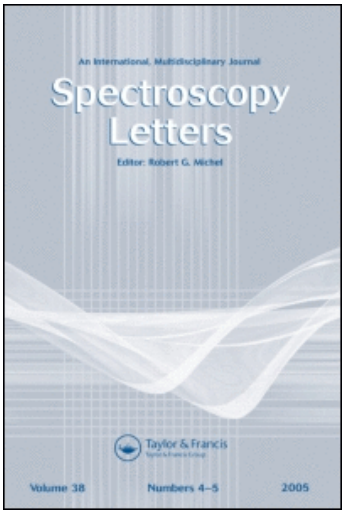

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Fourier Transform Infrared Spectroscopy of Aliphatic *bis*(Amidinohydrazones) and Their Deuterated Analogues

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FOURIER TRANSFORM INFRARED SPECTROSCOPY OF ALIPHATIC BIS(AMIDINOHYDRAZONES) AND THEIR DEUTERATED ANALOGUES

Key Words: Adenosylmethionine Decarboxylase Inhibitors, Deuteration, Methylglyoxal Bis(guanylhydrazone) Analogues, Polyamine Antimetabolites, Substituent Effects in Infrared Spectroscopy

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ABSTRACT

The first study on the infrared spectroscopy of the bis(amidinohydrazones) of various glyoxals is reported. The compounds studied include the antileukemic agents glyoxal bis(amidinohydrazone) and methylglyoxal bis(amidinohydrazone) (Mitoguazone) as well as seven mono- and dialkylglyoxal analogues thereof. Free bases as well as doubly protonated species (divalent salts) were investigated. Selectively deuterated analogues were also studied and were synthesized by exchanging nitrogen-bound hydrogen atoms for deuterium atoms. The effects of substituents, protonation and deuteration on the FT-IR spectra of the compounds are discussed.

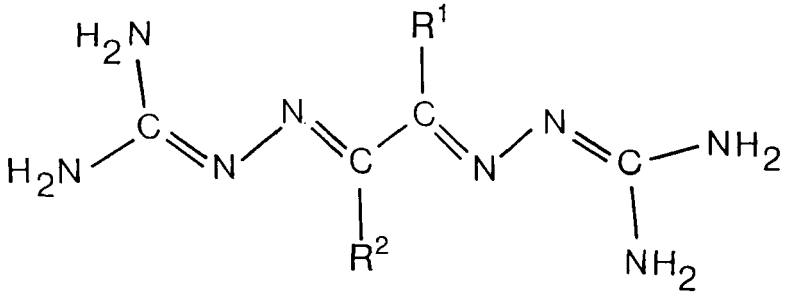
INTRODUCTION

Various bis(amidinohydrazones) ['bis(guanylhydrazones)'] are of interest because many of them are highly potent specific inhibitors of adenosylmethionine decarboxylase, a key enzyme of polyamine biosynthesis, and also because two of them are potent antileukemic agents [1-14]. No reports have appeared on the IR spectroscopy of these agents, in contrast to their NMR [5, 15-20], mass [21] and UV/VIS spectroscopy [22]. We have previously studied in detail the NMR spectroscopy of various bis(amidinohydrazones) and have found interesting correlations between NMR parameters and inhibitor constants [5, 15-20]. Therefore, we considered further spectroscopic studies worthwhile, and thus report now an FT-IR study on a large number of congeners belonging to this class of compounds.

THE COMPOUNDS STUDIED

The bis(amidinohydrazones) of various glyoxals are commonly called bis(guanylhydrazones). Therefore, the commonly used abbreviations of their

names contain the letters GBG (G for glyoxal, B for bis, and G for guanyl), preceded by an indication of substituents (e.g., DE for diethyl or EM for ethyl methyl). The term bis(amidinohydrazone) is, however, more appropriate than the chemically incorrect bis(guanylhydrazone). The Chemical Abstracts' systematic name for methylglyoxal bis(amidinohydrazone) is 2,2'-(1-methyl-1,2-ethanediylidene)bis(hydrazinecarboximidamide), and other congeners are named analogously. The structure of the free bases of the compounds studied has recently been shown [23] to be the one represented by formula I.

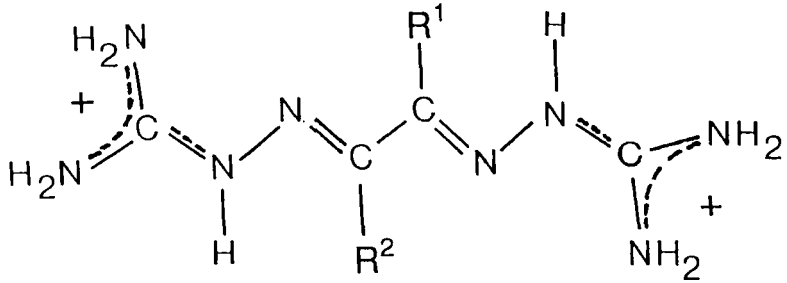


I

The infrared spectra of the following compounds have now been studied:

GBG:	$R^1 = R^2$ = hydrogen
MGBG:	R^1 = hydrogen, R^2 = methyl (or vice versa)
EGBG:	R^1 = hydrogen, R^2 = ethyl (or vice versa)
DMGBG:	$R^1 = R^2$ = methyl
EMGBG:	R^1 = methyl, R^2 = ethyl (or vice versa)
DEGBG:	$R^1 = R^2$ = ethyl
MPGBG:	R^1 = methyl, R^2 = propyl (or vice versa)
BMGBG:	R^1 = methyl, R^2 = butyl (or vice versa)
DPGBG:	$R^1 = R^2$ = propyl

The species studied contained free bases (formula I) as well as divalent salts. In the latter ones, the bis(amidinohydrazone) is in the doubly protonated form (i.e., as a dication), the structure of which has been shown [5, 8, 9, 15, 24, 25] to be the one represented by formula II. Selectively deuterated congeners (free bases as well as divalent salts) in which nitrogen-bound hydrogens (but not carbon-bound hydrogens) were replaced by deuterium atoms, were prepared and their spectra were likewise studied.



II

EXPERIMENTAL

The syntheses of the divalent salts and free bases were carried out as previously described [5, 26]. Nitrogen-bound hydrogen atoms were exchanged for deuterium atoms by first dissolving each compound in D_2O (ca. 2 - 28 mg/ml depending on solubility) (99.9 atom % D; Aldrich-Chemie, Steinheim, Germany) in a flask protected by a $CaCl_2$ tube and heated in a water bath at ca. 70 - 80°C. The solution was allowed to cool and was then put onto an ice bath. After standing overnight at ca. 4°C, the precipitate that had been formed was filtered off and dried *in vacuo*.

Fourier transform infrared spectra were recorded at room temperature using KBr pellets [spectroscopy grade (Uvasol) KBr, E. Merck, Darmstadt, Germany]. The

spectra (4800-400 cm^{-1}, 32 scans, resolution 4.00 cm^{-1}) were measured using a Nicolet 510P FT-IR Spectrometer and PC/IR Desktop Spectroscopy Software, Version 2.0.

RESULTS AND DISCUSSION

The IR spectra of the compounds studied are shown in Figs. 1-24 and the wavenumbers of the strongest absorption peaks in Tables 1-24.

In the spectrum of GBG free base (Fig. 1, Table 1), NH deformation (ca. 1618 and 1653 cm^{-1}), C=N stretching (ca. 1497, 1522 and 1570 cm^{-1}) and NH stretching (broad band around ca. 3400 cm^{-1}) give strong bands. The individual assignment of the NH deformation and C=N stretching lines given is based on the disappearance of the peaks at 1618 and 1653 cm^{-1} on deuteration of NH_2 groups and the conservation of the peaks that were interpretated as C=N stretching bands (a strong band at 1497, absorption although no maximum also around 1522 and a line at 1576 cm^{-1}; Fig. 2, Table 2). The lines at 1490, 1522 and perhaps also 1570 cm^{-1} might be caused by sodium hydroxide, since the spectrum of commercial analytical grade NaOH contains a strong band at 1451 cm^{-1} and the possibility cannot be absolutely excluded that the free bases of the bis(amidinohydrazones) studied might contain small amounts of residual NaOH, since they were prepared from corresponding divalent salts with the aid of fairly concentrated aqueous NaOH solutions. Yet, this possibility is not probable, since potentiometric studies on GBG free base [13] and the free bases of EMGBG and BMGBG [27] did not reveal the presence of NaOH. The presence of the obvious C=N stretching peaks also in deuterated GBG free base very strongly suggest that these peaks are not due to NaOH, since the deuterated compounds was prepared by dissolving the undeuterated congeners in a quite large volume of D_2O (7 mg GBG / ml D_2O) and the coprecipitation of NaOH or NaOD with deuterated GBG would not be expected to occur.

