Acta Farm. Bonaerense **16** (3): 145-50 (1997)
Recibido el 17 de marzo de 1997
Aceptado el 18 de abril de 1997

Vibrational Spectrum of $KBi(C_6H_4O_7).3\ H_2O$, the Most Simple Species present in Colloidal Bismuth Subcitrate

Gloria E.TOBON-ZAPATA, Susana B.ETCHEVERRY and Enrique J.BARAN

Centro de Química Inorgánica (CEQUINOR), Facultad de Ciencias Exactas, Universidad Nacional de La Plata, Casilla de Correo 962, 1900-La Plata, Argentina

SUMMARY. The infrared and Raman spectra of the title complex, the stoichiometrically most simple species present in the pharmaceutical preparations currently known as colloidal bismuth subcitrate, were recorded and discussed in relation to the known structural characteristics of the compound.

RESUMEN. "Espectro Vibracional del KBi(C6H4O7). 3 H_2O, la Especie más Simple Presente en el Subcitrato de Bismuto Coloidal". Se registraron los espectros de infrarrojo y Raman del complejo del título, la especie estequiométricamente más sencilla presente en el fármaco comunmente llamado subcitrato de bismuto coloidal, y se los discute en relación a las características estructurales del compuesto.

INTRODUCTION

In recent years renewed interest has been developed in the pharmacology of different bismuth compounds, specially after the discovery of its effectivity against the bacterium *Helicobacter pylori,* responsible for chronic gastritis and peptic ulcers. Among the modern bismuth-based pharmaceuticals, preparations based on colloidal bismuth subcitrate (CBS) are the most widely used. The chemistry of this system is very complex, because it is constituted by a number of different polynuclear Bi(III) species in equilibrium [1-6].

In order to advance in the understanding of the general physicochemical properties of this system; we have initiated some spectroscopic work on species involved in this kind of drug.

The stoichiometrically most simple complex present in these bismuth preparations seems to be $KBi(C_6H_4O_7).\ 3\ H_2O$, whose crystal structure was first reported by Herrmann *et al.* [1] and further refined by Asato *et al.* [4]. In a first approach, and as shown schematically in Figure 1, the Bi(III) cation is coordinated by three oxygen atoms, one of a terminal carboxylate, one of the central carboxylate and the third one from the deprotonated alcoholic OH-group of citric acid. The other terminal carboxylate group is coordinated to a second Bi(III) ion, as a bidentate lig-

KEY WORDS: Bi(III) citrate, Infrared Spectrum, Raman Spectrum.
PALABRAS CLAVE: Citrato de Bi(III), Espectro de Infrarrojo, Espectro Raman.

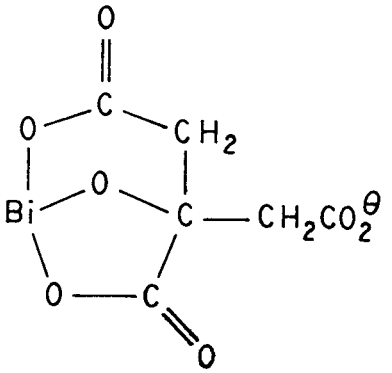

Figure 1. Primary interaction of Bi(III) with citric acid (adapted from Herrmann *et al.* [1]).

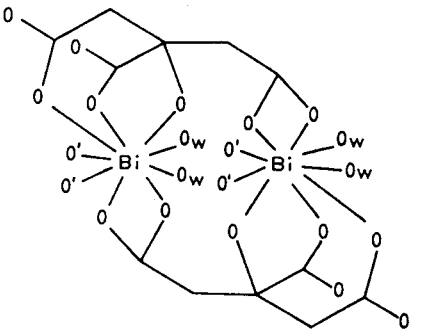

Figure 2. Dinuclear subunit present in the investigated compound (O_w are the oxygen atoms from the H_2O molecules; O'are the atoms arising from the vicinal dimer).

and, generating the very stable dimeric subunit Bi(cit)(cit)Bi, which is the characteristic building block of this type of bismuth complexes [4-6]. The coordination sphere of each of the Bi(III) ions is completed by two oxygen atoms provided by H_2O molecules, one of which is only loosely coordinated [1,4].

