NQR Spectra of ^{79}Br and ^{127}I in the Halogen Derivatives of the Benzoic and Hippuric Acids*

T. A. Babushkina, K. Yu. Volgin, and S. F. Gushtchin
Institute of Biophysics, Ministry of Health, Moscow, USSR

Z. Naturforsch. **41 a**, 186–189 (1986); revised version received September 25, 1985

Quadrupole interactions in ortho-, meta- and para-Br- and I-benzoic and hippuric acids have been studied by means of NQR spectroscopy. It is shown that the formation of the Na-salts results in NQR frequency changes. The temperature dependence of the ^{79}Br and ^{127}I NQR frequencies in the para-halogen derivatives of the benzoic and hippuric acids are investigated. The ^{127}I NQR spectra in a few derivatives of 2, 4, 6-$I_3C_6H_2COOH$ are studied at 77 K.

Introduction

Dimers of carboxylic acids are suitable objects for investigations of the energetics and dynamics of proton transfer via H-bonds. If the compounds contain halogenes, the NQR method is convenient for this purpose.

The crystalline and molecular structures of the ortho-Cl and ortho-Br-benzoic acids are known from X-ray analyses [1, 2]. Both structures have the following features:

1) The carboxyl groups are turned around the $C_{arom} - C_{exo}$ axis by 13.7 and 18.3 °, respectively.
2) The halogen and C_{exo} atoms are outside the aromatic plane.
3) The $C-C_{exo}$ and C–Hal bonds are displaced in different directions, and the corresponding valence angles are increased.
4) The $C_{exo} \cdots$ Hal and $O_{carbonyl} \cdots$ Hal distances are considerably larger than the sum of the Van der Waals atomic radii.
5) The lengths of the C–O bonds in the carboxyl group are not equal (1.295 Å and 1.208 Å for Cl-isomer, 1.346 Å and 1.202 Å for Br-isomer).

The different lengths of the C–O bonds certainly have some influence on the energetics and dynamics of the proton transfer in the H-bonding dimers of the benzoic acids, resulting in a small difference of the energy of the two dimer configurations in the solid state. The rate and the activation energy of the proton transfer in the solid state were estimated in a series of derivatives of benzoic acid by the proton relaxation time T_1 method [3, 4]. It was found that the proton transfers in the dimers of solid aliphatic and aromatic carboxylic acids are similar and are characterized by small energetic barriers (4.5 – 6.5 kJ/mol). This is in accord with the calculation [5] showing that the H-bond is mainly of σ-type. For ortho-halogen benzoic acids (Hal = Cl, Br) higher energetics barriers (53 – 57 kJ/mol) were found. This is connected with the steric crowding in the ortho-isomer molecules and, accordingly, with the longer $O \cdots O'$ distance.

Results and Discussion

The ^{79}Br and ^{127}I NQR data for mono-halogen derivatives of benzoic acid are in accord with the structure of these molecules, determined by X-ray crystallography. The NQR frequencies are shown in Table 1.

The comparison of the NQR ^{79}Br frequencies of the ortho-isomers of benzoic acid and its methyl ester indicates that intramolecular $O-H \cdots Br$ bonding is absent, because the frequencies compared are close to one another. This is not in contradiction with the cis-position of the bromine atom and the carbonyl oxygen atom.

The considerable asymmetry parameter of the electric field gradient (EFG) at the iodine nucleus in ortho-I-benzoic acid indicates strong overcrowd-

* Presented at the VIIIth International Symposium on Nuclear Quadrupole Resonance Spectroscopy, Darmstadt, July 22–26, 1985.

Reprint requests to Dr. T. A. Babushkina, Institute of Biophysics, Ministry of Health Zhivopisnaja ul., 46, 123182 Moscow, USSR.

0340-4811 / 86 / 0100-0186 $ 01.30/0. – Please order a reprint rather than making your own copy.

Table 1. NQR frequencies of ^{79}Br and ^{127}I, quadrupole coupling constants, and asymmetry parameters of EFG of ^{127}I for same derivatives of the benzoic and hippuric acids.