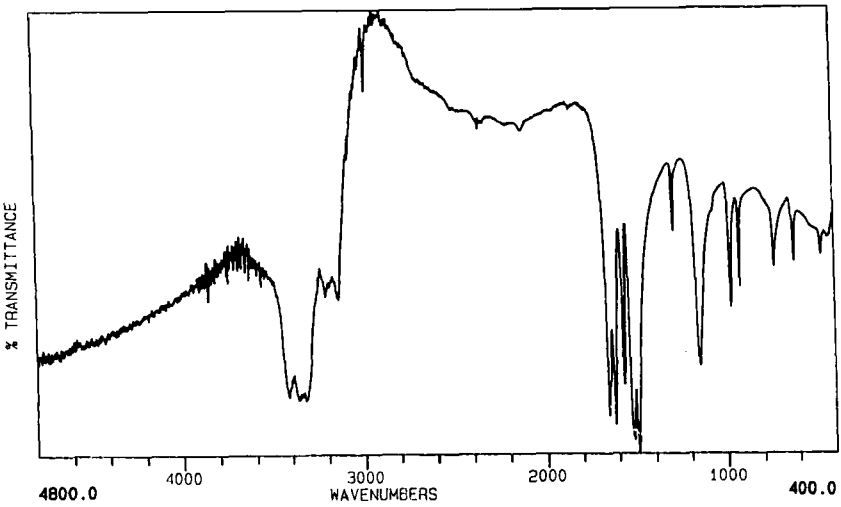


FIG. 1. IR spectrum of GBG free base.

TABLE 1.

IR Spectrum of GBG Free base

Wavenumber (cm^{-1})	Interpretation
3414	NH stretching
3362	NH stretching
3322	NH stretching
3210	
3137	
2975	
1653	NH_2 bending
1618	NH_2 bending
1570	C=N stretching
1522	C=N stretching
1497	C=N stretching
1289	skeletal vibrations
1148	C-N stretching
974	skeletal vibrations
922	skeletal vibrations
733	
621	

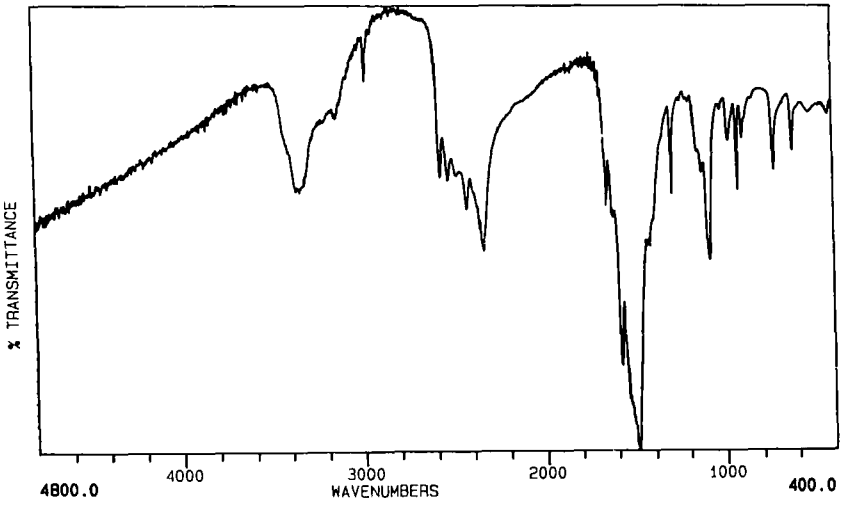


FIG. 2. IR spectrum of deuterated GBG free base.

TABLE 2.

IR Spectrum of Deuterated GBG Free Base

Wavenumber (cm^{-1})	Interpretation
3339	
2570	ND stretching
2529	ND stretching
2421	ND stretching
2352	ND stretching
2332	ND stretching
1653	
1617	
1576	C=N stretching
1497	C=N stretching
1435	
1418	
1289	skeletal vibrations
1123	
1084	
968	skeletal vibrations
922	skeletal vibrations
893	
723	
615	

In addition to the above mentioned bands, some bands of less self-evident origin are seen in the spectrum of undeuterated GBG base. At roughly 3200 cm^{-1}, associated NH stretching or possibly NH bending overtones are seen, and slightly below 3000 cm^{-1}, a peak is observed whose origin remains unclear. It obviously cannot result from an NH bending overtone because it is conserved on deuteration. At 1148 cm^{-1}, a peak is observed that possibly results from C-N stretching. Less intense peaks that possibly result from skeletal vibrations are also present (922, 974 and 1289 cm^{-1}). In the spectrum of deuterated GBG free base, the NH stretching band is absent, just as it should, and ND stretching is seen instead (ca. 2300 - 2600 cm^{-1}). Skeletal vibrations are seen also in this spectrum. The peaks observed at 1496 and 1522 cm^{-1} in the spectrum of undeutered GBG base are changed into a broader band without distinct fine structure on deuteration.

In the spectrum of GBG sulphate (Fig. 3, Table 3), the absorption band seen at roughly 3400 cm^{-1} is broadened, as compared to the spectrum of the free base. This may result from the intense hydrogen bond network known to exist in the sulphates of bis(amidinohydrazones) in the solid state [5, 9, 25]. A further factor that must also be considered as a possible reason for the broadening is constituted by the very strong resonance that is possible in the case of the dication present in the sulphate salt but not in the case of the free base and that must affect the nature of the bonds in the dication. The peaks in the spectrum of GBG free base that were interpreted as resulting from C=N stretching are absent in the sulphate salt, which may result from the fact that two of the four C=N groups have been protonated at the nitrogen atom, the clear-cut double bond character of the C=N bond having simultaneously been weakened considerably. The intensity of skeletal vibrations is decreased. An SO_4^{2-} stretching band can also been seen (1115 cm^{-1}). In deuterated GBG sulphate (Fig 4, Table 4), an ND stretching band appears just as in the spectrum of the deuterated base, their pattern however being different. The difference may be due to deuterium bond formation analogously with the undeuterated case.

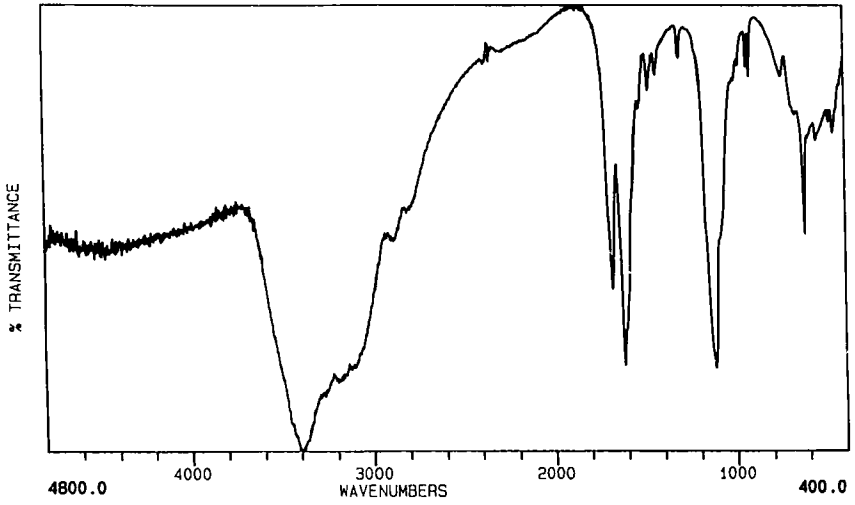


FIG. 3. IR spectrum of GBG sulphate.

