} case, besides four bonds with AsW_9 oxygens, two valences are coordinating water molecules. In Hervé structure, the three metal cations are alternating with three Na atoms, in order to stabilize the structure. The three Na ions and three metallic cations form a central belt in the sandwich structure [1, 7, 11].

UV spectra

UV recorded spectra are characteristic to POM and show intense maximum at 185 - 195 nm corresponding to $\text{W}=\text{O}_d$ bonds [15]. The measurements were conducted between 190 nm and 400 nm so only the tail of this maximum appear (Figure 3).

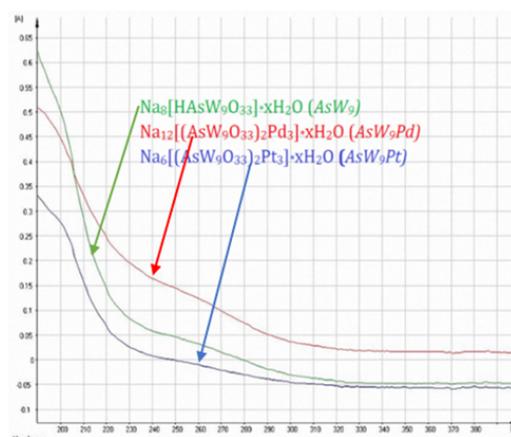


Figure 3.

UV spectra of Pd^{2+} and Pt^{4+} complexes and AsW_9 ligand

The peak is very intense corresponding to higher energies. This maximum does not show large differences in these compounds (all having the same

addenda, W) demonstrating that $W=O_d$ are not involved in cations coordination.

The second peak on spectra is characteristic to $W-O_{b,c}-W$ bonds (Table I). These peaks are wider due to all types of $W-O$ bond (except $W=O_d$) according to the structure described by Sidgwick [10]. In all complexes spectra, these second peak move towards lower values of wavelength (hypsochromic shift). This is due to the influence of coordinated cations especially on edges-tricentric bonds from AsW_9 structure [7, 9].

Table I
UV maxima recorded values of synthesized compounds

	AsW ₉	AsW ₉ Pd	AsW ₉ Pt
λ (nm)	257	251	248

IR determination

The IR spectra (Figure 4) shows characteristic peaks for sandwich-type structures (Table II).

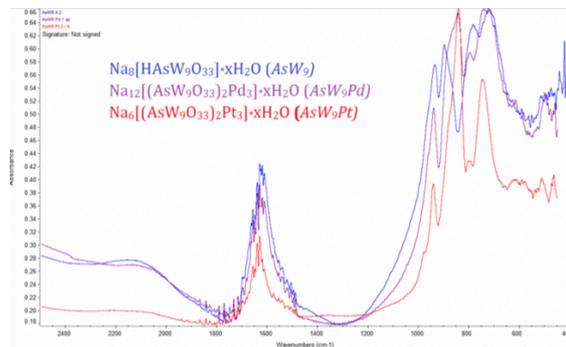


Figure 4.

IR recorded spectra of synthesized compounds

Table II
IR absorption maxima recorded (cm^{-1}) and bond correspondence

Compound	$W=O_d$	$W-O_{b,c}-W$	$W-O-As$	$W-O_c-W$
$Na_6[\{Na(H_2O)\}_3\{Ni(Htaz)\}_3(AsW_9O_{33})_2] \cdot 4H_2O$ [7]	942	891	801	737
$Na_6[\{Na(H_2O)\}_3\{Co(Htaz)\}_3(AsW_9O_{33})_2] \cdot 8H_2O$ [7]	935	874	801	732
$Na_6[\{Na(H_2O)_{0.5}\}_3\{Mn(Htaz)\}_3(AsW_9O_{33})_2] \cdot 11H_2O$ [7]	942	888	807	732
$[Cu(2,20-bpy)_3]_4H_2[Cu(H_2O)_4(As_2W_{18}O_{62})_2]$ [12]	953	881	830	760
$Cs_{8.5}(NH_4)_{2.75}Na_{0.75}[(C_4H_8Te)_3As_2W_{18}O_{66}] \cdot 30H_2O$ [6]	951	884	804	
AsW ₉ Pd	940	844	792	739
AsW ₉ Pt	941.2	841.6	805	746.4
AsW ₉ (own synthesis)	935.5	897.4	783.8	721.5

Vibrational bands of $W=O_d$ bonds are easily misplaced proving once again that metallic cations are not coordinated at this level.

Significant differences occur in the $W-O_{b,c}-W$, $W-O-As$ bands, having different intensities and wave-number. In AsW_9 spectra (unsaturated POW) a minimum appears between 783.8 cm^{-1} and 897.4 cm^{-1} because this compound is an unsaturated Keggin type, trilacunar one, formed by loss of three octahedrons and it has an open structure. The formed vacancies, by conversion of $W-O-W$ in $W=O$, are characterized by an excess of electrons, a high electron density which promotes coordination of cations. This minimum is reduced after coordination. In complexes spectra this minimum is reduced and two new bands appear corresponding to coordinated metallic cations: for Pd 499.7 cm^{-1} ; for Pt 511.5 cm^{-1} .

