^{1}H, ^{13}C AND ^{15}N NMR SPECTRA OF COUPLING PRODUCTS OF BENZENEDIAZONIUM SALTS WITH ALIPHATIC NITRO COMPOUNDS AND STUDY OF THEIR *E/Z* ISOMERISM

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The ^{1}H, ^{13}C and ^{15}N NMR spectra have been measured of coupling products of benzenediazonium salts with nitromethane, nitroethane, 1-nitropropane, 2-nitroethanol and of their sodium salts, and the chemical shifts have been unambiguously assigned. The coupling products have been found to exist only in their hydrazone tautomeric forms. Stereospecific behaviour of the coupling constants $^{2}J(^{15}N,^{1}H)$ and $^{2}J(^{15}N,^{13}C)$ in the ^{15}N isotopomers and NOESY have been used to differentiate between the *E* and *Z* geometrical isomers. The above-mentioned compounds exist as *Z* isomers in deuteriochloroform and predominantly (>95%) as *E* isomers in dimethyl sulfoxide, while the sodium salts are present only as *E* isomers in dimethyl sulfoxide.

Key words: 1-Nitroaldehyde phenylhydrazones; ^{1}H, ^{13}C and ^{15}N NMR; *E/Z* isomerism.

As early as 1875, Mayer[1] found that benzenediazonium sulfate reacted with nitroethane to give a coloured product and assigned to it the structure of azo compound $C_6H_5–N=N–CH(CH_3)NO_2$. Bamberger and Schmidt[2] described an isolation of two “azo” forms of the reaction product of benzenediazonium salt with nitromethane which had the melting points of 74.5 and 84.5 °C. Jones and Kenner[3] isolated a single compound only with rather different melting point (92 °C), and, on the other hand, they obtained two forms in the case of the coupling product of benzenediazonium salt with 2-nitroethanol. Later it was proved[4] that the coupling products of benzenediazonium salts can exist in the respective hydrazone forms, which makes the *E/Z* geometrical isomerism possible. Results of studies of these and similar types of compounds are summarized in a review article[4]. Different isomers can be obtained from different solvents[5–8]. It was suggested to adopt the dilution ^{1}H NMR experiments[5] (which presume that the position of intramolecularly bound acidic proton does not change with dilution) or the different magnitudes of the coupling constants $^{1}J(^{13}C,^{1}H)$ (ref.[8]) for differentiation between the *E* and *Z* isomers.

The aim of the present communication was to measure the ^{1}H, ^{13}C and ^{15}N NMR spectra of the substances prepared by coupling of benzenediazonium chloride with aliphatic nitro compounds, assign unequivocal chemical shifts, adopt the NOESY spectroscopy and stereospecific behaviour of the coupling constants $^2J(^{15}N,^1H)$ and $^2J(^{15}N,^{13}C)$ in the ^{15}N isotopomers and their anions for differentiation between the *E* and *Z* geometrical isomers, and experimentally (dis)prove the conclusions published earlier.

EXPERIMENTAL

Nitroformaldehyde phenylhydrazone (**1**), 1-nitroacetaldehyde phenylhydrazone (**2**), 1-nitropropionaldehyde phenylhydrazone (**3**), and 1-nitro-2-hydroxyacetaldehyde phenylhydrazone (**4**) were prepared by azo coupling reactions of benzenediazonium chloride with nitromethane, nitroethane, 1-nitropropane, and 2-nitroethanol, respectively, in weak acid or basic media[1].

The ^{15}N labelled isotopomers were prepared similarly by using ^{15}N-aniline (15% ^{15}N) and $Na^{15}NO_2$ (95% ^{15}N).