The structure is additionally complicated because two pairs of such Bi(III) dimers, generated as described above, interact further with participation of the non coordinated oxygen atoms (arising from the terminal and the central carboxylate groups *(cf.* Figure 1) finally originating a tetranuclear subunit [4]. This means that the coordination sphere around each of the Bi(III) ions is constituted by the three oxygen atoms shown in Figure 1, two oxygen atoms from the water molecules, two oxygen atoms from the bidentate carboxylate group arising from the other Bi(III) ion of the dimer and two oxygen atoms provided by the vicinal dimer[4], as shown schematically in Figure 2. As a result of this arrangement, the coordination polyhedron around each metal center is roughly nine. The Bi-O distances vary widely, between 2.12 and 3.41 Å, but even the long bonds are significantly shorter than the sum of the van der Waals radii (3.67 Å) [4]. The shortest Bi-O distance is that involving the deprotonated alcoholic group of the ligand (2.11 Å) and the stereochemical active lone pair of Bi(III) is surely located in trans position to this bond [1,4].

EXPERIMENTAL

Synthesis of the complex

To a solution of 0.54 g of potassium citrate, $K_5C_6H_5O_7.H_2O$ (Sigma), dissolved in 20 ml of distilled water and heated at 60 °C, 2 g of bismuth citrate, $Bi(C_6H_5O_7)$, freshly prepared in the laboratory from $Bi(NO_3)_3$ and citric acid [7], were slowly added, under constant stirring. The resulting suspension was neutralized by dropwise addition of a 10% NH_4OH solution. The limpid solution was heated during one hour more at 60 °C. After cooling, the complex precipitated as a white microcrystalline powder, which was filtered off and washed several times with cold distilled water and finally dried in an oven at 60 °C. The purity of the compound was checked by chemical analysis.

Spectroscopic measurements

Infrared spectra were measured between 4000 and 400 cm^{-1} with a Bruker FTIR model 113v instrument, with the powdered samples dispersed in KBr pellets. Raman spectra were obtained with the FRA 106 Raman accessory of a Bruker FTIR IF 66 spectrometer. The 1064 nm line of an Nd: YAG laser was used for excitation.

RESULTS AND DISCUSSION

The infrared spectra in the regions between 3700-2700 and 1700-400 cm^{-1} are shown in Figures 3 and 4, respectively. The Raman spectrum in two of the most characteristic regions is presented in Figure 5.

The assignment of these spectra is complicated by the fact that vibrational modes of different origins appear superimposed in most of the spectral regions. Notwithstanding, in Table 1 we propose a general assignment, based on general literature data [8,9] as well as on spectra of related species [7,10,11].

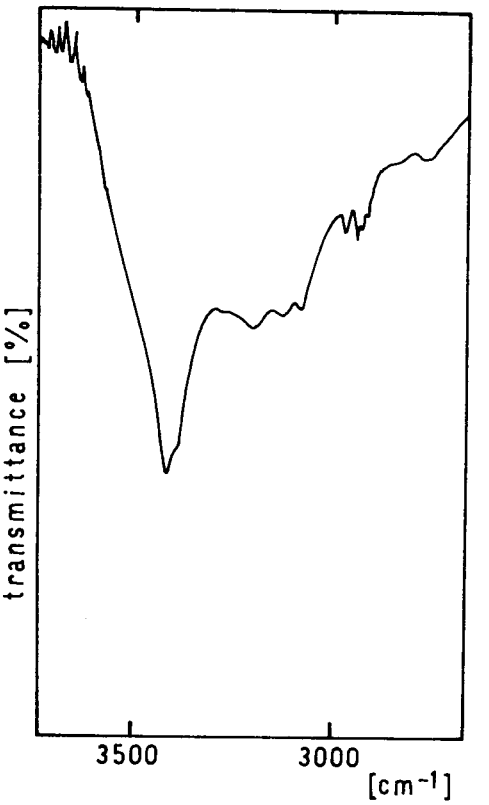

Figure 3. FTIR spectrum of $KBi(C_6H_4O_7)$. 3 H_2O between 3700 and 2700 cm^{-1}.