Substituents	T, K	ν/MHz $\Delta m = 1/2-3/2$	ν/MHz $\Delta m = 3/2-5/2$	$e^2 Q q$/MHz	η (%)
1-COOH, 2-I	77	297.79[a]	579.15[a]	1939.15	14.7
1-$COONa^+$, 2-I	77	290.30[b]	...	...	...
1-COOH, 3-I	77	278.57[a]			
	301	275.67[a]	548.52[a]	1830.1	6.3
1-$COOCH_3$, 3-I	301	276.24[a]	550.16[a]	1835.0	5.7
1-$COONa^+$, 3-I	77	275.00[b]	...	...	...
		279.20	...	...	...
1-COOH, 4-I	77	275.82[a]	549.79[a]	1833.6	5.1
1-$COOCH_3$, 4-I	301	284.03[a]	564.21[a]	1882.7	7.3
1-$CONHCH_2COOH$, 2-I	77	291.40[a, b]	...	...	...
		290.47	575.31	1921.7	10.0
1-$CONHCH_2COONa$, 2-I	77	291.00[a, b]	557.12	1869.55	19.0
		283.27	554.27	1854.09	13.0
1-$CONH_2^+CH_2COOH$, 2-I	77	285.40	...	...	...
1-$CONHCH_2COOH$, 3-I	77	278.40[b]	552.80	1844.75	7.5
1-$CONHCH_2COONa$, 3-I	77	281.20[b]	558.21	1862.90	7.6
		278.42	549.99	1836.90	9.8
1-$CONHCH_2COOH$, 4-I	77	275.90[b]	548.50	1830.14	6.8
1-$CONHCH_2COONa$, 4-I	77	283.85[b]	...	...	...
2,4,6-I_3, 1-COOH,	77	287.95[c]	574.01	1914.37	5.0
3-$NHCOCH_3$		299.85 × 2	593.05	1980.32	9.3
(triiodotrast)		300.60	595.57	1988.14	8.6
		301.90	598.04	1996.51	8.6
		312.42	620.87	2071.66	7.0
2,4,6-I_3, 1-COOH,	77	302.79[c]	601.54	2007.05	7.5
3,5-$(NHCOCH_3)_2$		310.35 × 2	616.75	2057.94	7.0
(triombrine)		322.65	627.75	2101.95	14.5
		314.28	...	...	...
		317.10	...	...	...
2,4,6,-I_3, 1-COONa,	77	300.24[c]	...	...	...
3,5,-$(NHCOCH_3)_2$		305.88 × 2	...	...	...
		309.48	...	...	...
		310.68	...	...	...
		315.30	...	...	...
1,1′-$(COOH)_2$, 2,2′,4,4′,	77	292.35[c]	...	...	...
6,6′-I_6, 3,3′-$(NHCO(CH_2)_2)_2$		294.25 × 2	...	...	...
(bilignost)		300.54	...	...	...
		301.65	...	...	...
		303.24	...	...	...
1-COOH, 2-Br	77	285.25[a]			
1-$COOCH_3$, 2-Br	77	286.23[a]			
1-COOH, 3-Br	77	272.80[a]			
1-$COOCH_3$, 3-Br	77	271.77[a]			
1-COOH, 4-Br	77	271.05[a]			
1-$COOCH_3$, 4-Br	77	275.96[a]			
1-$CONHCH_2COOH$, 2-Br	77	277.60			
1-$CONHCH_2COOH$, 3-Br	77	272.60			
1-$CONHCH_2COOH$, 4-Br	77	270.35			

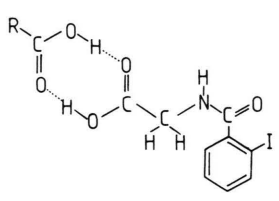
[a]) G. K. Semin [9]. [b]) V. V. Chrapov [10]. [c]) T. A. Babushkina [11].

ing of the molecule and distortion of the EFG along the axis perpendicular to the direction of the C–I bond lying in the aromatic plane. The visible decrease of the ^{127}I NQR frequency for the ortho-I-benzoate $Na^{\oplus}$ is supposed to be due to the influence at the I atom of the negative charge of the oxygen atoms following salt formation. The distruction of the O–H ··· O dimers in case of the meta-isomers of the Br- and I-benzoic acids does not influence the NQR halogen frequencies.

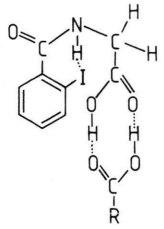
The considerable increase of the NQR frequency for the para-isomers on breaking of the O–H ··· O

dimers in the methyl esters of Br- and I-benzoic acids attracted our attention.

In the NQR spectrum of the ortho-I-hippuric acid there are two lines with similar frequencies and different intensities. The intensities of these lines depend on the degree of purity of the compound: the purer the compound, the smaller the intensity of the low frequency line. Probably solid ortho-I-hippuric acid exists in two space conformers differing in the orientation of the substituent around the C–I axis.