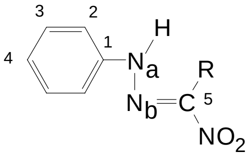
The ^1H, ^{13}C and ^{15}N NMR spectra (δ, ppm) were measured with a Bruker AMX-360 apparatus at 360.13, 90.56, and 36.50 MHz, respectively, at room temperature. The ^1H and ^{13}C chemical shifts are referenced to internal tetramethylsilane (δ = 0.0) and the ^{15}N chemical shifts to external nitromethane in a coaxial capillary (δ = 0.0). Positive values of the chemical shifts denote downfield shifts with respect to the standard.

For the measurements we used ca 0.3 M solutions in $CDCl_3$ and $[D_6]$DMSO. The anions of compounds **1–3** were prepared in situ by adding the equivalent amount of 4 M sodium methoxide into the solutions of the compounds in hexadeuteriodimethyl sulfoxide.

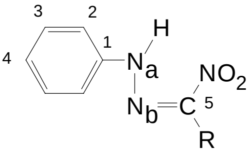
RESULTS AND DISCUSSION

The values of ^1H, ^{13}C and ^{15}N chemical shifts and the coupling constants $^nJ(^{15}N,^1H)$ and $^nJ(^{15}N,^{13}C)$ of compounds **1–4** and their salts are presented in Tables I–IV.

Compounds **1–4** exist in solutions as the hydrazone forms, which can be proved by NMR especially on the basis of the value of chemical shift of the quaternary carbon atom C-5, the coupling constant $^1J(^{15}N_a,^1H)$ ca 97 Hz, and the values $\delta(^{15}N)$ typical of the C–NH–N=C arrangement[9,10].



E



Z

	R
1	H
2	CH_3
3	CH_2CH_3
4	CH_2OH

With regard to the unsymmetrical substitution at the C-5 carbon atom these compounds can exist as *E* or *Z* isomers. For differentiation between these geometrical isomers of hydrazones it was suggested[5] to adopt the dilution ^{1}H NMR experiments which are based on the fact that the position of an acidic NH proton involved in intramolecular bond does not change with changing concentration in contrast to the $\delta(^1H)$ value of an NH group involved in intermolecular or no hydrogen bond[11].

We used the NOESY spectroscopy[12] to evaluate the spatial arrangement of substituents and observed the respective cross-peaks of NH proton with *ortho* protons in the phenyl nucleus in both $CDCl_3$ and [D$_6$]DMSO, the additional interactions with the nearest proton of R substituent of $=CRNO_2$ fragment (R = H, CH_3, CH_2OH, and CH_2CH_3) being observed only in [D$_6$]DMSO. From these results it follows that the compounds **1–4** exist only as *Z* isomers in deuteriochloroform but as *E* isomers (at least 95%) in

TABLE I
^{1}H, ^{13}C and ^{15}N NMR chemical shifts (δ, ppm) and absolute values of coupling constants (*J*(±0.3 Hz), Hz) in *Z* isomers of compounds **1–4** in deuteriochloroform

Atom	Compound							
	1		**2**		**3**		**4**	
	δ^1H	$\delta^{13}C$	δ^1H	$\delta^{13}C$	δ^1H	$\delta^{13}C$	δ^1H	$\delta^{13}C$
1	–	141.39 (6.9)[a]	–	141.59 (6.8)[a]	–	141.81 (6.3)[a]	–	142.28 (6.7)[a]
2	7.29	115.23 (2.1)[a]	7.25	114.86 (2.1)[a]	7.24	114.79 (2.8)[a]	7.29	115.51 (2.4)[a]
3	7.38	129.62	7.34	129.51	7.33	129.45	7.37	129.63
4	7.16	125.21	7.08	124.29	7.08	124.11	7.15	125.34
5	7.46 (16.8)[b]	124.51 (3.7)[a]	–	132.56 (5.7)[a]	–	136.38 (5.6)[a]	–	134.32 (5.1)[a]
6	–	–	2.41 (3.3)[b]	17.99 (10.3)[a]	2.79 (3.3)[b]	24.64 (9.1)[a]	4.66	61.19 (11.3)[a]
7	–	–	–	–	1.28	10.72 (2.7)[a]	–	–
N_a	12.48 (97.7)[h]	–222.4[c,d]	12.25 (97.4)[h]	–226.3[c,e]	12.19 (97.4)[h]	–227.0[c,f]	12.35 (97.5)[h]	–222.6[c,g]
N_b	(2.5)[b]	–62.1[c,d]	(2.4)[b]	–70.5[c,e]	(2.4)[b]	–71.5[c,f]	(2.5)[b]	–63.7[c,g]