TABLE 3.

IR Spectrum of GBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3399	NH stretching
2348	
1678	NH bending
1617	NH bending
1478	
1433	
1300	
1115	SO_4^{2-} stretching
932	
914	
745	
617	
550	
461	

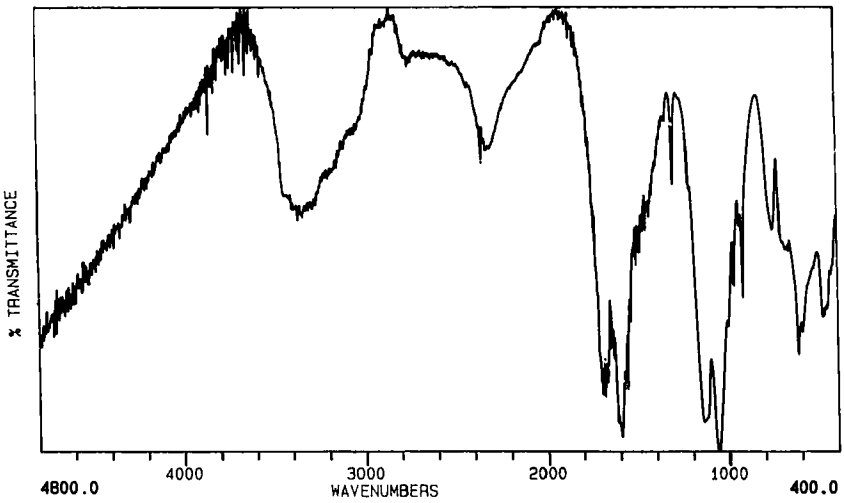


FIG. 4. IR spectrum of deuterated GBG sulphate.

TABLE 4.

IR Spectrum of Deuterated GBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3364	residual NH or H_2O
2352	ND stretching
1705	C=N stretching
1700	C=N stretching
1684	C=N stretching
1669	C=N stretching
1653	C=N stretching
1636	C=N stretching
1593	C=N stretching
1559	
1539	
1507	
1489	
1472	
1140	SO_4^{2-} stretching
1059	
968	
920	
617	
476	

The IR spectrum of the free base of the symmetrical dialkyl congener DMGBG (Fig. 5, Table 5) that contains no protons bound to the glyoxal carbons comprises a largely similar pattern as in the case of GBG free base, NH stretching, CH stretching, C=N stretching, NH bending, skeletal vibrations and obviously C-N stretching being observed. Most peaks are, however, slightly shifted to higher wavenumbers as compared to GBG.

On deuteration, the NH stretching bands disappear from the spectrum of DMGBG base (Fig. 6, Table 6), confirming the assignment. The skeletal vibration peak at 1354 cm^{-1} remains at the same wavenumber as in the undeuterated compound. On deuteration, a fairly intensive band also appears in the spectrum at 1074 cm^{-1}.

When deuterated DMGBG free base is compared to deuterated GBG free base, a distinct difference is observed: the fairly intensive band at ca. 3300 cm^{-1} has almost disappeared and the remaining smaller band has been shifted to higher wavenumbers (ca. 3400 cm^{-1}). An ND stretching band can be observed at ca. 2300-2600 cm^{-1}, but its pattern is different from that in the spectrum of deuterated GBG. An obvious C=N stretching band can also be observed in the spectrum of deuterated DMGBG.

In the spectrum of DMGBG dihydrochloride (Fig. 7, Table 7), a very broad absorption band is seen whose maximum is located at 3146 cm^{-1}. This might be due to a shift of the maximum of the NH stretching band from ca. 3400 cm^{-1} to this region. It must, however, be noticed that in this part of the spectrum of DMGBG, the changes observed on going from the free base to the dihydrochloride salt are completely different from those observed in the spectrum of GBG when its free base is converted to the sulphate salt. DMGBG dihydrochloride is known to exist in the form of a dihydrate [28], and thus it is most obvious that the absorption around 3100 cm^{-1} is largely or wholly due to the crystal water. This interpretation is in line with the observation of a slightly

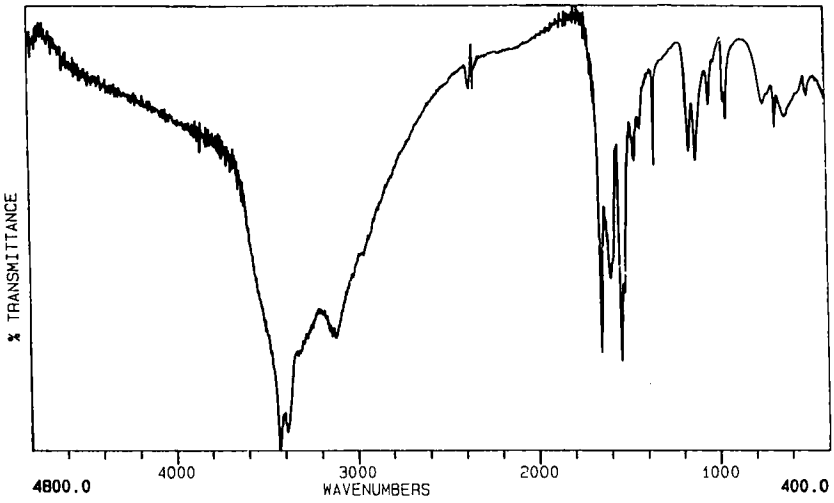


FIG. 5. IR spectrum of DMGBG free base.

TABLE 5.

IR Spectrum of DMGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3436	NH stretching
3391	NH stretching
3115	
1655	NH_2 bending
1601	NH_2 bending
1561	C=N stretching
1541	C=N stretching
1460	
1354	skeletal vibrations
1159	C-N stretching
1123	
953	
677	

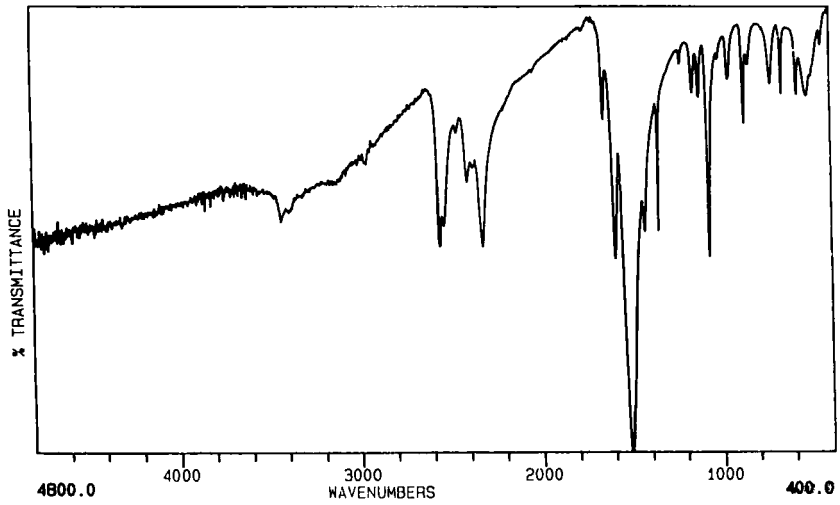


FIG. 6. IR spectrum of deuterated DMGBG free base.

TABLE 6.

