PROTON-COUPLED ^{13}C NMR SPECTRA OF 2- AND 3-SUBSTITUTED PYRIDINES

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The proton-coupled ^{13}C NMR and PMR spectra of pyridine and the 2- and 3-monosubstituted pyridines NC_5H_4X [where X = CH_3, CN, $COCH_3$, $COOCH_3$, $N(CH_3)_2$, NO_2, OCH_3, Cl, or Br] for one-molar solutions of the compounds in DMSO-D_6, have been analyzed. The signs and values of the $^{13}C-^{1}H$ HSSCs have been determined. Equations have been obtained connecting the $^{13}C-^{1}H$ SSCCs in the 2- and 3-substituted pyridines and the monosubstituted benzenes. A satisfactory correlation of $^{1}J_{CH}$ with the F and R constants of the substituents has been shown.

The ^{13}C NMR spectra of monosubstituted pyridines have already been studied. The influence of the substituents on the chemical shifts of the ^{13}C nuclei of the heteroaromatic ring has been investigated in detail and relationships have been found connecting the chemical shifts of the ^{13}C nuclei in the spectra of the monosubstituted pyridines and benzenes and also the dependence of these parameters on the σ-constants of the substituents [1-3]. However, there is practically no information in the literature that characterizes the influence of substituents on the $^{13}C-^{1}H$ SSCCs, which is connected with specific difficulties in analyzing the proton-coupled ^{13}C NMR spectra of the compounds [4]. The complete analysis of such spectra (involving accurate values of the parameters of the PMR spectra of the compound) have been made only for pyridine and 2-bromopyridine [4], and in other investigations the $^{13}C-^{1}H$ SSCCs were obtained with a relatively low accuracy [5, 6] which does not permit a detailed study to be made of the influence of the substituents on the constants. All the investigations were performed for highly concentrated solutions of the compounds but the influence of the solvents and the concentration on the $^{13}C-^{1}H$ SSCCs was not studied in detail.

In the investigations performed previously, it was observed that the $^{13}C-^{1}H$ SSCCs can serve as a reliable tool for the study of the structure and electronic effect in organic compounds [7, 8]. The informativeness of the $^{13}C-^{1}H$ SSCCs is particularly high (in comparison with the other parameters of the NMR spectra) in the study of the influence of substitution on the NMR spectra of aromatic and heteroaromatic compounds. Thus, the amount of information on the $^{13}C-^{1}H$ SSCCs in monosubstituted benzenes is close to that of the total in-

TABLE 1. Parameters of the PMR Spectra of the 2-Substituted Pyridines NC_5H_4X

Compound	X	Chemical shifts, δ, ppm					J_{HH}, Hz						MSD[a], Hz
		3-H	4-H	5-H	6-H	CH_3	J_{34}	J_{35}	J_{36}	J_{45}	J_{46}	J_{56}	
I[b]	H	7,395	7,795	7,395	8,604	—	7,65	1,46	0,94	7,65	1,84	4,91	0,029
II[c]	CH_3	7,243	7,667	7,174	8,458	2,471	7,79	1,18	0,97	7,49	1,89	4,88	0,016
III	CN	8,072	8,101	7,784	8,802	—	7,81	1,20	0,96	7,84	1,73	4,83	0,002
IV	$COCH_3$	7,980	8,023	7,685	8,756	2,668	7,85	1,24	0,91	7,59	1,75	4,75	0,013
V	$COOCH_3$	8,096	8,041	7,690	8,773	3,938	7,85	1,21	0,92	7,66	1,77	4,72	0,002
VI	$N(CH_3)_2$	6,608	7,486	6,556	8,089	3,003	8,60	0,93	0,90	7,07	2,03	4,93	0,013
VII	NO_2	8,362	8,309	7,954	8,737	—	8,18	0,96	0,78	7,53	1,81	4,66	0,002
VIII	OCH_3	6,823	7,702	6,977	8,189	3,859	8,36	0,92	0,90	7,09	2,02	5,04	0,011
IX	Cl	7,541	7,895	7,446	8,457	—	8,06	0,96	0,82	7,42	2,06	4,86	0,002
X	Br	7,676	7,791	7,478	8,433	—	8,04	0,98	0,82	7,41	2,10	4,83	0,002

a) Mean square deviation of the experimental and calculated transition frequencies. b) J_{26} = −0.13 Hz. c) SSCCs for protons of the methyl group: J_3 = −0.51, J_4 = 0.26, J_5 = −0.62, J_6 = 0.26 (±0.03) Hz.