[a] $^2J(^{15}N_b,^{13}C)$; [b] $^nJ(^{15}N_b,H)$; [c] $\delta(^{15}N)$; [d] $^1J(^{15}N_a,^{15}N_b)$ = 9.4 Hz; [e] $^1J(^{15}N_a,^{15}N_b)$ = 9.6 Hz; [f] $^1J(^{15}N_a,^{15}N_b)$ = 9.9 Hz; [g] $^1J(^{15}N_a,^{15}N_b)$ = 9.6 Hz; [h] $^nJ(^{15}N_a,H)$.

[D_6]DMSO. In contrast to ref.[8], we observed no isomerisation of compounds **1–4** in deuteriochloroform. However, the compounds **1–4** are little stable and decompose on standing in solutions after several days.

Both the dilution experiments and NOESY with the compounds studied by us have the drawback in that they do not allow evaluation of the arrangement of substituents in salts of compounds **1–4**, i.e. in the cases when the signal of NH group is absent from the ^{1}H NMR spectra.

Bradamante et al.[8] suggested utilization of different magnitudes of coupling constant $^1J(^{13}C,^1H)$ of =CHR group in the compounds $C_6H_5NHN=CHR$. The values of $^1J(^{13}C,^1H)$ are greater in the *Z* isomer than in the *E* isomer; thus for R = CH_3 $^1J(^{13}C,^1H)$ = 180.6 Hz in *Z* isomer and $^1J(^{13}C,^1H)$ = 160 Hz in *E* isomer. These values, however, depend distinctly on the type of substituent R, hence the unequivocalness of the method will make itself felt only in the cases when both the isomers are available and their

TABLE II
^{1}H, ^{13}C and ^{15}N NMR chemical shifts (δ, ppm) and absolute values of coupling constants (*J*(±0.3 Hz), Hz) in *E* isomers of compounds **1–4** in hexadeuteriodimethyl sulfoxide

Atom	Compound							
	1		**2**		**3**		**4**	
	δ^1H	$\delta^{13}C$	δ^1H	$\delta^{13}C$	δ^1H	$\delta^{13}C$	δ^1H	$\delta^{13}C$
1	–	142.21 (6.2)[a]	–	143.46 (6.5)[a]	–	143.86 (6.6)[a]	–	144.01 (6.6)[a]
2	7.28	114.46 (2.6)[a]	7.38	114.59 (2.6)[a]	7.38	114.89 (2.3)[a]	7.21	114.77 (2.3)[a]
3	7.41	129.65	7.38	129.41	7.38	129.33	7.41	129.46
4	7.09	123.25	7.04	122.44	7.05	122.54	7.07	122.93
5	8.59 (2.5)[b] (2.7)[c]	136.22 (13.1)[a]	–	143.68 (14.3)[a]	–	147.44 (13.8)[a]	–	145.21 (13.8)[a]
6	–	–	2.51 (1.4)[b]	11.53 (1.4)[a]	3.01 (0.8)[b]	18.21 (1.9)[a]	4.28	52.35
7	–	–	–	–	1.17	9.78	–	–
N_a	11.95	–231.4[d,e]	10.48	–236.9[d,f]	10.61	–233.9[d,g]	11.01	–222.6[d,h]
N_b		–36.8[d,e]	–	–52.5[d,f]		–54.3[d,g]		–63.7[d,h]