IR Spectrum of Deuterated DMGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3432	residual NH or H_2O
2564	ND stretching
2541	ND stretching
2409	ND stretching
2325	ND stretching
1593	C=N stretching
1516	C=N stretching
1431	
1354	skeletal vibrations
1074	C-N stretching
876	
664	
527	

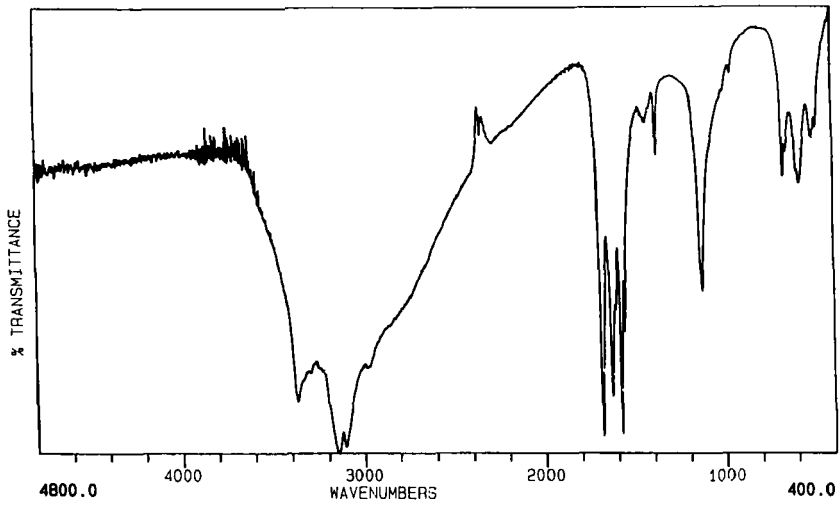


FIG. 7. IR spectrum of DMGBG hydrochloride.

TABLE 7.

IR Spectrum of DMGBG Hydrochloride

Wavenumber (cm^{-1})	Interpretation
3364	NH stretching
3146	NH stretching/H_2O
3106	NH stretching/H_2O
1686	NH_2 bending
1630	NH_2 bending
1578	CN stretching
1557	CN stretching
1129	CN stretching
673	
584	

less intense maximum (in the spectrum of DMGBG dihydrochloride) at ca. 3400 cm^{-1} that obviously must be due to NH stretching. A fairly intense peak is observed at 1128 cm^{-1}, analogously to the deuterated free base. This peak might be due to CN stretching.

The free base of another symmetric compound with two aliphatic side chains, the diethyl congener DEGBG, gave a spectrum (Fig. 8, Table 8), in which the CH stretching peaks are displayed better than in the spectrum of DMGBG free base, obviously because of the larger number of CH_2 groups present. In the deuterated free base of DEGBG (Fig. 9, Table 9), a small band is again observed at ca. 3400 cm^{-1} that is slightly more prominent than in the case of the dimethyl analogue. This absorption is difficult to explain without assuming that it is caused by some residual NH or NH_2 groups or H_2O present. CH stretching, ND_2 bending and obvious C=N stretching can also be observed.

In the spectrum of DEGBG sulphate (Fig. 10, Table 10), NH stretching is prominently displayed as a broad band. Again, this band is stronger than in the spectrum of the corresponding free base. Similarity to GBG sulphate is thus observed, while it is clearly evident that the compound behaves in a way that is distinctly different from that of the dihydrate of DMGBG dihydrochloride. C=N stretching and NH bending are clearly evident, the pattern of these peaks being simpler than in the spectra of the deuterated and undeuterated free base. This difference may result from the numerous strong hydrogen bonds in the sulphate salts. A strong sulphate band can also be observed. The spectrum of deuterated DEGBG sulphate (Fig. 11, Table 11) resembles that of deuterated GBG sulphate in that a fairly strong broad band is seen at ca. 3350 cm^{-1}, and also in that an ND stretching band is clearly evident (ca. 2300 cm^{-1}). Also in other respects, the spectra of the two deuterated sulphates are very similar.

The symmetric compound DPGBG was also studied. The spectrum of the free base (Fig. 12, Table 12) was found to be much like that of the other

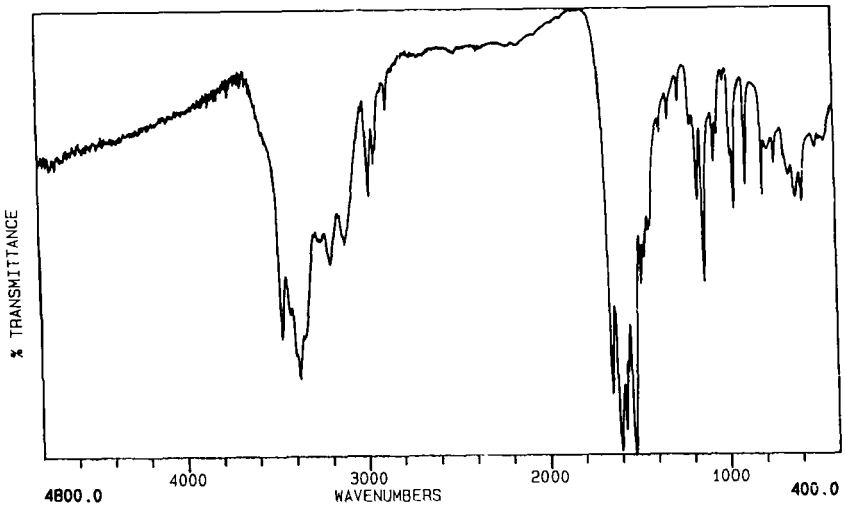


FIG. 8. IR spectrum of DEGBG free base.

TABLE 8.

IR Spectrum of DEGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3468	NH stretching
3372	NH stretching
3249	NH stretching
3198	NH stretching
3114	NH stretching
2977	
1651	NH_2 bending
1603	
1574	C=N stretching
1559	C=N stretching
1524	C=N stretching
1480	
1464	
1437	
1161	
1129	
958.74	skeletal vibrations
800.56	
617.30	
582.58	

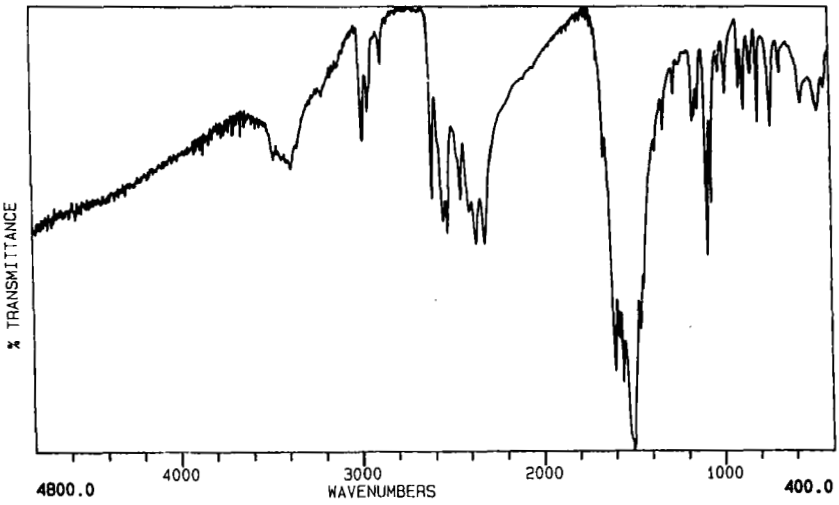


FIG. 9. IR spectrum of deuterated DEGBG free base.

TABLE 9.

IR Spectrum of Deuterated DEGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3467	residual NH or H_2O
3372	
2602	
2543	ND stretching
2517	ND stretching
2442	ND stretching
2394	ND stretching
2355	ND stretching
2309	ND stretching
1653	
1597	C=N stretching
1574	C=N stretching
1559	C=N stretching
1507	C=N stretching
1456	
1437	
1080	
1059	

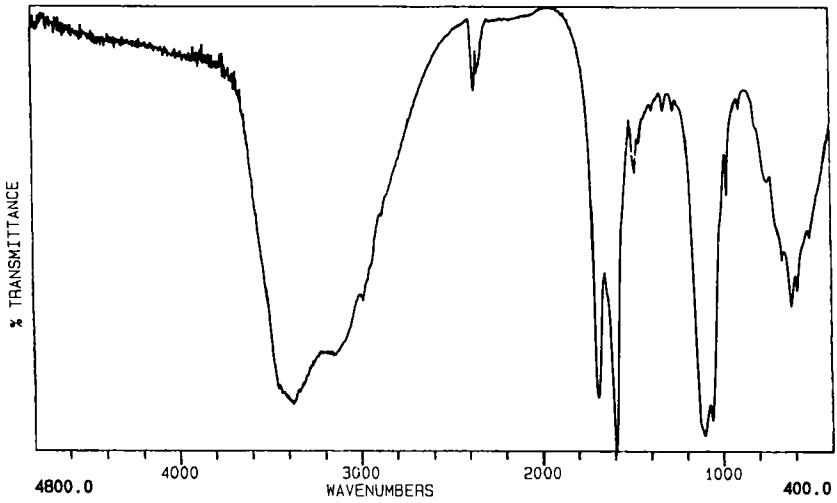


FIG. 10. IR spectrum of DEGBG sulphate.