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TABLE 2. Parameters of the PMR Spectra of the 3-Substituted Pyridines NC_5H_4X

Compound	X	Chemical shifts, δ, ppm					J_{HH}, Hz						MSD
		2-H	4-H	5-H	6-H	CH_3	J_{24}	J_{25}	J_{26}	J_{45}	J_{46}	J_{56}	
XI[a]	CH_3	8,435	7,599	7,282	8,393	2,296	2,32	0,91	—[b]	7,76	1,69	4,77	0,007
XII	CN	9,054	8,347	7,660	8,897	—	2,18	0,94	−0,23	7,99	1,70	4,96	0,002
XIII	$COCH_3$	9,156	8,305	7,586	8,822	2,663	2,30	0,90	—[b]	7,97	1,72	4,82	0,002
XIV	$COOCH_3$	9,114	8,308	7,600	8,857	3,932	2,23	0,90	—[b]	7,97	1,74	4,85	0,002
XV	$N(CH_3)_2$	8,128	7,071	7,165	7,901	2,913	3,12	0,71	−0,20	8,51	1,35	4,55	0,010
XVI	NO_2	9,396	8,636	7,771	9,006	—	2,71	0,73	−0,32	8,45	1,48	4,79	0,001
XVII	OCH_3	8,320	7,384	7,339	8,189	3,833	3,05	0,69	−0,23	8,46	1,36	4,65	0,010
XVIII	Cl	8,657	7,956	7,482	8,571	—	2,57	0,76	−0,26	8,25	1,42	4,73	0,001
XIX	Br	8,733	8,076	7,419	8,596	—	2,44	0,77	−0,26	8,21	1,43	4,72	0,001

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a) SSCCs of the protons of the methyl group: $J_2 = -0.66$, $J_4 = -0.70$, $J_5 = 0.40$, $J_6 = -0.55$ (±0.03) Hz. b) $|J_{HH}| < 0.15$ Hz.

formation that can be obtained from an analysis of the influence of substituents on the $^1H-^1H$ SSCCs and the chemical shifts of the protons and the ^{13}C nuclei [8].

The calculated values of the $^{13}C-^1H$ SSCCs for nitrogen-containing heterocycles are in poor agreement with their experimental values [9]. It has been shown [10] that, at the present time, in order to predict the influence of substitution on the $^{13}C-^1H$ SSCCs, correlations with empirical parameters are more useful than theoretical calculations. Consequently, the aim of the present work was to study the empirical dependences of the $^{13}C-^1H$ SSCCs in 2- and 3-substituted pyridines on the properties of the substituents.

We have made a complete analysis of the proton-coupled ^{13}C NMR spectra of a number of 2- and 3-substitute pyridines recorded under standard conditions using the parameters of the PMR spectra. The compounds investigated contained substituents which, in relation to the degree of their action of the systems studied, may be arbitrarily divided into the following groups [8]: electroneutral — H, CH_3; π-acceptors — CN, NO_2, $COCH_3$, $COOCH_3$; π-donors — $N(CH_3)_2$, OCH_3; and halogens — Cl, Br.

Tables 1 and 2 give the parameters of the PMR spectra of the 2- and 3-substituted pyridines. The negative sign of J_{26} in the 3-substituted pyridines follows from the calculations of the PMR spectra of pyridine and 3-cyanopyridine; in the other compounds the sign of the constant is taken by analogy with these values. On comparison of the values obtained for the $^1H-^1H$ SSCCs with those known previously [11-13], a difference between the results of up to 0.2 Hz can be seen, which may be connected with errors in the investigations performed previously and also with the influence of the solvent and the concentration of the compounds under investigation on the values of these constants [14].

The parameters of the PMR spectra obtained were used in an analysis of the proton-coupled ^{13}C NMR spectra. The spectrum of each ^{13}C-isotopomer was calculated separately. As

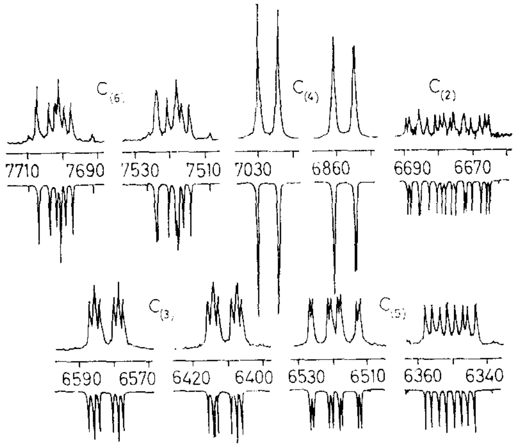

Fig. 1. Experimental and calculated ^{13}C NMR spectra of the monoresonance of 2-cyanopyridine, δ, Hz.