1



2

Both conformers are retained on formation of ortho-I-hippurate $Na^{\oplus}$. In this case the NQR frequencies are not as close as in the acid. The asymmetry parameters of the EFGs are also different. In conformer **1** the iodine atom is near the oxygen atom of the carbonyl and the destruction of the O–H···O dimer has a negligible influence on the C–I bond and the ^{127}I NQR frequency. In conformer **2** there is the possibility of N–H···I intramolecular H-bonding, therefore the breaking the O–H···O dimer distinctly influences the EFG at the I nucleus, because in this case the negative charge of the oxygen atom will be near the iodine atom. The ^{127}I NQR frequency decreases.

The protonation of the nitrogen atom in the exocyclic bond also decreases the ^{127}I NQR frequency since the hybridisation of the nitrogen atom and the charge distribution in the $CONH_2$ group change. In this case only conformer **1** may exist. To explain the increase or decrease of the NQR frequency by the influence of the exo charges we must know which orbitals of the I (Br) atom will interact with these charges and also take into consideration the Townes-Dailey equation [6]

$$e^2 Q q h^{-1} = (e^2 q Q h^{-1}) \left(\frac{N_x + N_y}{2} - N_z \right)_{at},$$

where $e^2 Q q h^{-1}$ is the quadrupole coupling constant (QCC) for the halogen nucleus in the molecule, $(e^2 Q q h^{-1})$ at the QCC due to one unbalanced p-electron per halogen and N_i are the occupation numbers of the p_i orbitals. The increase of the negative charge at the p_x or p_y-orbitals, perpendicular to the direction of the C–I (C–Br) bond, increases the EFG at the nucleus of the halogen atom. If the negative charge is in the line along the C–I (C–Br) bond, it decreases the EFG at the nucleus of the iodine (bromine) atom.

The comparison of the ^{127}I NQR frequencies for the meta isomers of I-hippuric acid and its Na^+ salt shows that the breaking of the O–H···O dimers has a negligible influence on the characteristics of the C–Hal bond.

In a case of the para-isomer of I-hippuric acid and the para-isomers of the halogenbenzoic acids the breaking of O–H···O dimers results in an appreciable increase of the ^{127}I NQR frequency. Due to the σ-type of the H-bond [5] its influence on the characteristics of the C–Hal bond should be negligible for the para-isomers of carboxylic acids. Therefore, for the estimation of the special features of the H-bond in the para-isomers of benzoic acids and in para-Br-hippuric acid, we studied the temperature dependence of the ^{79}Br and ^{127}I ($\Delta m = 1/2 - 3/2$) NQR frequencies.

The experimental temperature dependences of the NQR frequencies are shown in Figs. 1 and 2. No peculiarities due to the weakening of the H-bond O–H···O in the dimers with increasing temperature are observed. The temperature dependence of the NQR frequencies in the para isomers of the Br- and I-benzoic acids are well enough approximated by the Bayer theory [7], when the frequencies of the torsional vibrations of the molecules of the order of $30\ cm^{-1}$ are used. A small discontinuity in the temperature dependence of the NQR ^{79}Br frequency in the para-Br-hippuric acid is observed near 200 K. This indicates the onset of some additional degree of freedom.

Apparently the difference of the NQR frequencies of the halogen between the dimers of the carboxylic acids and the monomeric methyl ester or their $Na^{\oplus}$-salts is caused by the different contributions of the crystalline field for the different molecular structures of the substances.

Due to the different structures, the asymmetry parameters η of the EFG's increase a little at the nuclei of the Br and I atoms in the methyl-parabromine and iondine benzoates, $\eta = 9.4\%$ [8] and $\eta = 7.3\%$, respectively, in comparison to that of the

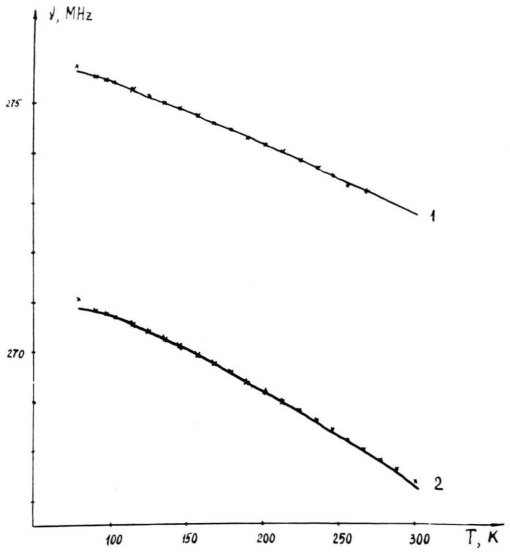


Fig. 1. Temperature dependence of the ^{127}I NQR frequencies in para-I-benzoic acid (1), ($\Delta m = 1/2 - 3/2$) and in para-Br-benzoic acid (2), ^{79}Br NQR. The solid curves were calculated from the Bayer theory using for (1) $\nu_t = 21.65\ cm^{-1}$ and for (2) $\nu_t = 27.27\ cm^{-1}$.