TABLE 10.

IR Spectrum of DEGBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3374	NH stretching
2363	
2344	
1694	NH bending
1595	NH bending
1478	C=N stretching
1319	
1264	
1105	SO_4^{2-} stretching
1061	
970	
903	
669	
617	
583	

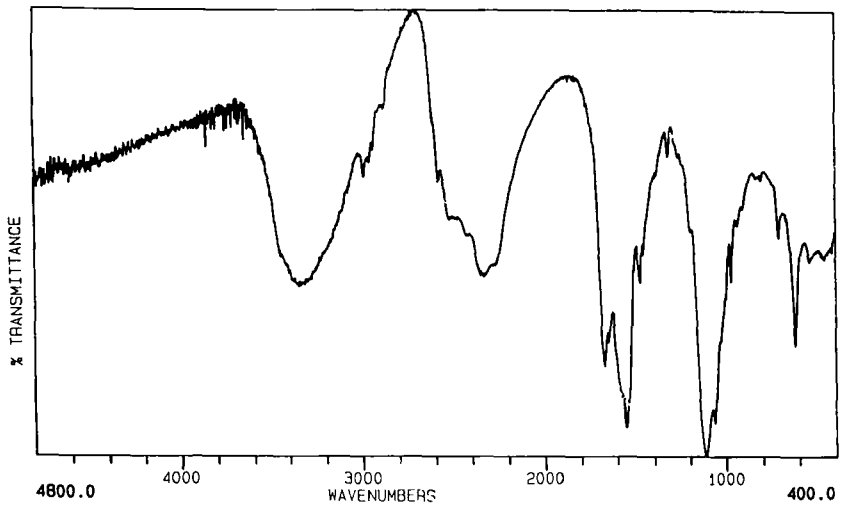


FIG. 11. IR spectrum of deuterated DEGBG sulphate.

TABLE 11.

IR Spectrum of Deuterated DEGBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3355	residual NH or H_2O
2990	CH stretching
2583	ND stretching
2328	ND stretching
1669	
1645	
1553	C=N stretching
1474	
1456	
1318	
1117	SO_4^{2-} stretching
1063	
968	
710	
619	
536	
462.97	

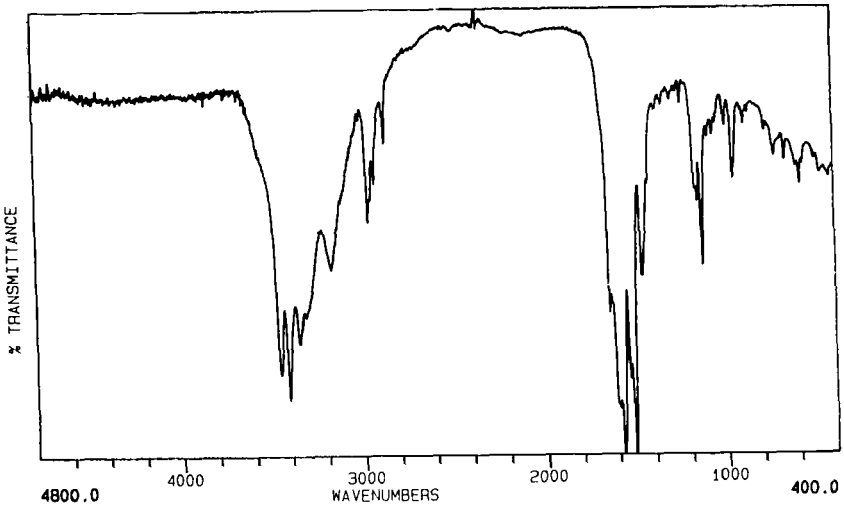


FIG. 12. IR spectrum of DPGBG free base.

TABLE 12.

IR Spectrum of DPGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3461	NH stretching
3413	NH stretching
3353	
3173	
2965	
2930	
1645	NH_2 bending
1597	NH_2 bending
1578	NH_2 bending
1541	C=N stretching
1518	C=N stretching
1470	
1462	
1152	
1129	
955	
725	
669	
586	
430	

symmetric bases, especially DEGBG. Skeletal vibrations are less prominently displayed than in the spectra of congeners with shorter side chains. The spectrum of the corresponding sulphate (Fig. 13, Table 13) was very largely similar to that of the diethyl analog DEGBG.

Also unsymmetric compounds (R^1 different from R^2) were studied. In the case of the methylglyoxal derivative MGBG in which one of the side chains is a hydrogen atom and the other one is a methyl group, only the free base was available for study, and its spectrum (Fig. 14, Table 14) was found to be much like that of GBG free base. In the case of the ethylglyoxal analog EGBG, only the sulphate salt was available, its spectrum (Fig. 15, Table 15) being much like those of the sulphates of the symmetric congeners GBG, DEGBG and DPGBG. The NH stretching pattern was, however, different from that in the spectra of the last mentioned compounds in which the two side chains are identical with each other.

In the spectrum of the free base of EMGBG (Fig. 16, Table 16), a congener with two different alkyl side chains, no gross difference could be observed as compared to the spectra of other dialkyl congeners, especially DMGBG. In this spectrum, the broad NH stretching band contains a fairly narrow peak at 3445 cm^{-1}. The spectrum of deuterated EMGBG base (Fig. 17, Table 17) does not contain a noteworthy band in the region around 3400 cm^{-1}. The most prominent feature of the spectrum is constituted by a very strong sharp peak at 1507 cm^{-1}. A sharp peak is also seen at 2571 cm^{-1} (ND stretching). In the spectrum of EMGBG sulphate (Fig. 18, Table 18), the sulphate band contains two peaks and is slightly less prominent than that in the spectra of the other sulphate salts. This might be due to the unsymmetry of the compound, the two components of the sulphate band possibly resulting from the two termini of the bis(amidinohydrazone) backbone.

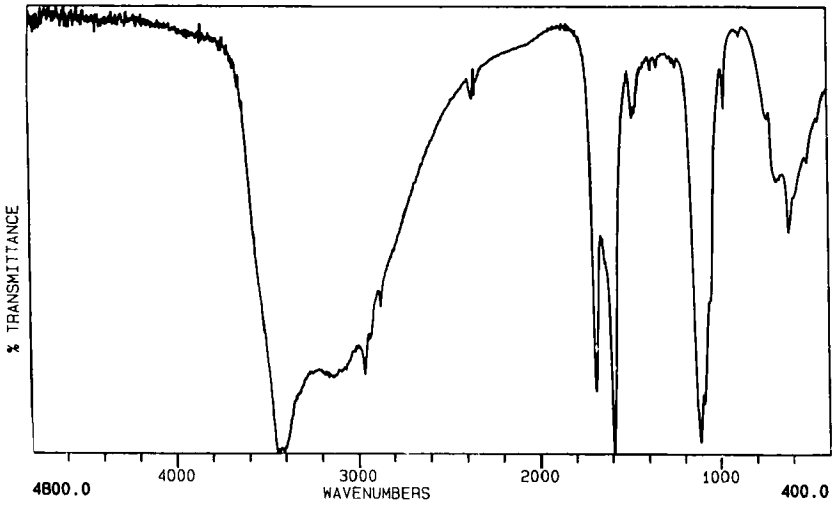


FIG. 13. IR spectrum of DPGBG sulphate.

TABLE 13.

