# Synthesis, FT-IR and $^1$H NMR Studies of Alkali and Alkaline Earth Metal Complexes with Guanosine

J. BARIYANGA and T. THEOPHANIDES*

*Department of Chemistry, Université de Montréal, Montreal, Que., H3C 3V1, Canada*

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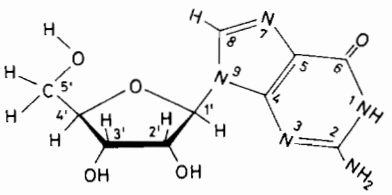
## Abstract

The synthesis of complexes of Li(I), K(I), Mg(II), Ca(II) and Ba(II) with guanosine in basic non aqueous solutions is described. The complexes were of two types: (1) complexes having the general formula, $M(Guo)_nX_m \cdot YH_2O \cdot ZC_2H_5OH$, where M = Mg(II), Ca(II), Ba(II) and Li(I), n = 1,2,4, X = $Cl^-$, $Br^-$, $NO_3^-$, $ClO_4^-$ and $OH^-$, m = 1,2, Y = 0–6 and X = 0–2, and (2) complexes with the general formula, $M(GuoH\text{-}1)(OH)_{n-1} \cdot YH_2O$, where M = K(I), Ca(II) and Ba(II), GuoH-1 = Ionized guanosine at $N_1$, n = 1,2 and Y = 1–3. The complexes are characterized by their proton nuclear magnetic resonance ($^1$H NMR) and Fourier transform infrared (FT-IR) spectra. The FT-IR and $^1$H NMR data of the non ionized nucleoside complexes suggest that the metal binding is through the $N_7$-site of guanine and that the anion (X) is hydrogen bonded to $N_1H$ and $NH_2$ groups. In the $N_1$-ionized guanosine complexes the metal binding is via the $O_6^-$ of guanine. All the complexes formed exhibited a transition of the sugar conformation from $C_2'$-*endo/anti* in the free nucleoside to $C_3'$-*endo/anti* in the metal complexes.

## Introduction

Numerous efforts have been made to study the nature of alkali and alkaline earth metal ion interactions with nucleosides, using NMR spectroscopic techniques [1–3]. Shimokawa *et al.* [1] have suggested that the above metal ions formed chemical bonds with the $N_1H$ or $NH_2$ groups of the guanosine moiety. However, a recent study by NMR relaxation time [3] has shown that the $Cl^-$ anions form hydrogen bonds with $N_1H$ and $NH_2$ groups of the guanosine. In these studies no attempt has been made to isolate and characterize the metal complexes formed. Metal complexes with deprotonated guanosine and organomercuric compounds have been studied previously [4]. In theses complexes the metal ion was found to coordinate at the $N_1$-site of the nucleoside.

In the present work we report the isolation and characterization of several alkali and alkaline earth metal ion complexes with guanosine in basic non aqueous solutions as studied by elemental analysis, $^1$H NMR and FT-IR spectroscopy. Furthermore, several characteristic vibrational frequencies have been correlated with the sugar conformation and have been found to be diagnostic of $C_2'$-*endo/anti* or $C_3'$-*endo/anti* conformation. The structure and atom numbering of the guanosine molecule is given in Scheme 1.



Scheme 1.

## Experimental

### *Materials*

The metal ion salts and their hydroxides have been purchased from J. T. Baker Chemical Company and used as supplied. Guanosine was from Sigma Chemical Company. Trimethylorthoformate (TMOF) was from Aldrich Chemical Company. Other Chemicals were reagent grade and used without further purification.

### *Preparation of Mg–Guanosine Complexes*

The magnesium salt (1 mmol) was refluxed in a mixture of ethanol (50 ml) and trimethylorthoformate (10 ml) for 24 h. Guanosine (1 mmol) was then added and refluxing was continued for about 6 h. After cooling at room temperature, the solution was refrigerated for 12 h. A white precipitate was formed. This was filtered and washed with ether and dried over $CaCl_2$.

*Author to whom correspondence should be addressed.

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*Preparation of Ca(II) and Ba(II)–Guanosine Complexes*

The metal salt (1 mmol) was refluxed in ethanol–water mixture (50v/10v) for 12 h. Guanosine (1 mmol) was then added and refluxing continued for another 12 h. A white precipitate was obtained, which was then filtered off and washed with ethanol–ether and dried over $CaCl_2$.

*Preparation of the Ionized Metal–Complexes*

The metal hydroxide and guanosine were mixed in a ratio 1:1 in the presence of HCl 0.1 N (50 ml) and refluxed for 12 h. The yellow solution was filtered off and evaporated under vacuum. The residue was washed with ethanol and ether several times and finally dried over $CaCl_2$. The elemental analyses of the metal–guanosine complexes are given in Table I. The $Li(Guo)OH \cdot C_2H_5OH \cdot H_2O$ compound was also prepared with the same method.

*Physical Measurements*

$^1H$ NMR spectra have been recorded on a Varian EM-360-60 MHz. Dimethylsulphoxide ($d_6$) was used as a solvent and trimethylsilane (TMS) as an internal reference.

FT-IR spectra have been recorded with a DIGI-LAB FTS-15/C Fourier Transform Michelson infrared interferometer equipped with a high sensitivity Hg-CdTe detector and KBr beam splitter with a spectral resolution of 4 $cm^{-1}$ as KBr pellets.