TABLE 3. ^{13}C Chemical Shifts, δ, ppm, and $^nJ_{CH}$ SSCCs, Hz, in the 2-Substituted Pyridines

Compound	C(2)						C(3)						C(4)					
	δ	$^2J_{23}$	$^3J_{24}$	$^3J_{26}$	$^4J_{25}$	MSD	δ	$^1J_{33}$	$^2J_{34}$	$^3J_{35}$	$^4J_{36}$	MSD	δ	$^1J_{44}$	$^2J_{43}$	$^2J_{45}$	$^3J_{46}$	MSD
I	149,57	3,19	6,84	11,08	−0,87	0,030	123,83	163,79	0,98	6,53	−1,62	0,043	136,03	163,33	0,74	0,74	6,25	0,047
II[a]	158,13	2,6	7,1	11,1	−1,0	0,087	123,71	162,39	0,91	6,73	−1,61	0,064	137,02	162,59	0,68	1,12	6,43	0,037
III[b]	132,72	1,8	8,3	12,9	−1,1	0,063	129,10	170,91	1,66	6,96	−1,59	0,019	137,96	168,73	0,20	0,88	6,02	0,036
IV[c]	152,96	1,32	6,52	10,65	−1,11	0,018	121,05	166,60	1,32	6,86	−1,58	0,033	137,34	165,58	0,51	0,78	6,05	0,056
V[d]	147,49	1,1	7,1	11,3	−1,1	0,093	124,82	167,42	1,39	6,82	−1,53	0,036	137,45	166,35	0,39	0,96	6,10	0,042
VI[e]	159,14	1,2	8,1	11,5	−1,2	0,096	105,83	162,00	1,51	6,60	−1,64	0,008	137,19	159,75	−0,33	1,63	6,83	0,055
VII	156,50	−1,3	10,2	12,4	−1,6	0,148	118,17	174,62	1,69	7,36	−1,51	0,058	140,84	169,60	−0,25	1,42	6,40	0,058
VIII[g]	163,52	−1,1	9,6	11,6	−1,1	0,061	110,55	165,74	1,32	6,95	−1,56	0,012	138,95	162,43	—f	1,67	7,14	0,012
IX	150,33	−1,0	11,1	13,7	−1,8	0,085	124,44	172,19	1,38	7,15	−1,52	0,042	139,78	166,41	0,29	1,45	6,72	0,029
X	141,43	−0,8	11,0	13,7	−1,7	0,062	128,15	172,91	1,35	7,10	−1,50	0,019	139,49	166,58	0,38	1,46	6,67	0,054

Compound	C(5)						C(6)					
	δ	$^1J_{55}$	$^2J_{54}$	$^2J_{56}$	$^3J_{53}$	MSD	δ	$^1J_{66}$	$^2J_{65}$	$^3J_{64}$	$^4J_{63}$	MSD
I	123,83	163,79	0,98	8,35	6,53	0,043	149,57	177,94	3,19	6,84	−0,87	0,030
II	121,40	164,56	0,96	7,93	6,48	0,013	149,04	177,21	3,46	7,08	−0,56	0,020
III	127,87	167,77	0,92	8,23	6,18	0,019	151,24	183,73	3,43	7,11	−0,75	0,030
IV	127,55	165,60	1,23	8,62	6,43	0,042	149,11	180,65	3,50	6,88	−0,56	0,058
V	127,32	166,20	1,00	8,82	6,14	0,058	149,75	181,13	3,50	7,06	−0,56	0,055
VI	111,39	164,69	0,95	7,83	6,25	0,018	147,59	174,45	3,85	7,47	—f	0,014
VII	129,97	168,27	1,28	8,67	6,15	0,049	148,94	186,02	4,04	7,73	−0,24	0,042
VIII	116,91	165,28	0,99	7,86	6,47	0,007	146,84	178,32	3,97	7,74	—f	0,023
IX	123,08	167,02	0,95	8,04	6,24	0,032	149,97	183,02	3,98	7,79	−0,30	0,032
X	123,35	166,93	0,95	8,09	6,16	0,054	150,46	183,40	3,96	7,71	−0,39	0,037