IR Spectrum of DPGBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3443	NH stretching
2965	CH stretching
2874	CH stretching
2365	
2346	
1692	NH bending
1591	C=N stretching
1480	
1377	
1343	
1113	SO_4^{2-} stretching
970	
617	

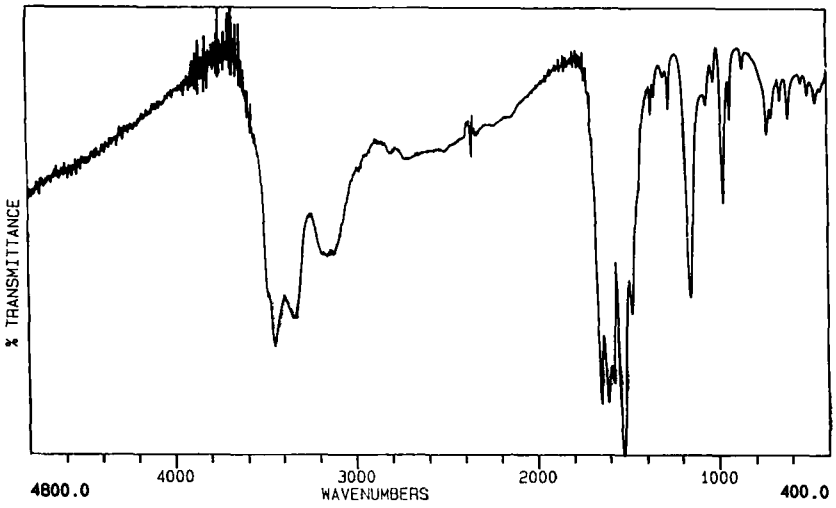


FIG. 14. IR spectrum of MGBG free base.

TABLE 14.

IR Spectrum of MGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3443	NH stretching
3335	NH stretching
3156	
2706	
2352	
2328	
1645	NH_2 bending
1609	NH_2 bending
1576	C=N stretching
1530	C=N stretching
1480	C=N stretching
1368	
1267	
1152	C-N stretching
968	
930	
729	
613	

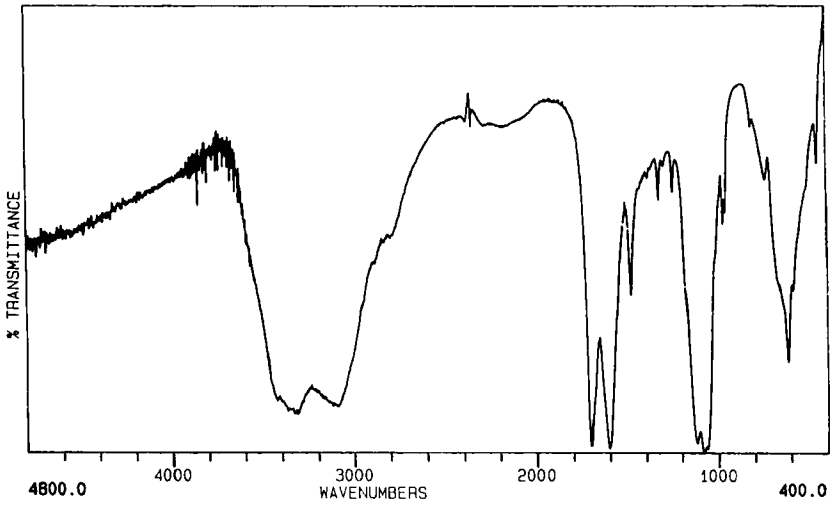


FIG. 15. IR spectrum of EGBG sulphate.

TABLE 15.

IR Spectrum of EGBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3752	
3677	
3650	
3630	
3330	NH stretching
3090	
1703	NH bending
1603	C=N stretching
1476	
1321	
1242	
1082	SO_4^{2-} stretching
968	
735	
615	

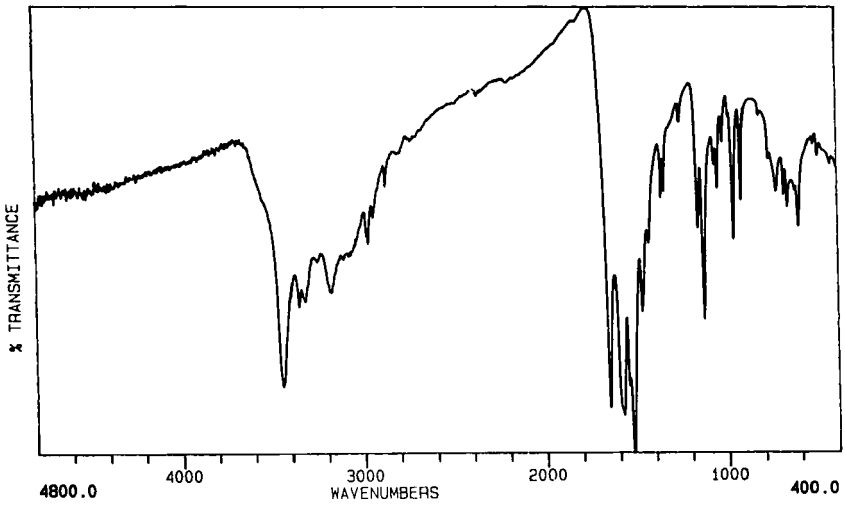


FIG. 16. IR spectrum of EMGBG free base.

TABLE 16.

IR Spectrum of EMGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3445	NH stretching
3357	
3326	
3179	
2980	
2971	
2942	
1649	NH_2 bending
1578	C=N stretching
1545	C=N stretching
1524	C=N stretching
1472	
1431	
1360	
1157	
1129	C-N stretching
964	
920	
667	
606	

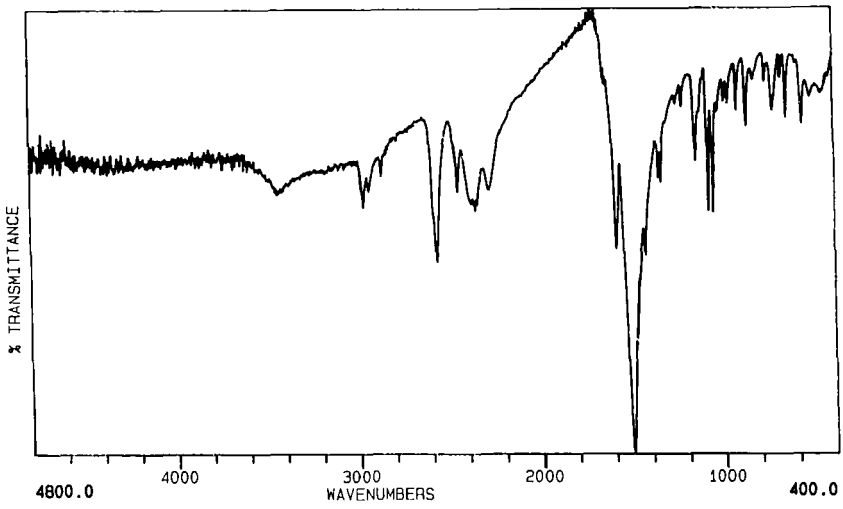


FIG. 17. IR spectrum of deuterated EMGBG free base.

TABLE 17.

IR Spectrum of Deuterated EMGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3440	residual NH or H_2O
2973	
2872	
2571	ND stretching
2456	
2357	
2282	
1590	
1507	C=N stretching
1433	
1358	
1343	
1082	
1057	

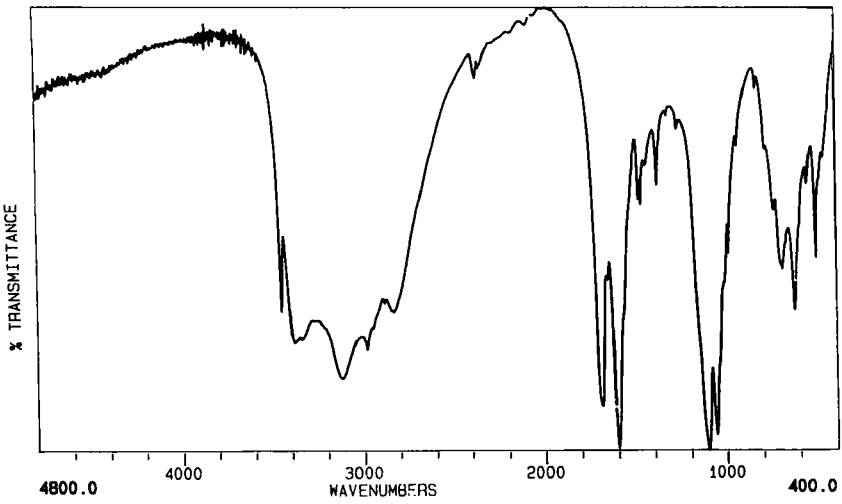


FIG. 18. IR spectrum of EMGBG sulphate.