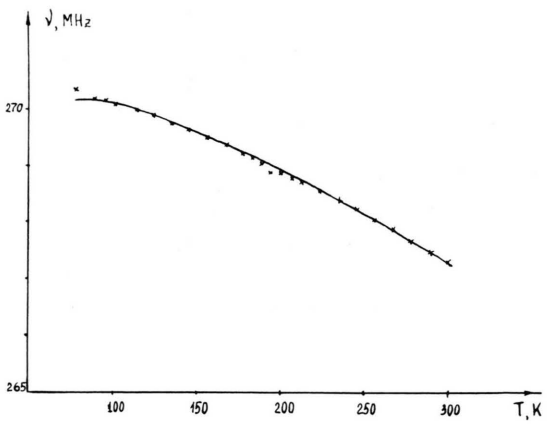


Fig. 2. Temperature dependence of the NQR frequency in para-Br-hippuric acid, ^{79}Br NQR. The solid curve was calculated from the Bayer theory using $\nu_t = 30.77\ cm^{-1}$.

[1] G. Ferguson and G. A. Sim, Acta Cryst. **13,** 1262 (1961).
[2] G. Ferguson and G. A. Sim, Acta Cryst. **15,** 346 (1962).
[3] S. Nagaoka, T. Terao, F. Imashiro, A. Saika, N. Hirota, and S. Hayashi, J. Chem. Phys. **79,** 4694 (1983).
[4] B. H. Meier, F. Graf, and R. R. Ernst, J. Chem. Phys. **76,** 767 (1982).
[5] S. Nagaoka, N. Hirota, T. Matsushita, and K. Nishimoto, Chem. Phys. Lett. **92,** 498 (1982).
[6] C. H. Townes and B. P. Dailey, J. Chem. Phys. **17,** 782 (1949).
[7] H. Bayer, Z. Physik **130,** 227 (1951).

para-halogen isomers of the acids ($\eta = 5.1\%$ for the I-derivative).

Therefore the O–H ··· O hydrogen bond, the formation of the dimers and their destruction do not act directly on the properties of the C–Hal bond in the mono-halogen isomers of the benzoic and hippuric acids. Mainly the crystal and molecular structures of the compounds influence the NQR parameters of the halogen nuclei. The main structural factors to be considered are the overcrowding and the steric hindrance in the molecule, the possible existence of several conformers in the solid state, the redistribution of the electron charges on the formation of the salts, the change of the crystal structure and the packing of the molecules in the methyl esters of the acids.

The derivatives of the 2,4,6-I-benzoic acid (triiodotrast, triombrine, bilignost) are used in diagnostic medicine. The structure of these molecules is overcrowded. Probably the acid group is turned around the $C_{arom} - C_{exo}$ axis and the iodine atoms at the ortho-position to the COOH-group are outside the aromatic plane. For these molecules probably there are a few confirmations depending on the environment of the iodine atoms.

The ^{127}I NQR spectra for triiodotrast, triombrine, and triombrine Na^+ have five lines. One of them has double intensity. This indicates the existence of two independent molecules in the unit cell for these compounds. The conformations of the two molecules are different.

In the crystal the bilignost molecule occupies the general position. Therefore the five lines of the NQR spectrum (one of them has a double intensity) arise from the six iodine atoms of the molecule. A very large frequency spread (10–15 MHz) of the NQR spectra of these molecules may show of the importance of the H-bonds, when we consider the distribution of the EFG's at the iodine nuclei.

[8] R. Angelone, P. Cecchi, and A. Colligiani, J. Chem. Phys. **53,** 4096 (1970).
[9] G. K. Semin, T. A. Babushkina, and G. G. Jacobson, Primenenije jadernogo kvadrupolnogo resonansa v chimii, Isd. Chimija, Leningrad 1972 (Russian), Translation. Nuclear Quadrupole Resonance in Chemistry, John Wiley + Sons, N.Y., Toronto 1975.
[10] V. V. Chrapov, L. G. Shtirkov, T. A. Babushkina, N. G. Iroshnikova, and V. I. Stanko, Isv. AN SSSR, ser. fis. **39,** 2569 (1975) (Russian), Translation. Bull. of Acad. Sci. USSR **39,** N12, 102.
[11] T. A. Babushkina, A. M. Alimov, N. G. Iroshnikova, N. N. Suykova, A. F. Volkov, and V. I. Stanko, Teor. Exper. Chimija **14,** 91 (Russian) 1977.