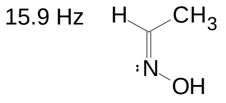
[a] $^nJ(^{15}N_b,^{13}C)$; [b] $^nJ(^{15}N_b,H)$; [c] $^3J(^{15}N_a,H)$; [d] $\delta(^{15}N)$; [e] $^1J(^{15}N_a,^{15}N_b)$ = 9.3 Hz; [f] $^1J(^{15}N_a,^{15}N_b)$ = 9.8 Hz; [g] $^1J(^{15}N_a,^{15}N_b)$ = 9.8 Hz; [h] $^1J(^{15}N_a,^{15}N_b)$ = 9.6 Hz.

coupling constants can thus be compared. For compound **1** only the coupling constant $^1J(^{13}C,^1H)$ = 210 Hz of the major isomer was measured[8], the other isomer being present in very low amount (insufficient for the measurement). In the case of anion of compound **1**, which also shows only one set of NMR signals, the spatial arrangement of substituents could be unambiguously determined neither[8]. The method cannot be used for compounds of the type C_6H_5–NHN=CR^1R^2 where there is no corresponding coupling constant and the differences in $^1J(^{13}C,^1H)$ values of the more distant carbon atoms are not conclusive.

For unequivocal differentiation between the *E* and *Z* isomers of compounds **1–4** and their sodium salts we adopted the stereospecific behaviour of the coupling constants $^2J(^{15}N_b,^1H)$ and $^2J(^{15}N_b,^{13}C)$ in the ^{15}N enriched compounds as a generally applicable method. The values of the respective coupling constants are distinctly higher in the "*cis*" orientation of free electron pair at nitrogen and the corresponding proton or carbon atom[13,14], which follows from the data published for the model compounds **5–7**.

The values of coupling constants for planar arrangement of substituents differs very distinctly and are very little affected by the character of substituents.

$^2J(^{15}N,H)$



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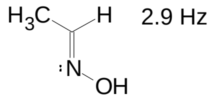

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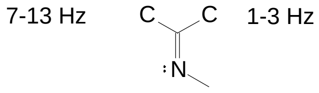
$^2J(^{15}N,^{13}C)$



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From the comparison of $^2J(^{15}N_b,^1H)$ values for the arrangement =$CHNO_2$ in compound **1** in deuteriochloroform (*J* = 16.8 Hz, Table I) and in [D_6]DMSO (*J* = 2.5 Hz, Table II) it is obvious that compound **1** has the configuration *Z* in $CDCl_3$ and configuration *E* in [D_6]DMSO. The same conclusion is also valid for compounds **2–4** if the different magnitudes of coupling constants $^2J(^{15}N_b,^{13}C\text{-}5)$ in $CDCl_3$ and [D_6]DMSO are taken into account (see Tables I and II).

In the case of anion of compound **1**, which also shows only one set of NMR signals, it was impossible to unequivocally determine the spatial arrangement of substituents[8].

TABLE III
^{15}N Chemical shifts (δ, ppm) and absolute values of coupling constants (J(±0.3 Hz), Hz) in Z isomers of compounds **1–3** in hexadeuteriodimethyl sulfoxide

Nitrogen atoms	Compound **1**	Compound **2**	Compound **3**
N_a	–63.9	–72.9	–73.7
N_b	–220.9	–222.1	–222.9
$^1J(^{15}N_a,^{15}N_b)$		9.9	9.8

TABLE IV
^{1}H, ^{13}C and ^{15}N NMR chemical shifts (δ, ppm) and absolute values of coupling constants (J(±0.3 Hz), Hz) in E isomers of sodium salts of compounds **1–3** in hexadeuteriodimethyl sulfoxide