TABLE 18.

IR Spectrum of EMGBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3380	NH stretching
3117	NH stretching
2978	
2828	
1684	NH bending
1601	
1476	CN stretching
1462	
1372	
1258	
1103	SO_4^{2-} stretching
1057	SO_4^{2-} stretching
980	
928	
733	
693	
625	
552	
507	

In the case of MPGBG free base (Fig. 19, Table 19), the pattern of the NH stretching region resembles that in the spectrum of EMGBG free base, but is slightly different from that in the spectra of the other free bases studied. This may be due to the remarkable unsymmetry of MPGBG, leading perhaps to a marked difference between the two guanidino groups as concerns interactions with the environment. Also intramolecular effects caused by the unsymmetry must, however, be considered, and it is even possible that the differences are only due to different amounts of crystal water.

The spectrum of MPGBG free base shown in Fig. 19 was obtained using an MPGBG sample that had been prepared from pure MPGBG sulphate that had been purified by recrystallization. Before the availability of this sample, a spectrum had been recorded using an unpurified sample of the free base that had been isolated by precipitating with aqueous NaOH directly from the synthesis mixture of MPGBG sulphate after isolation of the main part of the sulphate salt. In the spectrum of the unpure free base, a sharp peak of medium intensity was observed at 866 cm^{-1}. In the spectrum of the purified compound, only a very small peak was observed at a near-by wavenumber (875 cm^{-1}). This peak that obviously cannot be due to MPGBG itself but to an impurity is most probably due to carbonate ions. In the spectrum of anhydrous Na_2CO_3 as well as in $Na_2CO_3.10H_2O$, a sharp peak is observed at essentially the same wavenumber (880 cm^{-1} in the former and 849 cm^{-1} in the latter). The presence of carbonate ions in the compounds studied is possible since one of the starting materials in the syntheses of the bis(amidinohydrazones) studied was, according to common practice, aminoguanidine bicarbonate [5, 26]. Bicarbonate ions are commonly removed by treating aminoguanidine bicarbonate with an equivalent amount or a small excess of a mineral acid and by mixing the warmed solution for some time before the synthesis. The present results suggest that more efficient methods of bicarbonate removal (a larger excess of acid, longer bubbling time and a higher temperature) may be necessary in order to obtain carbonate-free products.

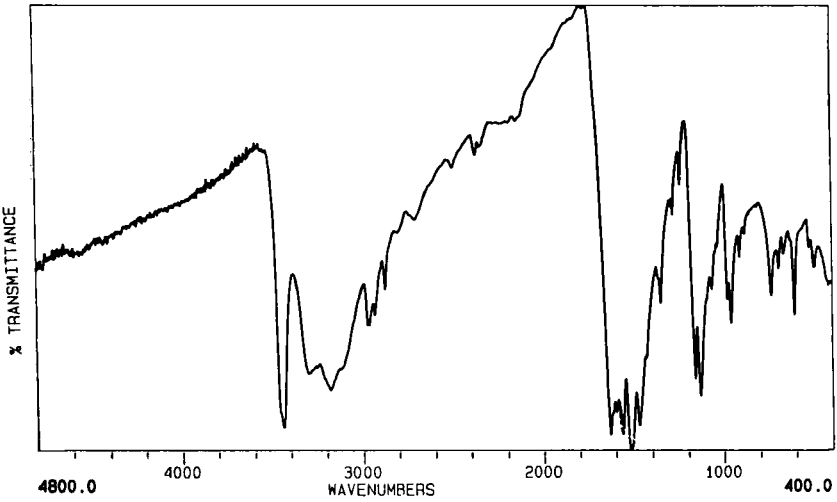


FIG. 19. IR spectrum of MPGBG free base.

TABLE 19.

IR Spectrum of MPGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3441	NH stretching
3179	NH stretching
2963	
2872	
1632	NH_2 bending
1566	C=N stretching
1520	C=N stretching
1474	
1346	
1273	
1159	
1132	C-N stretching
974	
955	
903	
735	
693	
662	
606	
494	

Perhaps even the isolation and recrystallization of aminoguanidine salts such as monohydrochloride or hemisulphate should be encouraged.

On a closer examination, also the spectra of some other compounds in addition to those of MPGBG free base were found to contain a small or a very small peak or a shoulder near 875 cm^{-1} (MPGBG sulphate, deuterated free bases of GBG, DMGBG and DEGBG, undeuterated free base of DEGBG, DEGBG sulphate and deuterated sulphate, DPGBG free base and sulphate, free bases of MGBG and EMGBG), which may suggest the presence of small amounts of carbonate or bicarbonate ions. No methods have been reported for the analysis of the carbonate content of bis(amidinohydrazones). The present results suggest that IR spectroscopy might be a suitable method for this purpose.

The spectrum of MPGBG sulphate (Fig. 20, Table 20) is largely similar to that of EMGBG sulphate. The sulphate band is broad and its shape suggests that it may consist of several overlapping peaks, which might be due to differences in the hydrogen bonding of the sulphate oxygens.

The spectrum of BMGBG free base (Fig. 21, Table 21), a compound with a still larger difference between the lengths of the side chains, is largely similar to that of MPGBG, only the NH stretching pattern being distinctly different. In the case of deuterated BMGBG free base (Fig. 22, Table 22), the NH stretching band essentially disappears, only a small band of unknown origin (residual NH protons?) remaining. The CH stretching peaks are essentially unchanged after deuteration. An intense ND stretching band appear between ca. 2300 and 2700 cm^{-1}, and the C=N stretching and C-N stretching bands are shifted to slightly smaller wavenumbers, as compared to the undeuterated base.

In the spectrum of BMGBG sulphate (Fig. 23, Table 23), prominent bands due to NH stretching and either C=N stretching or N-H bending (or both) can be

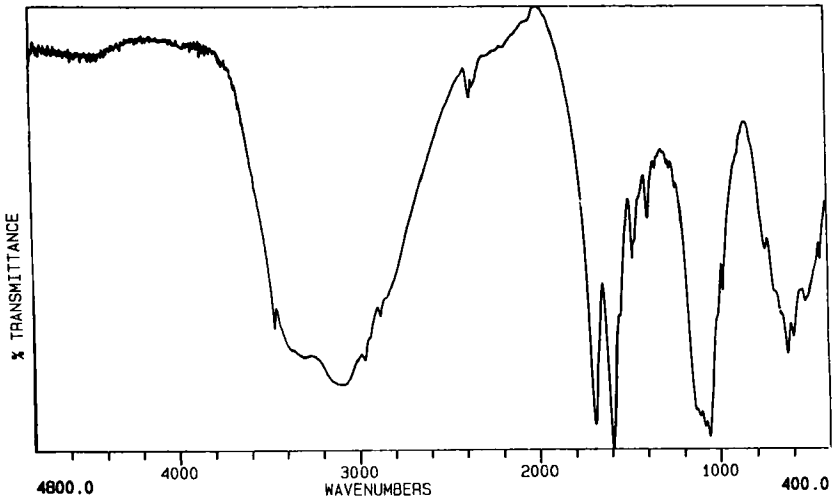


FIG. 20. IR spectrum of MPGBG sulphate.

TABLE 20.