*Elemental Analysis*

The metal was determined gravimetrically and C, H and N were analysed by Schwarzkopf Microanalytical Laboratories (U.S.A.). The chlorine and bromine anions were determined argentimetrically by Volhard titration. The analytical data are in Table I.

## Results and Discussion

According to the analytical data given in Table I, the reactions of Mg(II), Ca(II) and Ba(II) ions with guanosine can be summarized as follows:

$$MgCl_2 + 4Guo \xrightarrow[TMOF]{C_2H_5OH} Mg(Guo)_4Cl_2$$

$$CaCl_2 + 4Guo \xrightarrow{C_2H_5OH/H_2O} Ca(Guo)_4Cl_2$$

$$BaCl_2 + Guo \xrightarrow{C_2H_5OH/H_2O} BaGuo \cdot Cl_2$$

The reaction with $MgCl_2 \cdot 6H_2O$ was carried out in the presence of TMOF (dehydrating agent) which facilitates the formation of the Mg–guanosine adduct.

For the ionized compounds of K(I), Ca(II) and Ba(II) the reaction was done with the corresponding metal hydroxide at pH = 10–12 with deprotonation at $N_1H$. In this case the metal nucleoside interaction is electrostatic between the negatively charged $O_6^-$ and the metal cation:

$$M(OH)_n + Guo \xrightarrow{H_2O} M(GuoH\text{-}1)(OH)_{n-1} + H_2O$$

where M = K(I), Ca(II) and Ba(II) and n = 1,2.

*$^1H$ NMR Spectra*

Proton NMR spectra were obtained in DMSO ($d_6$) solutions and the data for the proton $H_8$, $N_1H$, $NH_2$ and sugar $H_1'$ resonances are shown in Fig. 1 and Table II. The other ribose protons were not significantly affected upon metal complexation. The proton of the $N_1H$ group was not observed in $Mg(Guo)_4Cl_2 \cdot C_2H_5OH \cdot 3H_2O$, $Mg(Guo)_2Br_2 \cdot 6H_2O$ and $Li(Guo)OH \cdot C_2H_5OH \cdot H_2O$ adducts. The reason for this is most probably the fast exchange of the

TABLE I. Elemental Analysis of the Guanosine Metal Complexes (calculated (found)).

| Compound | % M | % C | % H | % N | % Cl | % Br |
|---|---|---|---|---|---|---|
| $Ba(Guo)Cl_2 \cdot H_2O$ | 26.95(26.00) | 23.55(23.60) | 2.95(3.01) | 13.75(13.21) | 13.94(14.80) | – |
| $Ca(Guo)_4Cl_2 \cdot 4H_2O$ | 3.04(3.80) | 36.49(36.27) | 4.60(4.12) | 21.29(20.93) | 5.39(4.90) | – |
| $Mg(Guo)_2Br_2 \cdot 6H_2O$ | 2.83(3.00) | 27.96(27.40) | 4.42(4.23) | 16.31(16.03) | – | 18.62(17.65) |
| $Mg(Guo)_4Cl_2 \cdot 3H_2O \cdot a$ | 1.83(1.02) | 37.96(38.04) | 4.93(4.76) | 21.09(20.54) | 5.35(4.69) | – |
| $Mg(Guo)_2(ClO_4)_2 \cdot 4H_2O \cdot a$ | 2.68(2.00) | 29.42(29.31) | 4.46(4.23) | 15.60(15.87) | 7.82(7.00) | – |
| $Mg(Guo)_4(NO_3)_2 \cdot 6H_2O \cdot 2a$ | 1.64(1.79) | 35.65(35.46) | 5.77(5.71) | 20.80(20.28) | | |
| $Li(Guo)OH \cdot H_2O \cdot a$ | 1.89(2.00) | 38.91(38.66) | 5.67(5.16) | 18.91(19.76) | | |
| $K(GuoH\text{-}1) \cdot H_2O$ | 11.53(12.06) | 35.38(35.85) | 4.13(4.44) | 20.64(19.70) | | |
| $Ba(GuoH\text{-}1)OH \cdot 1 \cdot 5H_2O$ | 27.99(27.00) | 24.46(24.90) | 3.87(3.37) | 14.26(13.74) | | |
| $Ca(GuoH\text{-}1)OH \cdot 3H_2O$ | 10.00(9.50) | 32.78(33.38) | 4.37(4.37) | 19.12(18.45) | | |

a = alcohol

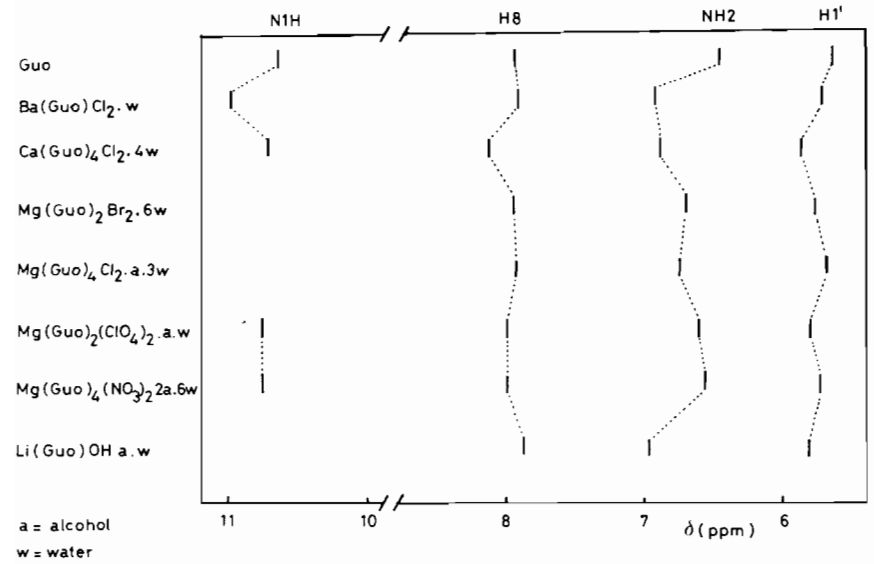



Fig. 1. $^1$H NMR spectra of guanosine and its metal complexes.