Atom	Compound **1**		**2**		**3**	
	δ^1H	δ^{13}C	δ^1H	δ^{13}C	δ^1H	δ^{13}C
1	–	154.94 $(5.5)^a$	–	153.88 $(5.7)^a$	–	153.52 $(5.4)^a$
2	7.54	120.58 $(4.2)^a$	7.61	120.53 $(3.9)^a$	7.54	120.25 $(3.6)^a$
3	7.34	129.03	7.34	129.31	7.33	129.14
4	7.14	125.38	7.12	125.05	7.09	125.01
5	8.36 $(1.6)^b$	133.76 $(6.6)^a$	–	141.15 $(5.9)^a$	–	145.6 $(5.6)^a$
6	–	–	2.33	11.42 $(1.4)^a$	2.92	18.22 $(1.5)^a$
7	–	–	–	–	1.4	10.74
N_a		2.2^c		$–15.3^c$		22.6^c
N_b		74.2^c		56.6^c		$72.4^{c,d}$

^{a} $^nJ(^{15}N_b,^{13}C)$; ^{b} $^2J(^{15}N_b,H)$; ^{c} $\delta(^{15}N)$; ^{d} $^1J(^{15}N_a,^{15}N_b)$ = 13.9 Hz.

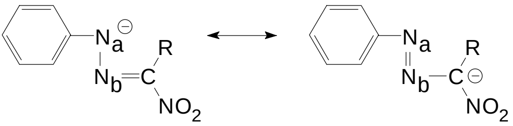
(In ref.[8] the anions were obtained with sodium dimsyl, whereas we used 4 M sodium methoxide. The differences in values of ^{13}C chemical shifts of compound **1** are lower than 0.8 ppm.) A single set of signals was also obtained with each of the anions of compounds **2** and **3**. This can correspond to the presence of either one isomer or two interconvertible isomers whose interconversion would, of course, have to be fast in the NMR time scale. The coupling constant $^2J(^{15}N_b,^1H)$ is approximately the same in compound **1** and its anion (2.5 and 1.5 Hz, respectively), and similarly the coupling constants $^2J(^{15}N_b,^{13}C)$ of compounds **2** and **3** differ only very little from those of their respective anions. Hence it can be stated that the anions of compounds **1–3** maintain the same mutual arrangement of substituents as the starting substances, and a rapid rotation in NMR time scale can be excluded too because in such a case the values of coupling constants of *E* and *Z* forms would have to approach their arithmetic mean, i.e. the values of ca 8–10 Hz for $^2J(^{15}N_b,^1H)$ and 5–6 Hz for $^2J(^{15}N_b,^{13}C\text{-}5)$. They would have to be about twice as large in the *Z* isomer. The above-described analysis documents the advantages of application of ^{15}N labelled compounds and general applicability and unambiguousness of the result obtained.

In our previous communications we dealt with studies of products of azo coupling[15–17] of arenediazonium salts and with nitrosation[18] of substances with activated methylene group.

Tables I–IV present the values of $\delta(^{15}N)$ of compounds **1–4** and their anions. The effect of nitro group in compounds **1–4** is manifested by an upfield shift of $\delta(^{15}N)$ by ca 15–20 ppm as compared with the coupling products at a methylene group activated by less electronegative substituents[15–17].

On the basis of empirical calculations, Bradamante et al.[8] presume the presence of negative charge at the aldehydic methine carbon atom such as shown in Scheme 1.

The ^{15}N chemical shifts that we have measured for the anions of compounds **1–3**, and the coupling constant $^1J(^{15}N,^{15}N)$ = 13.9 Hz for the anion of compound **3** distinctly support this idea experimentally (better than the ^{13}C NMR data do). The downfield shift of $\delta(^{15}N)$ in the anions of compounds **1–3**, as compared with the starting compounds **1–3** themselves, can be considered a shift to values typical of –N=N– arrangement. In (*E*)-azobenzene it is $\delta(^{15}N)$ = 130.1 (hexadeuteriodimethyl sulfoxide)[19], in substituted azobenzenes the values of $^1J(^{15}N,^{15}N)$ reach the value of ca 15 Hz (ref.[19]).



SCHEME 1

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