IR Spectrum of MPGBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3461	NH stretching
3094	NH stretching
2872	
2359	
2344	
1690	NH bending
1593	C-N stretching
1474	
1385	
1339	
1057	SO_4^{2-} stretching
974	
743	
623	
590	
521	

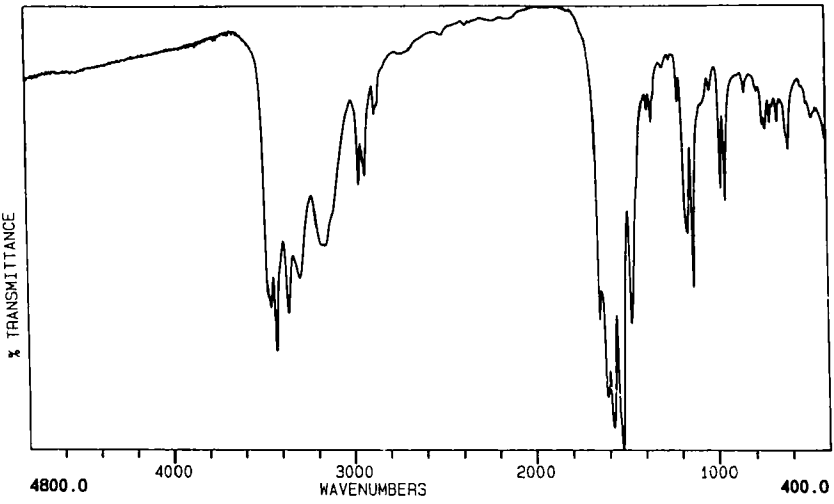


FIG. 21. IR spectrum of BMGBG free base.

TABLE 21.

IR Spectrum of BMGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3455	NH stretching
3424	NH stretching
3355	NH stretching
3291	NH stretching
3150	NH stretching
2957	CH stretching
2926	CH stretching
1645	NH_2 bending
1606	
1572	C=N stretching
1522	C=N stretching
1468	C=N stretching
1157	C-N stretching
1129	
972	
947	
745	
729	
702	
606	

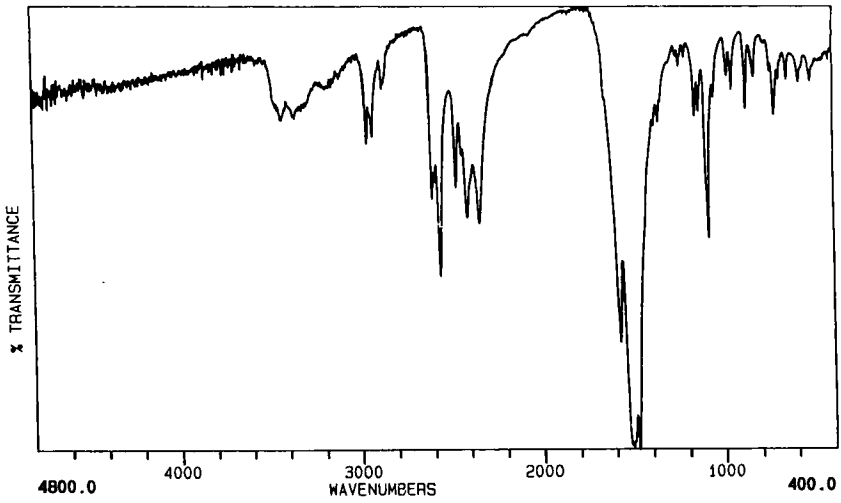


FIG. 22. IR spectrum of deuterated BMGBG free base.

TABLE 22.

IR Spectrum of Deuterated BMGBG Free Base

Wavenumber (cm^{-1})	Interpretation
3426	residual NH or H_2O
3355	residual NH or H_2O
2957	CH stretching
2924	CH stretching
2600	ND stretching
2585	ND stretching
2560	ND stretching
2467	ND stretching
2406	ND stretching
2340	ND stretching
1570	C=N stretching
1507	C=N stretching
1478	C=N stretching
1350	
1150	
1129	C-N stretching
1080	
872	
718	

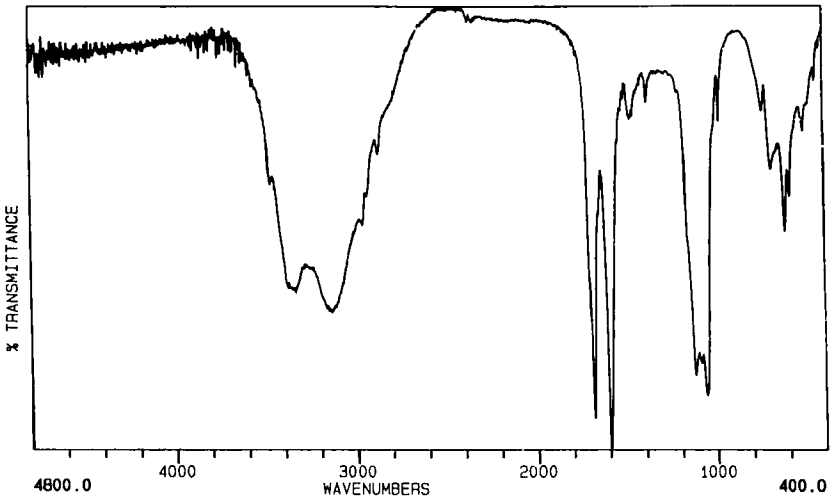


FIG. 23. IR spectrum of BMGBG sulphate.

TABLE 23.

IR Spectrum of BMGBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3588	NH stretching
3331	NH stretching
3133	NH stretching
2869	CH stretching
1684	NH bending
1597	C=N stretching
1474	
1383	
1123	SO_4^{2-} stretching
1057	
976	
739	
691	
619	
592	
513	

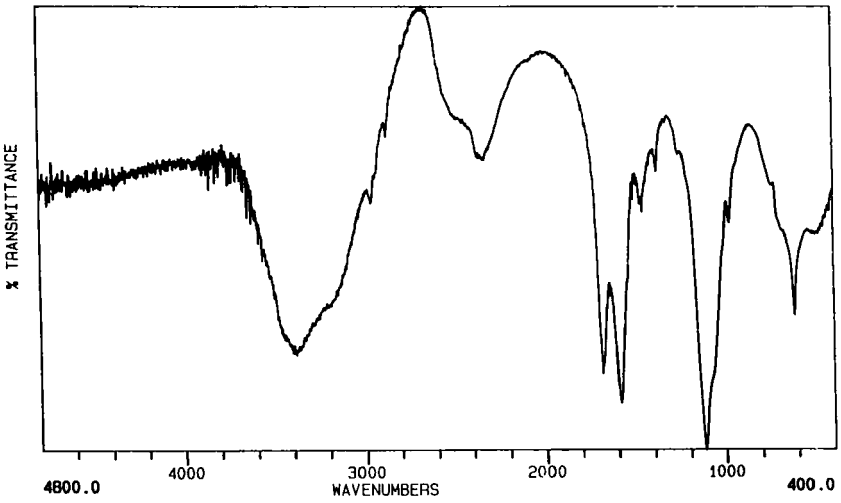


FIG. 24. IR spectrum of deuterated BMGBG sulphate.

TABLE 24.

IR Spectrum of Deuterated BMGBG Sulphate

Wavenumber (cm^{-1})	Interpretation
3384	residual NH or H_2O
2961	CH stretching
2332	ND stretching
1684	C=N stretching
1586	C=N stretching
1507	
1456	
1117	SO_4^{2-} stretching
972	
617	

observed, alongside with a strong band that is obviously due to SO_4^{2-} stretching and possibly also CN stretching. In the spectrum of deuterated BMGBG sulphate (Fig. 24, Table 24), a strong band is seen in the NH stretching region that is difficult to assign. The possibility must be taken into account that the method used for deuteration has failed to some extent in the case of BMGBG sulphate, the band being only due to residual NH stretching. This interpretation is, however, not supported by the appearance of a marked ND stretching band (ca. 2200 - 2700 cm^{-1}). In the spectrum of the deuterated sulphate salt, C=N stretching and/or ND_2 bending as well as SO_4^{2-} stretching bands can also be observed.

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