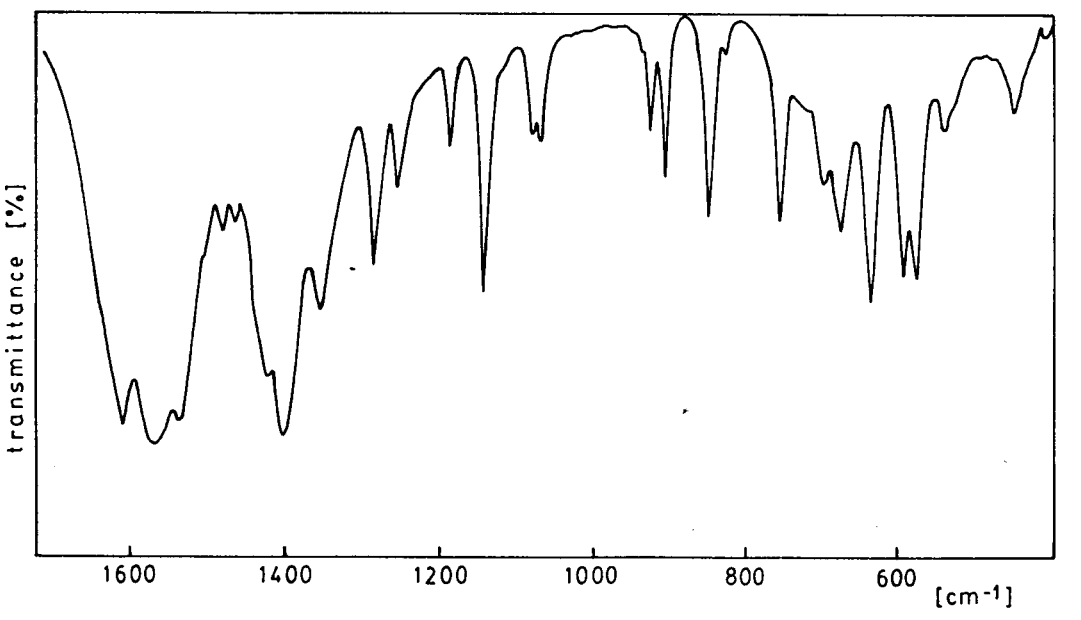

Figure 4. FTIR spectrum of $KBi(C_6H_4O_7)$. 3 H_2O between 1700 and 400 cm^{-1}.

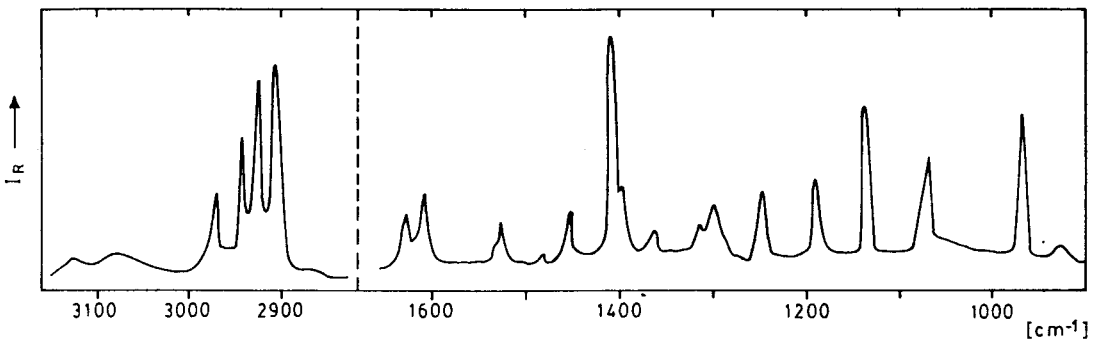

Figure 5. FT-Raman spectrum of $KBi(C_6H_4O_7)$. 3 H_2O in the two most interesting regions.