TABLE II. $^1$H NMR Chemical Shifts of Guanosine and its Metal Complexes.

| Compounds | $N_1H$ | $H_8$ | $NH_2$ | $H_1'$ |
|---|---|---|---|---|
| Guanosine (Guo) | 10.66 | 7.97 | 6.47 | 5.66 |
| $Ba(Guo)Cl_2 \cdot H_2O$ | 11.00 | 7.93 | 6.93 | 5.73 |
| $Ca(Guo)_4Cl_2 \cdot 4H_2O$ | 10.73 | 8.13 | 6.90 | 5.86 |
| $Mg(Guo)_2Br_2 \cdot 6H_2O$ | n/v | 7.96 | 6.70 | 5.76 |
| $Mg(Guo)_4Cl_2 \cdot 3H_2O \cdot a$ | n/v | 7.93 | 6.75 | 5.69 |
| $Mg(Guo)_2(ClO_4)_2 \cdot 4H_2O \cdot a$ | 10.76 | 8.00 | 6.60 | 5.80 |
| $Mg(Guo)_4(NO_3)_2 \cdot 6H_2O \cdot 2a$ | 10.75 | 8.00 | 6.56 | 5.73 |
| $Li(Guo)OH \cdot H_2O \cdot a$ | n/v | 7.88 | 6.96 | 5.80 |
| $K(GuoH\text{-}1) \cdot H_2O$ | – | 7.70 | 5.72 | 5.72 |
| $Ba(GuoH\text{-}1)OH \cdot 1.5H_2O$ | – | 7.80 | 6.38 | 5.72 |
| $Ca(GuoH\text{-}1)OH \cdot 3H_2O$ | – | 7.80 | 6.10 | 5.70 |

*n/v* = not visible, a = alcohol.

$N_1H$ proton with the small amounts of $D_2O$ present in DMSO-$d_6$. Similar exchange has been observed for the $N_1H$ proton of inosine in DMSO solutions [5]. The proton NMR spectra for the other complexes have shown considerable changes for the $N_1H$ and $-NH_2$ chemical shifts (Table II). The $-NH_2$ resonance of the complexes, $Ba(Guo)Cl_2 \cdot H_2O$, $Ca(Guo)_4Cl_2 \cdot 4H_2O$ and $Li(Guo)OH \cdot C_2H_5OH \cdot H_2O$ showed a large downfield shift (0.43 ppm) with respect to free nucleoside (Table II). The Mg–guanosine complexes also exhibited a downfield shift for the $-NH_2$ group (0.1–0.23 ppm). The changes observed here in the chemical shifts of the $NH_2$ group may be due to hydrogen bonding formed between the anions $Cl^-$ or $Br^-$ and the $NH_2$ group. Similar hydrogen bonding may also be responsible for the $N_1H$ chemical shifts in the above metal–complexes. Solution studies [3, 6] have shown similar results in the related metal–guanosine compounds.

The $H_8$ proton showed a downfield shift of 0.16 ppm for the $Ca(Guo)_4Cl_2 \cdot 4H_2O$ compound, which is consistent with the participation of the $N_7$-atom of the guanosine in the metal–molecule bond formation. Considerable downfield shifts (0.14–0.2 ppm) were also observed for $H_1'$ in $Ca(Guo)_4Cl_2 \cdot 4H_2O$, $Li(Guo)OH \cdot C_2H_5OH \cdot H_2O$ and $Mg(Guo)_2(ClO_4)_2 \cdot C_2H_5OH \cdot 4H_2O$ compounds. Canty and Tobias [4] have observed similar downfield shifts for the $H_1'$ proton in $[H(Guo)]NO_3$ and $[RHg(Guo)]NO_3$, where R = alkyl group, suggesting proton-acid Hg–$N_7$ binding respectively in these compounds.

The sugar $H_1'$ exhibited a downfield shift in all metal complexes which may be related to a sugar conformational transition form $^2$E to $^3$E (see FT-IR spectra).

The $^1$H NMR spectra of the ionized guanosine–metal complexes showed an upfield shift of $H_8$ and $NH_2$ proton resonances (Fig. 2 and Table II), but only a slight change in the $H_1'$ resonances of the sugar moiety. The upfield shifts observed in the $H_8$ and $NH_2$ resonances could be due to the deprotonation of the $N_1H$ which causes a large perturbation and conjugation of the double bonds within the ring system (see Scheme 2). The interaction of the metal ion in these complexes is most likely through the $O^-_6$-atom of the guanine.