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a) δ_{CH_3} = 24.17 ppm; SSCCs of the protons of the methyl group: $J_{C(2)}$ = −5.5, $J_{C(3)}$ = 4.2, $J_{C(4)}$ = −0.3, $J_{C(5)}$ = 0.8, $J_{C(6)}$ = −0.4 (±0.1) Hz. b) δ_{CN} = 117.50 ppm. c) δ_{CH_3} = 25.50, δ_{CO} = 186.34 ppm. d) δ_{CH_3} = 52.33, δ_{CO} = 165.20 ppm. e) δ_{CH_3} = 37.65 ppm. f) $|J_{CH}| < 0.2$ Hz. g) δ_{CH_3} = 52.88 ppm.

TABLE 4. ^{13}C Chemical Shifts, δ, ppm, and $^nJ_{CH}$ SSCCs, Hz, in the 3-Substituted Pyridines

Compound	$C_{(2)}$						$C_{(3)}$						$C_{(4)}$					
	δ	$^1J_{22}$	$^3J_{24}$	$^3J_{26}$	$^4J_{25}$	MSD	δ	$^2J_{32}$	$^2J_{34}$	$^3J_{35}$	$^4J_{36}$	MSD	δ	$^1J_{44}$	$^2J_{45}$	$^3J_{42}$	$^3J_{46}$	MSD
XI[a]	149,90	175,69	6,10	11,43	−1,13	0,016	132,91	7,7	0,6	6,5	−1,4	0,075	136,33	160,81	0,87	5,66	6,60	0,051
XII[b]	152,42	187,57	5,30	11,62	−0,85	0,017	109,24	7,42	— c	7,88	−1,81	0,022	140,02	171,02	1,41	4,82	6,38	0,040
XIII[d]	149,51	180,53	5,48	11,40	−0,80	0,016	131,98	6,7	— c	6,7	−1,6	0,064	135,52	165,21	1,02	5,21	6,37	0,020
XIV[e]	149,97	182,78	5,31	11,48	−0,91	0,013	125,53	6,4	−0,4	6,4	−1,6	0,067	136,74	166,94	1,10	5,04	6,36	0,025
XV[f]	134,71	176,80	4,64	11,34	−1,05	0,036	146,08	6,0	−0,8	7,4	−1,4	0,076	118,36	160,45	1,28	4,39	6,51	0,026
XVI	144,54	189,72	3,83	11,97	−1,07	0,012	144,34	3,8	−3,5	8,5	−1,8	0,108	131,48	172,70	1,24	3,79	6,76	0,017
XVII[g]	137,48	178,91	4,17	11,61	−1,20	0,026	155,42	3,9	−2,6	8,2	−1,6	0,062	120,26	163,05	0,85	4,05	6,93	0,013
XVIII	148,19	186,24	4,47	11,85	−1,17	0,009	131,19	4,09	−3,35	9,34	−1,90	0,019	136,00	169,54	1,05	4,32	6,86	0,008
XIX	150,78	187,06	4,86	11,65	−1,13	0,010	121,30	4,49	−3,15	9,27	−1,89	0,008	140,04	170,29	1,04	4,64	6,78	0,009

Compound	$C_{(5)}$						$C_{(6)}$					
	δ	$^1J_{55}$	$^2J_{54}$	$^2J_{56}$	$^4J_{52}$	MSD	δ	$^1J_{66}$	$^2J_{65}$	$^3J_{62}$	$^3J_{64}$	MSD
XI	123,23	162,93	0,94	8,70	−1,53	0,035	146,71	178,12	3,12	11,01	6,85	0,014
XII	124,10	169,32	0,17	8,39	−1,56	0,028	153,26	182,76	3,17	10,98	6,75	0,017
XIII	123,82	166,60	0,41	8,50	−1,48	0,020	153,39	180,15	3,46	11,16	6,92	0,016
XIV	123,83	167,22	0,54	8,49	−1,51	0,016	153,62	180,62	3,41	11,28	6,92	0,018
XV	123,28	160,92	−0,56	9,26	−1,28	0,055	137,10	178,75	2,86	10,86	6,89	0,012
XVI	124,57	170,64	−0,50	8,97	−1,52	0,022	155,15	183,18	3,32	11,31	7,00	0,019
XVII	124,03	163,43	−0,68	9,46	−1,37	0,016	141,64	179,61	2,81	11,12	6,97	0,014
XVIII	125,09	167,00	0,01	9,20	−1,55	0,030	147,92	181,41	2,88	11,01	6,94	0,004
XIX	126,62	167,72	0,02	8,93	−1,60	0,014	148,64	181,80	2,94	10,78	6,94	0,006