Band position (cm^{-1})	**Approximate assignment**
3411 vs	ν (O-H)
3188 w/3111 w/3066 w	ν (O-H)
2964 w/2943 w/2925 w/2907 vw	ν_{as} (CH2)/ν_s (CH_2)
2755 w (?)	
1608 s	
1566 vs/1555 sh	ν_{as} (COO^-)
1535 m	
1479 w/1462 w	(CH_2) sciss.
1432 sh/1419 w	
1403 vs	ν_s (COO^-)
1355 m	
1286 s	
1255 m	
1187 m	
1143 vs	ν (C-O) alc.
1079 m/1068 m	ν (C-C)
935 sh/926 m/906 s	ν (C-C)
849 vs	
755 vs	(CH_2) rock.
697 w/674 s	δ (COO^-)
635 vs	δ (COO^-)
593 s/576 s	
540 w	
451 m	

Table 1. Infrared spectrum of $KBi(C_6H_4O_7)$. 3 H_2O. *vs:* very strong; *s:* strong; *m:* medium; *w:* weak; *vw:* very weak; *sh:* shoulder.

The higher frequency range is dominated by a strong and broad absorption with a very strong band located at 3411 cm^{-1} (*cf.* Figure 3). This band, as well as the other three less intense ones found at 3188, 3111 and 3066 cm^{-1}, can be confidently assigned to O-H stretching vibrations of the water molecules. The wide range covered by these vibrations is in agreement with the extensive hydrogen bridging between the water molecules and between these and the oxygen atoms

of the citrate ligands which, as shown by the structural analysis, are important factors in the stabilization of the complex architecture of the crystal lattice [1]. The position of these stretching bands suggest the formation of H-bridges of medium length, in agreement with the classification of Siebert [12]. The remaining bands in this spectral range are assigned to the stretchings of the CH_2-groups. These bands are somewhat displaced to higher frequencies in relation with the ranges commonly observed for them, in agreement with the fact that, as a consequence of its coordination to the metallic center, they are included in a strained ring structure [9].

The ν (CH_2) vibrations appear very well defined in the Raman spectrum as lines of strong and medium intensity located at 2970, 2942, 2926 and 2910 cm^{-1}. On the contrary, in this case the ν (O-H) bands are not well defined and only two weak and broad signals can be identified at about 3080 and 3130 cm^{-1} *(cf.* Figure 5).

The antisymmetric stretching of the carboxylate groups appears very well resolved in the IR spectrum, with three components and a shoulder, in agreement with the different structural peculiarities of each of the three carboxylate groups of the ligand. The same behavior can be observed in the Raman spectrum in which three lines (1626, 1607 and 1534 cm^{-1}) can be observed with a weak shoulder on the higher frequency side of the last of these lines *(cf.* Figure 5). Besides, in the case of the symmetric stretching mode of these acidic groups, three components are found in both the IR and Raman spectra. In this case, one of the components of these multiplet is the strongest Raman line in this region (1418 cm^{-1}); the other two are found at 1452 (with a weak shoulder at 1396) and 1362 cm^{-1} *(cf.* Figure 5).

It should be also mentioned that in the regions associated with the mentioned ν (COO^-) modes other vibrations are expected and they surely enhance some of the observed bands. For instance, the bending mode of H_2O usually lies around 1590-1660 cm^{-1} [13], whereas CH_2 deformational modes are expected in the 1500-1150 cm^{-1} range [9].