*FT-IR Spectra*

FT-IR spectra of guanosine, 1-methylguanosine and their metal complexes were recorded and analysed and the main features of the spectra are given in Table III and Figs. 3 and 4. The assignments are in agreement with Lord and Thomas [7], Novak [8] and Tsuboi *et al.* [9]. Our present study covers only two regions, namely, 1800–1000 $cm^{-1}$ and 1000–600 $cm^{-1}$. From the region of 3700–2700

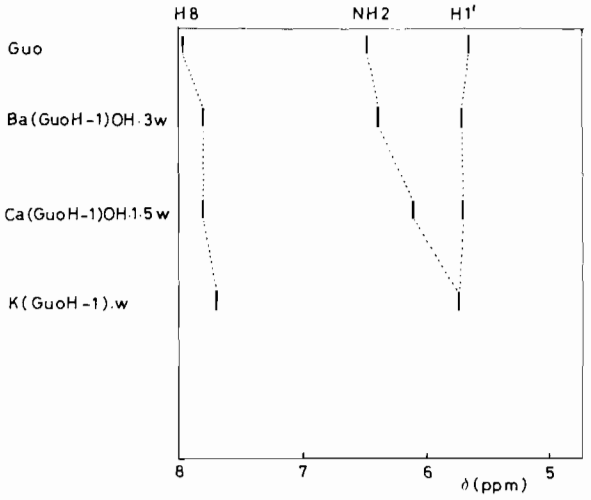
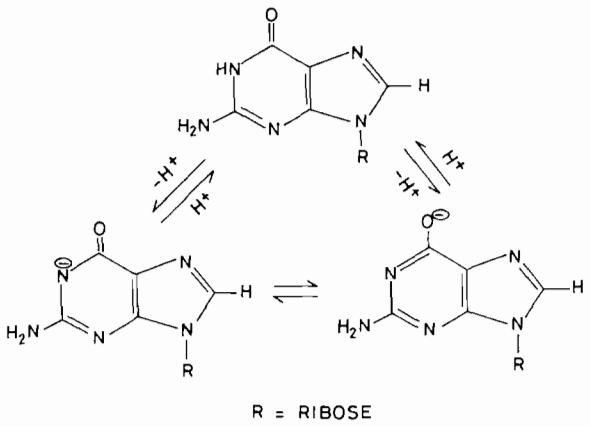



Fig. 2. $^1H$ NMR spectra of ionized guanosine metal complexes.




Scheme 2.

$cm^{-1}$ it is not possible to draw conclusions about the nature of the metal–ligand bonding.

*The Region 1800–1000 $cm^{-1}$*

The two strong bands at 1732 and 1691 $cm^{-1}$ in the spectra of free guanosine have been assigned to the $C_6{=}O_6$ stretching of the two distinct crystalline structures of guanosine [10, 11, 12]. Isotopic substitution of $^{16}O_6$ by $^{18}O_6$ has shown that the single band at 1665 $cm^{-1}$ in solution shifted to 1651 $cm^{-1}$ [13] and thus did not interfere with the $NH_2$ deformation mode which was observed at 1637 $cm^{-1}$. The band at 1732 $cm^{-1}$ was observed only in the spectra of the free guanosine, but not in the spectra of 1-methylguanosine and in the metal complexes. The band at 1691 $cm^{-1}$ did not change upon nucleoside metalation (Table III and Fig. 3, d). The band at 1637 $cm^{-1}$ in the free base spectra was assigned to the $NH_2$ deformation mode [9] which shifted to 1649 $cm^{-1}$ for 1-methylguanosine and for most

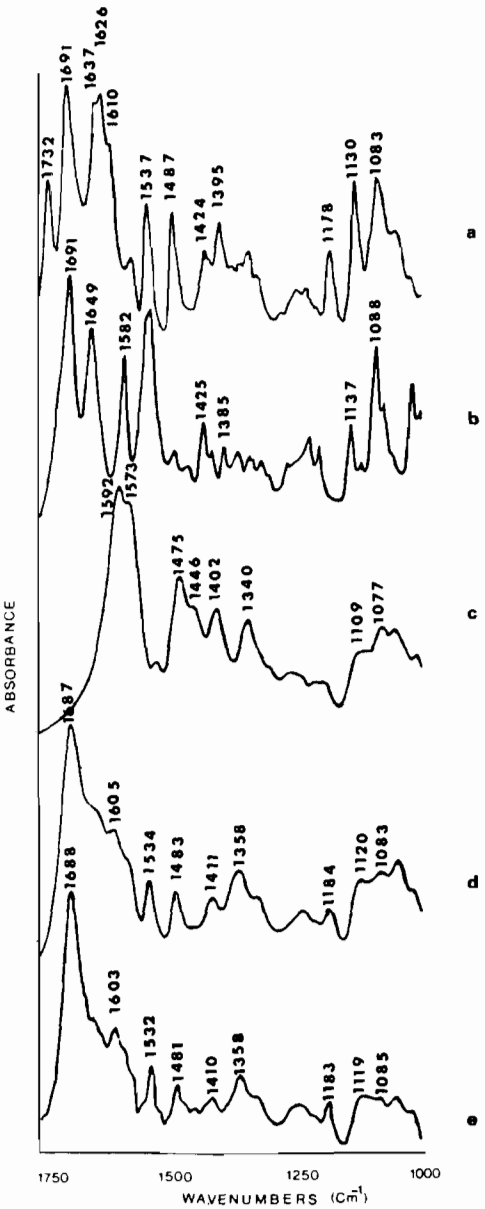



Fig. 3. FT-IR spectra of guanosine·$2H_2O$, 1-methylguanosine and their metal–complexes in the region 1750–1000 $cm^{-1}$. (a) Guo·$2H_2O$ (b) 1-methylguanosine (c) K(GuoH-1)·$H_2O$ (d) $Mg(Guo)_4Cl_2{\cdot}3H_2O{\cdot}C_2H_5OH$ and $Ca(Guo)_4Cl_2{\cdot}4H_2O$.

of the metal complexes (see Fig. 3 and Table III). The changes observed for this vibration are consistent with the $^1H$ NMR results (Table II). The very strong band at 1626 $cm^{-1}$ disappeared upon 1-methyl substitution and is therefore assigned to the $N_1H$ deformation. The band at 1610 $cm^{-1}$ is assigned to the C=C stretching vibration which showed slight changes on complex formation.