The $\approx 1620\text{ cm}^{-1}$ band is associated with coordinated water molecules.

TGA analysis

The thermal stability of synthesized compounds was determined in pure crystalline samples, in N_2 atmosphere, temperature range $50 - 500^\circ\text{C}$, with a heating rate of $20^\circ\text{C}/\text{minute}$. Thermal behaviour of the compounds was very similar (Figure 5).

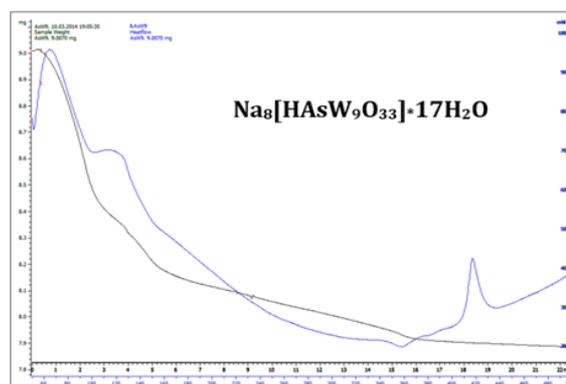


Figure 5.

Thermal behaviour of $Na_8[HAsW_9O_{33}] \cdot 17H_2O$

Behaviour of POW compounds is generally the same, starting with weight loss due to elimination of crystal water molecules (at 100 - 150°C, accompanied by endothermic effect, energy absorption), then water molecules from the POW building and ending with the destruction of structure and formation of new interoxidic bonds (> 400°C, with exothermic effect).

Water molecules number is larger in case of Pt complex because Pt coordinates water molecules itself.

X-ray diffraction

Both synthesized complexes (AsW₉Pd, AsW₉Pt) were analysed by powder X-ray diffraction. The structure was refined automatically (Rietveld refinements) using FullProf Software. Diffractograms were compared with ones of similar polyoxometalates found in the literature using MATCH Software and PDF2 database. Spectra (Figure 6) exhibit similarities with those from the database but are not identical.

Using data from diffractograms, we were able to estimate crystallinity degree, crystallites dimensions and the major interplanar distances for both synthesized complexes structures (Tables III and IV).

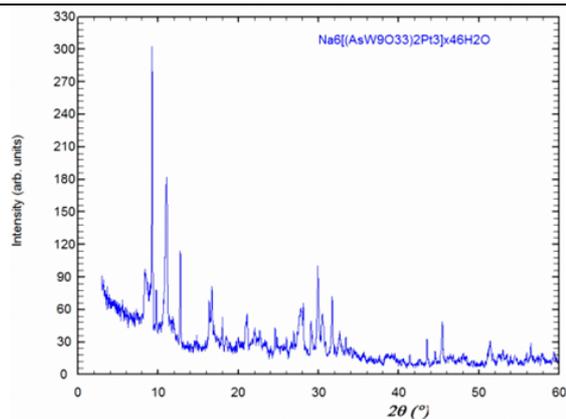


Figure 6.

Na₆[(AsW₉O₃₃)₂Pt₃]₄₆H₂O recorded diffractogram

Table III

Crystallinity degree and crystal size of synthesized complexes

	AsW ₉ Pd	AsW ₉ Pt
Crystallinity degree	61%	63%
Crystal size	405 Å	383 Å

Table IV

Interplanar distances (Å) of synthesized complexes

	Interplanar distances (Å)								
AsW ₉ Pd	12,646	10,518	8,796	7,842	6,917	5,220	4,202	3,617	3,307
AsW ₉ Pt	12,580	10,494	8,000	7,815	6,894	5,240	4,200	3,611	3,306

By correlating calculated data obtained by X-ray diffraction with those found in the literature both complexes can be associated with Hervé structures, sandwich-type POW, as all analysis confirm.

These Hervé structures of AsW₉Pd/AsW₉Pt complexes are formed by two anions B-[AsW₉O₃₃]⁹⁻ (B-structure = saturated structure with four triples, [AsW₁₂O₄₀]⁵⁻; by leaving one octahedron of each triplet vacancies are formed) bridged O-Pd/Pt-O. Each Pd/Pt atom is coordinated by each B-[AsW₉O₃₃]⁹⁻ unit through two oxygen atoms. Pd²⁺ cation forms four bonds of the same type with four peaks, two of each tri-lacunar structure. In addition to these connections, the Pt⁴⁺ cation (coordination number = 6) coordinate two molecules of water. Thus, the spatial orientation of the two cations are all quadratic plan for Pd²⁺ and octahedral for Pt⁴⁺. The three metal atoms alternating with three sodium atoms stabilize the structure [1, 4, 14].

Antibacterial activity

The assessment of the antibacterial activity by disk diffusion methods showed that all of the three compounds presented antibacterial activity against *Staphylococcus aureus* and *Escherichia coli* (Table V). Overall, the three compounds presented higher inhibitory activity (higher inhibition diameters zones) against *Escherichia coli* than against *Staphylococcus*

aureus. For both bacterial strains, AsW₉Pt presented the largest inhibition diameter zone, compared to AsW₉Pd or AsW₉, and the complexes were more active than AsW₉ ligand. Further studies are required to establish the minimum inhibitory concentration for these compounds.