Not all of the remaining bands in the medium IR range could be unambiguously assigned, although two pairs of bands related to C-C stretchings and one rocking mode of the CH_2-groups could be identified. The strong Raman line located at 971 cm^{-1} can be probably related to a ν (C-C) mode. On the other hand, the strong IR band located at 1143 cm^{-1} has been tentatively assigned to the C-O stretching of the deprotonated alcohol group of the ligand. Such bands are usually found in the range between 1000 and 1100 cm^{-1} [14-17]. In the Raman spectrum this mode is found at 1141 cm^{-1}. Some of the remaining bands are probably related with CH_2 bendings [9].

In the range below 700 cm^{-1} we have assigned two δ (COO^-) modes. Bands at 593/576, 540 and 451 cm^{-1} probably include vibrational modes of the water molecules [17] as well as Bi-O motions.

To conclude, this spectroscopic study gives a first insight into the vibrational behavior of one of the bismuth(III) compounds present in CBS and allows to advance in the better understanding and characterization of this system, giving new tools for the analysis of other, more complex components, of this interesting inorganic drug.

Acknowledgements. This work has been supported by CONICET and CIC-Provincia de Buenos Aires. G.E.T.Z. is a fellow from the Fellowship Program for Latin American Graduates from CONICET.

REFERENCES

1. Herrmann, W.A., E. Herdtweck & L.Pajdla (1991) *Inorg. Chem.* **30** : 2579-81
2. Asato, E., W.L. Driessen, R.A.G. de Graaff, F.B. Hulsbergen & J. Reedijk (1991) *Inorg. Chem.* **30**: 4210-8
3. Asato, E., C.M. Hol, F.B. Hulsbergen, N.T.M. Klooster & J.Reedijk (1993) *Inorg. Chim. Acta* **214**: 159-67
4. Asato, E., K. Katsura, M. Mikuriya, T. Fujii & J. Reedijk (1993) *Inorg. Chem.* **32**: 5322-9
5. Asato, E., K. Katsura, M. Mikuriya, U. Turpeinen, I. Mutikainen & J. Reedijk (1995) *Inorg. Chem.* **34**: 2447-54
6. Baran, E.J. & G.E.Tobón-Zapata (1995) *Acta Farm. Bonaerense* **14**: 133-8
7. Tobón-Zapata, G.E. (1997) Ph.D. Thesis, Faculty of Exact Sciences, UNLP, Argentina, in preparation
8. Bellamy, L.J. (1955) *Ultrarot-Spektrum und Chemische Konstitution,* Steinkopf Verlag, Darmstadt
9. Lin-Vien, D., N.B. Colthup, W.G. Fateley & J.G. Grasselli (1991) *Infrared and Raman Characteristic Frequencies of Organic Molecules,* Academic Press, San Diego
10. Rao, K.M. & C.K. Narayanaswamy (1972) *Indian J. Pure Appl. Phys.* **10**: 176-7
11. Tobón-Zapata, G.E., O.E. Piro, S.B. Etcheverry & E.J. Baran (1997) unpublished
12. Siebert, H. (1966) *Anwendungen der Schwingungsspektroskopie in der Anorganischen Chemie,* Springer Verlag, Berlin
13. Lutz, H.D. (1988) *Struct.Bonding* **69**: 97-124
14. Barraclough, C.G., D.C. Bradley, J. Lewis & I.H.Thomas (1961) *J. Chem. Soc.* 2601-4
15. Etcheverry, S.B., P.A.M. Williams & E.J. Baran (1996) *Biol. Trace Elem. Res.* **51**: 169-76
16. Etcheverry, S.B., P.A.M. Williams & E.J. Baran (1996) *J. Inorg. Biochem.* **63**: 285-9
17. Nakamoto, K. (1978) *Infrared and Raman Spectra of Inorganic and Coordination Compounds,* J. Wiley, New York