The bands at 1487, 1425, 1270 $cm^{-1}$ assigned to the imidazol ring vibrational frequencies [8, 9, 10, 14] exhibited major intensity changes and shifting

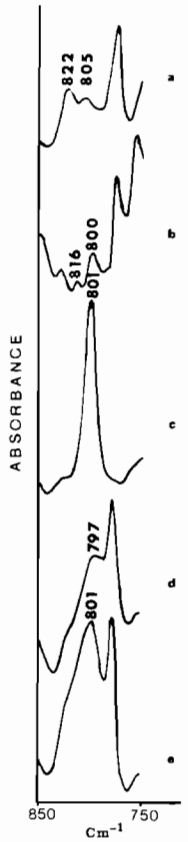



Fig. 4. FT-IR spectra of guanosine•$2H_2O$, 1-methylguanosine and their metal complexes in the region 1000–600 $cm^{-1}$ (a) Guo•$2H_2O$ (b) 1-methylguanosine (c) K(GuoH-1)•$H_2O$ (d) $Mg(Guo)_4 3H_2O$•$C_2H_5OH$ and (e) $Ca(Guo)_4Cl_2$•$4H_2O$.

upon metalation. It should be noted that the band at 1487 $cm^{-1}$ showed a decrease of intensity in the spectra of all metal complexes and in 1-methylguanosine (Fig. 3). The changes observed in this band in the spectra of all the metal nucleoside complexes are most likely due to $N_7$–metal interaction. In the spectrum of 1-methylguanosine the $CH_3$ group absorbs in the region of 1410–1480 $cm^{-1}$ [15] and it is difficult to differentiate the $CH_3$ bending from that of the imidazol vibrations. The band at 1424 $cm^{-1}$ in the free base spectra disappeared upon metalation, except for $CaCl_2$, $MgBr_2$ and $Mg(NO_3)_2$ complexes which showed shoulder bands near 1420 $cm^{-1}$. On the other hand the band at 1415 $cm^{-1}$ showed intensity increase upon complexation, whereas for 1-methylguanosine no changes were observed in the bands at 1424 and 1410 $cm^{-1}$. The weak bands at 1276 and 1207 $cm^{-1}$ in the free guanosine disappeared in the spectra of metal–guanosine compounds (Table III). It is interesting to note that the infrared spectra of the structurally known *cis*-$[Pt(NH_3)_2(Guo_2]Cl_2$ [16, 17] showed similar changes for the bands at 1424, 1276 and 1207 $cm^{-1}$ [18]. The band at 1487 $cm^{-1}$, shifted to 1499 $cm^{-1}$ in the spectra of *cis*-$[Pt(NH_3)_2(Guo)_2]Cl_2$ compound [18].

The pyrimidine vibrations of guanosine at about 1395 and 1369 $cm^{-1}$ [19] shifted towards lower frequencies ($\Delta\nu = 10$ $cm^{-1}$) and a band at 1360 $cm^{-1}$ was observed in the spectra of metal complexes in this region (Table III). This may be due to the hydrogen bonding system formed between the anion (X) and $N_1H$ or $NH_2$ or both group. The absorption bands near 1130–1000 $cm^{-1}$ being predominantly sugar vibrations [20, 21] showed little shifting upon complex formation. The strong band at 1090 $cm^{-1}$ in the spectra of $Mg(ClO_4)_2$ is assigned to the $ClO_4^-$ vibration [22].

On the basis of the data obtained here, the structure of Mg(II), Ca(II) and Li(II) guanosine complexes should involve a metal–$N_7$ binding where the anions (X) form hydrogen bonding with the $N_1H$ and $NH_2$ groups. The Mg(II) and Ca(II) complexes seem to have octahedral geometry with two or four guanosine molecules linked to the metal and the other coordination sites are filled with water molecules. Similar complexes have been shown from X-ray analysis [23] with urea, for example, $[Mg(urea)_4(H_2O)_2]Br_2$. The lithium complex is most likely tetrahedral, where lithium is linked to $N_7$ of guanine and to water molecules. An analogous structure has been found by X-ray analysis [24] in the complex of the coenzyme nicotinamide adenine ($NAD^+$) with $Li^+$.

*The Ionized Guanosine Metal Complexes*

The two strong bands at 1732 and 1692 $cm^{-1}$ in the spectrum of the free guanosine, assigned to $C_6{=}O_6$ stretching vibrations disappeared upon nucleoside ionization. The guanosine anion in the enolic form (Scheme 2) was adopted to explain the results obtained for 6-methoxypurine riboside and deprotonated inosine [25]. It should be noted that the disappearance of the bands at 1732 and 1692 $cm^{-1}$ upon ionization of the guanosine moiety was accompanied simultaneously by the presence of a new broad band at 1340 $cm^{-1}$ in the spectra of all the ionized metal–guanosine compounds here (Fig. 3 and Table III). This new band at about 1340 $cm^{-1}$ can be assigned to the $C{-}O^-$ stretching vibration of the deprotonated guanosine in the enolic form (Scheme 2) which can be compared with that of the phenolic $C{-}O^-$ absorption observed for inosine at 1300 $cm^{-1}$ [25].