Table V

Inhibition zones diameter (mm) of AsW₉ ligand and AsW₉Pd, AsW₉Pt complexes

Compound	AsW ₉	AsW ₉ Pd	AsW ₉ Pt
<i>Staphylococcus aureus</i>	11	16	18
<i>Escherichia coli</i>	13	17	23

Conclusions

In this paper, two new complexes of [AsW₉O₃₃]⁹⁻ with Pd²⁺ and Pt⁴⁺ cations are presented and analysed. After performing UV, IR, TGA, X-ray analysis, these compounds can be associated to Hervé structures (*pseudo*-Keggin), sandwich-type polyoxo-tungstate formed by two AsW₉ units connected by O-Pd/Pt-O bridges. In the equatorial plan, the three Pd/Pt cations alternate with three sodium atoms that stabilize the structures. Both complexes exhibit antibacterial activity, but platinum complexes presented a better antimicrobial activity than palladium one. Synthesized compounds were more active on *E. coli* than on *Staphylococcus aureus*, being more efficient

on Gram negative bacteria. In the future, we will concentrate on determining the MIC of these compounds for several bacterial strains.

Acknowledgement

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References

1. Bodoki E., Bogdan D., Săndulescu R., Ab initio study of the Na-colchicine positively charged complex. *Farmacia*, 2015; 63(4): 539-542.
2. Bosing M., Loose H.A., Pohlmann H., Krebs B., New Strategies for the Generation of Large Heteropolymetalate Clusters: The β -B-SbW, Fragment as a Multifunctional Unit. *Chem. Eur. J.*, 1997; 3(8): 1232-1237.
3. Dey K.C., Sharma V., Study of the heteropoly metal oxide complexes: principle of their synthesis, structure and applications. *Int. J. Chem. Tech. Res.*, 2010; 2(1): 368-375.
4. D'Souza L., Noeske M., Richards R.M., Kortz U., Polyoxotungstate stabilized palladium, gold, and silver nanoclusters: A study of cluster stability, catalysis, and effects of the stabilizing anions. *J. Colloid Interf. Sci.*, 2013; 394: 157-165.
5. Gouzerh P., Che M., From Scheele and Berzelius to Müller, Polyoxometalates revisited and the "missing link" between the bottom up and top down approaches. *L'actualité chimique*, 2006; 298: 9-22.
6. Kandasamy B., Bassil B.S., Haider A., Beckmann J., Chen B., Dalal N.S., Kortz U., Incorporation of organotellurium (IV) in polyoxometalates. *J. Organomet. Chem.*, 2015; 796: 33-38.
7. Liu J., Wang L., Yu K., Su Z., Wang C., Wang C., Zhou B., Synthesis, crystal structure and properties of sandwich type compounds based on {AsW₉} and a hexa-nuclear unit with three supporting TM-triazole complexes. *New J. Chem.*, 2015, 39: 1139-1147.
8. Long D.L., Tsunashima R., Cronin L., Polyoxometalates: Building Blocks for Functional Nanoscale Systems. *Angew. Chem. Int. Ed.*, 2010; 49: 1736-1758.
9. Rusu D., Crăciun C., Cercetări fizico-chimice în domeniul polioxometalaților complecși. Ed. Casa Cărții de Știință, Cluj-Napoca, 2006; 45-49, 40-41, 73-78, 239-243.
10. Stan C.D., Ștefanache A., Tătăringă G., Drăgan M., Tuchiluş C.G., Microbiological evaluation and preservative efficiency of new mandelic acid derivatives in ointments. *Farmacia*, 2015; 63(4): 577-580.
11. Tézé A., Hervé G., Formation et isomerisation des undeca et dodeca tungstosilicates et germanates isomeres. *J. Inorg. Nucl. Chem.*, 1977; 39(6): 999-1002.
12. Wang J., Wang W., Niu J., A novel dimeric arsenotungstate assembled by copper-bridged Dawson units, [Cu(2,20-bpy)₃]₄H₂[Cu(H₂O)₄(As₂W₁₈O₆₂)₂]: Synthesis and characterizations. *Inorg. Chem. Commun.*, 2007; 10: 520-522.
13. Wang Y., Zou B., Xiao L.N., Jin N., Peng Y., Wu F.Q., Ding H., Wang T.G., Gao Z.M., Zheng D.F., Cui X.B., Xu J.Q., Two new hybrid compounds assembled from Keggin-type polyoxometalates and transition metal coordination complexes. *J. Solid State Chem.*, 2011; 184: 557-562.
14. Wang Z.J., Zhang L.C., Zhu Z.M., Chen W.L., You W.S., Wang E.B., Two new sandwich-type tungstobismuthates constructed from trivacant Keggin units, esterin and transition metals. *Inorg. Chem. Commun.*, 2012; 17: 151-154.
15. Zhao Z., Zhou B., Su Z., Zhu C., Hydrothermal synthesis, structure and properties of a new arsenotungstate. *J. Solid State Chem.*, 2010; 183: 332-337.