The skeletal vibrations of the ring system at 1610 and 1537 $cm^{-1}$ in the free base upon deprotonation exhibited shifting ($\Delta\nu = 20$ $cm^{-1}$) towards lower frequencies which is due to the delocalisation of the electron distribution in the aromatic ring system. The band at 1626 $cm^{-1}$ is assigned to the $N_1H$ in-plane deformation which disappeared upon deprotonation (Fig. 3 and Table III). The imidazol bands at

TABLE III. FT-IR Absorption Bands ($cm^{-1}$) of the Guanosine and its Metal Complexes in the Region of 1800–1000 $cm^{-1}$ with Possible Band Assignments.

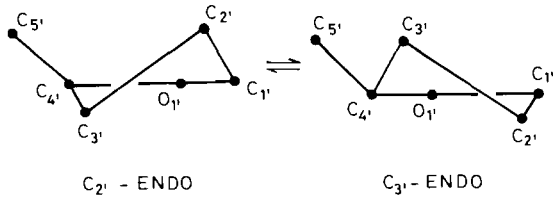
| Guo | Methyl-1 Guo | $Ba(Guo)Cl_2 \cdot H_2O$ | $Ca(Guo)_2Cl_2 \cdot 4H_2O$ | $Mg(Guo)_2Br_2 \cdot 6H_2O$ | $Mg(Guo)_2Cl_2 \cdot 3H_2O \cdot a$ | $Mg(Guo)_2(ClO_4)_2 \cdot 4H_2O \cdot a$ | $Mg(Guo)_2(NO_3)_2 \cdot 6H_2O \cdot 2a$ | $Li(Guo)OHC_2H_5OH \cdot H_2O \cdot a$ | $K(GuoH\text{-}1) \cdot H_2O$ | $Ba(GuoH\text{-}1)OH \cdot 1.5H_2O$ | $Ca(GuoH\text{-}1)OH \cdot 3H_2O$ | Assignments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1732 | – | – | – | – | – | – | – | – | – | – | – | $\nu C{=}O$ [10, 11] |
| 1691vs | 1691vs | 1689vs | 1688vs | 1691vs | 1687vs | 1689vs | 1692vs | 1689vs | – | – | – | |
| 1637vs | 1649vs | 1632sb | 1645s | 1656sb | 1633sh | 1656sb | 1660sb | 1638vs | – | 1666sh | 1656sh | $\delta NH_2 + \nu C_2N_2(9) + \delta H_2O$ |
| 1626vs | – | – | 1631s | 1643s<br>1624s | – | – | – | – | – | – | – | $\delta N_1H$ in plane |
| 1610vs | – | 1607s | 1605s | 1611s | 1603s | 1614s | 1608m | 1597vs | 1592vs | 1592vsb | 1591vsb | $\delta C_4N_3 + \delta C_4C_5 + \delta C_5N_7$ [8] |
| 1570m | 1582s | 1581sh | 1580sh | 1585m | 1566m | 1579m | 1582m | 1582sh | 1573vs | – | – | skeletal vibration |
| 1537s | 1534vs | 1534m | 1532m | 1534m | 1534m | 1537m | 1536m | 1536m | 1519w | 1528w | 1535w<br>1528w | $\nu C_4N_9 + \nu C_6{=}O + \nu C_2N_1$ [9] |
| 1487s | 1483m | 1482m | 1481m | 1482m | 1483m | 1484m | 1483m | 1480m | 1468sb | 1468sb | 1473sb | $\nu C_8H + \nu C_7{=}C_8$ [8, 19] |
| | 1456w | – | 1448w | 1444w | – | – | – | – | 1446m | – | – | $\delta CH$ [9] |
| 1424m | 1425m | – | 1422sh | 1420sh | – | – | 1420sh | – | – | – | – | imidazole [8] |
| 1415sh | 1410m | 1412m | 1410m | 1411m | 1411m | 1415m | – | 1410m | 1405m | 1405m | 1408m | |
| 1395m | 1385m | 1363bm | 1358m | 1360m | 1358m | 1361m | 1369m | 1365m | – | – | – | pyrimidine [19] |
| – | – | – | – | – | – | – | – | – | – | – | – | $NO_3$ [22] |
| 1359m | 1369m | – | – | – | – | – | – | – | – | – | – | |
| 1352m | 1337m | – | – | – | – | – | – | – | 1344m | 1344m | 1340m | $\nu C{-}O^-$ |
| 1337m | 1329m | – | 1329m | – | – | – | – | 1330sh | – | – | – | |
| 1323m | 1312m<br>1300m | 1323m | 1323m | 1323m | 1323m | 1325m | 1322sh | 1323sh | – | – | – | pyrimidine [19] |
| 1276w | 1261w | – | – | – | – | – | – | – | – | – | – | imidazole |
| 1245w | 1232m | 1234m | 1249w | 1235w | 1234w | 1236w | 1234w | 1236w | 1250w | 1250w | 1260w | base |
| 1224w | 1218m | 1213w | 1234w | – | 1213w | 1210w | – | – | – | – | 1226w | base |
| 1207w | 1200m | – | – | – | – | – | – | – | 1202w | 1206w<br>1193w | 1202w | |
| 1178m | – | 1178w | 1183w | 1181w | 1189w | 1177m | 1179w | 1178w | – | – | – | |
| 1130s | 1137m<br>1116w | 1124m | 1119m | 1119m | 1120m | 1107s | 1120m | 1120sh | 1146sh | 1146sh | 1146m | sugar [20] |
| 1083s | 1088s | 1083m | 1085m | 1081m | 1083m | 1090s($ClO_4$) | 1083m | 1085s | 1081s | 1083s | 1081s | $\delta(C{-}O{-}H)$ [21] |
| 1050m | 1073m | 1057m | 1051m | 1048m | 1049m | – | 1050m | 1054m | 1054sh | 1054sh | – | $\delta(O{-}C{-}H)$ [21] |
| 1023m | 1016m | 1018m | 1020w | 1016m | 1018m | 1019m | 1018w | 1016sh | 1016m | 1016m | 1017w | sugar |

$\delta$ = deformation, $\nu$ = stretching, b = broad, m = medium, s = strong, sh = shoulder, v = very and w = weak.

1487, 1424 and 1270 $cm^{-1}$ showed shifting and intensity changes on ionization. The bands at 1395 and 1369 $cm^{-1}$ related to the pyrimidine ring vibrational frequencies disappeared upon ionization (Fig. 3 and Table II). A new band near 1340 $cm^{-1}$ was observed in the spectra which is assigned to the $\nu C-O^-$. It is worth mentioning that the spectra of deprotonated inosine and 6-methoxypurine riboside showed the frequency of $\nu C-O^-$ vibration at about 1319–1299 $cm^{-1}$ [26].

*The Region 1000–600 $cm^{-1}$*

The bands at 918, 775 and 688 $cm^{-1}$, in the spectra of free guanosine are similar to the bands at 938, 795 and 694 $cm^{-1}$ of the purines in general and are assigned to the skeletal vibrations [8, 9]. The band at 918 $cm^{-1}$ shifted towards lower frequencies in the spectra of all metal complexes (Table IV). The band at 775 $cm^{-1}$ showed very little changes on base metalation, whereas the band at 688 $cm^{-1}$ shifted towards higher frequencies in the spectra of the metal guanosine compounds, except for lithium. Recently, FT-IR spectra of several metal–mononucleotide complexes have been reported [27] and marker bands for sugar conformational transitions have been identified. The band at 820 $cm^{-1}$ (sugar–phosphate) was assigned to the sugar $C_2'$-*endo/anti* conformation, while the band near 800 $cm^{-1}$ was assigned to the $C_3'$-*endo/anti* conformation (Scheme 3). It is known [12] that in the free guanosine the has a $C_2'$-*endo/anti* conformation. The medium band




Scheme 3.

observed at 822 $cm^{-1}$ in the spectrum of the free guanosine is characteristic of this conformation. The spectra of 1-methylguanosine showed two weak absorption bands in this region at 800 and 816 $cm^{-1}$ which may suggest that the sugar conformation in 1-methylguanosine is a mixture of $C_3'$-*endo/anti* and another conformation yet to be identified, may be $O_1'$-*endo/anti*.

The infrared spectra of all the metal-guanosine compounds showed a strong band at 800 $cm^{-1}$ which is indicative of the sugar being in the $C_3'$-*endo/anti* conformation (Table IV and Fig. 4). A band at 800 $cm^{-1}$ was also observed in the spectra of the structurally known [17] *cis*-$Pt(NH_3)_2(Guo)_2Cl_2$, where the $C_3'$-*endo/anti* sugar conformation has been found by X-rays analysis.

TABLE IV. FT-IR Absorption Bands ($cm^{-1}$) of the Guanosine and its Metal Complexes in the Region of 1000–600 $cm^{-1}$ with Possible Band Assignments.

| Guo | Methyl-1 Guo | $Ba(Guo)Cl_2$ $\cdot H_2O$ | $Ca(Guo)_2Cl_2$ $\cdot 4H_2O$ | $Mg(Guo)_2Br_2$ $\cdot 6H_2O$ | $Mg(Guo)_2Cl_2$ $\cdot 3H_2O \cdot a$ | $Mg(Guo)_2(ClO_4)_2$ $\cdot 4H_2O \cdot a$ | $Mg(Guo)_2(NO_3)_2$ $\cdot 6H_2O \cdot 2a$ | Li(Guo)OH $\cdot H_2O \cdot a$ | K(GuoH-1)·$H_2O$ | Ba(GuoH-1)OH $\cdot 1.5H_2O$ | Ca(GuoH-1)OH $\cdot 3H_2O$ | Assignments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 984sh | 984m | 987m | 988 | 988m | – | 988sh | 987m | 986m | 980sh | 980sh | 988m | $\delta$(C–C–H) [9, 21] |
| | 965m | | | | | | | | | | | |
| 918m | 904m | 904m | 904m | – | 903m | 905m | 905m | 906m | 900m | 908m | 904m | base [8] |
| 899m | – | – | – | – | – | – | – | – | – | – | – | – |
| 864m | 869m | 865m | 867m | 864m | 864m | 868m | 865m | 875m | 863m | 874m | 869m | $\delta N_1H$ [8, 9] |
| | 857m | | | | | | | | | | | |
| 822m | 816w | – | – | 822sh | – | – | 822sh | 824m | 822m | 832m | 826m | sugar, $C_2'$-*endo/anti* [27] |
| | | | | | | | | | | 822m | | |
| 805w | 800w | 799s | 801s | 794s | 797s | 801m | 802s | 801s | 801vs | 799s | 799vs | sugar, $C_3'$-*endo/anti* [27] |
| 775m | 777m | 781s | 781s | 779s | 780s | 780s | 780s | 782sh | 764sh | 781m | 764m | base [8] |
| 745m | 755m | – | – | – | – | – | – | 751s | 751m | 751m | 749m | base [27] |
| 733m | 734w | 730m | 730m | 727s | 728m | 727m | 729s | 730s | 740m | 730m | 739m | base [9] |
| 717m | 700m | – | – | – | 717m | – | – | – | – | – | – | – |
| 688s | 676s | 694s | 694s | 695s | 695m | 695s | 695s | 688s | 703m | 698s | 705m | breathing mode [9] |
| | | 689s | 689s | | | | | | | 683s | 694s | |
| 665m | – | 671s | 668m | 677s | – | – | 665s | 664s | 677m | 672s | 657s | base [8] |
| 653m | 643w | 637m | 635s | 635s | 637m | 626vs | 630s | 640vs | 640s | 640vs | 640vs | $H_2O$ [27] |
| | | | | | | | | | | 620s | | |
| 613m | 611w | 619m | 613s | 614s | 619m | – | 617s | – | 604m | 604s | 611s | |

## Conclusions

On the basis of $^1H$ NMR and FT-IR spectroscopic studies here the following points can be emphazised:

(1) In the non ionized metal–nucleoside complexes the metal ions Li(I), Mg(II), Ca(II) and Ba(II) bind to the purine ring, through $N_7$ while the anions are hydrogen bonded to $N_1H$ and $NH_2$ groups;

(2) In the ionized-guanosine compounds the metal binding is via the negatively charged oxygen atoms of the carbonyl group being in the enolic form $O_6^-$; and,

(3) The sugar ring which has a $C_2'$-*endo/anti* conformation in the free nucleoside flips to a $C_3'$-*endo/anti* pucker in all metal complexes studied here.

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## References

1 S. Shimokawa, H. Fukui, J. Sohma and K. Hotta, *J. Am. Chem. Soc., 95*, 1777 (1973).
2 G. W. Buchanan and M. J. Stothers, *Can. J. Chem., 60*, 787 (1982).
3 A. C. Plaush and R. Sharp, *J. Am. Chem. Soc., 98*, 7973 (1976).
4 A. J. Canty and R. S. Tobias, *Inorg. Chem., 18*, 413 (1979).
5 F. Jordan and B. Y. McFarquhar, *J. Am. Chem. Soc., 94*, 6557 (1972).
6 C. H. Chang and L. G. Marzilli, *J. Am. Chem. Soc., 96*, 3656 (1974).
7 R. C. Lord and G. J. Thomas, *Spectrochim. Acta, Part A: 23*, 2551 (1967).
8 A. Lautié and A. Novak, *J. Chim. Phys., 65*, 1359 (1968).
9 M. Tsuboi, S. Takahashi and I. Harada, in J. Duchensene (ed.), 'Physicochemical Properties of Nucleic Acid, Vol. 2', Academic Press, New York, 1973, p. 92.
10 J. M. Delabar and W. Guschlbauer, *Biopolymers, 18*, 2073 (1979).
11 M. Tsuboi, Y. Kyogoku and T. Shimanouchi, *Biochim. Biophys. Acta, 55*, 1 (1962).
12 U. Thewalt, C. E. Bugg and R. E. Mash, *Acta Crystallogr., Sect. B:, 26*, 1089 (1970).
13 F. B. Howard and H. Miles, *J. Biol. Chem., 240*, 80 (1965).
14 S. Mansy and W. L. Peticolas, *Biochemistry, 15*, 2650 (1976).
15 N. L. Alpert, W. E. Keiser and H. A. Szymanski, 'IR Theory and Practice of Infrared Spectroscopy', Plenum, New York, 1970, p. 210.
16 P. C. Kong and T. Theophanides, *Inorg. Chem., 13*, 1167 (1974).
17 R. E. Cramer, P. L. Dahlstrom, M. J. Seu, T. Norton and M. Kashiwagi, *Inorg. Chem., 19*, 148 (1980).
18 M. Polissiou and T. Theophanides, to be published.
19 J. M. Delabar, *J. Raman Spectrosc., 7*, 261 (1978).
20 H. C. Nelson and J. F. Villa, *J. Inorg. Nucl. Chem., 41*, 1643 (1979).
21 M. Mathlouthi, A. M. Seuvre, *Carbohydr. Res., 122*, 31 (1983).
22 R. A. Nyquist and R. O. Kagel, 'Infrared Spectra of Inorganic Compounds', Academic Press, New York, 1971, p. 123 and 445.
23 L. Lebioda and K. Lewinski, *Acta Crystallogr., Sect. B:, 36*, 693 (1980).
24 B. S. Reddy, W. Saenger, K. Muhlegger and G. Weimann, *J. Am. Chem. Soc., 103*, 907 (1981).
25 A. Psoda and D. Shugar, *Biochim. Biophys. Acta, 247*, 507 (1971).
26 J. Bariyanga and T. Theophanides, to be published.
27 T. Theophanides and H. A. Tajmir-Riahi, in E. Clementi, G. Corongiu, M. H. Sarma and R. H. Sarma (eds.), 'Structure and Motion: Membranes, Nucleic Acids and Proteins', Adenine, Albany, N.Y., 1985, p. 521.