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a) δ_{CH_3} = 17.87 ppm; SSCCs of the protons of the methyl group: $J_{C(2)}$ = 5.3, $J_{C(3)}$ = −5.9, $J_{C(4)}$ = 5.1, $J_{C(5)}$ = −0.4, $J_{C(6)}$ = 0.9 (±0.1) Hz. b) δ_{CN} = 116.99 ppm. c) $|J_{CH}| < 0.2$ Hz. d) δ_{CH_3} = 26.87, δ_{CO} = 197.37 ppm. e) δ_{CH_3} = 52.34, δ_{CO} = 165.18 ppm. f) δ_{CH_3} = 39.57 ppm. g) δ_{CH_3} = 55.34 ppm.

TABLE 5. SSCCs J_{CH}, Hz, in the Monosubstituted Benzenes C_6H_5X

X	$C_{(1)}$					$C_{(2)}$							$C_{(3)}$							$C_{(4)}$				
	J_{12}	J_{13}	J_{14}	MSD	N[a]	J_{22}	J_{23}	J_{24}	J_{25}	J_{26}	MSD	N	J_{32}	J_{33}	J_{34}	J_{35}	J_{36}	MSD	N	J_{42}	J_{43}	J_{44}	MSD	N
$COCH_3$	0,11	7,25	−1,34	0,024	16	160,69	1,58	7,70	−1,26	6,26	0,042	32	0,60	161,35	1,32	7,66	−1,15	0,027	28	7,62	1,36	160,35	0,033	26
$COOCH_3$	−0,52	7,72	−1,38	0,040	17	162,82	1,64	7,70	−1,32	6,06	0,040	31	0,61	161,62	1,26	7,71	−1,15	0,028	28	7,76	1,25	160,34	0,025	21
$N(CH_3)_2$	−0,75	8,37	−1,34	0,065	16	156,18	1,76	7,65	−1,33	5,46	0,037	39	−0,29	156,39	1,79	8,39	−0,78	0,065	30	7,45	0,87	160,18	0,026	28

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a) Number of transitions assigned in the calculations.

TABLE 6. Parameters of the ^{13}C—^1H SSCC Correlation in 2-Substituted Pyridines (J^{pyr}) and Monosubstituted Benzenes (J^{bz}) Calculated from the Equation $J^{pyr} = A \cdot J^{bz} + B$

J^{pyr}	J^{bz}	A	B	r	s	ΔJ^{pyr}, Hz[a]
$^2J_{23}$	$^2J_{12}$	0,871	1,80	0,978	0,32	4,49
$^3J_{24}$	$^3J_{13}$	1,223	−2,24	0,977	0,39	4,58
$^3J_{26}$	$^3J_{13}$	0,748	5,37	0,944	0,37	2,05
$^4J_{25}$	$^4J_{14}$	1,394	0,86	0,946	0,11	0,93
$^1J_{33}$	$^1J_{22}$	1,039	−0,08	0,981	0,91	12,62
$^2J_{34}$	$^2J_{23}$	1,009	−0,19	0,953	0,06	0,78
$^3J_{35}$	$^3J_{24}$	1,223	−2,77	0,899	0,11	0,83
$^4J_{36}$	$^4J_{25}$	—	—	0,172	—	0,14
$^1J_{44}$	$^1J_{33}$	1,125	−15,66	0,988	0,43	9,85
$^2J_{43}$	$^2J_{32}$	0,732	−0,04	0,958	0,11	1,07
$^2J_{45}$	$^2J_{34}$	1,443	−0,88	0,961	0,11	0,93
$^3J_{46}$	$^3J_{35}$	0,880	−0,63	0,956	0,10	1,12
$^1J_{55}$	$^1J_{44}$	1,078	−7,13	0,952	0,45	4,48
$^2J_{54}$	$^2J_{43}$	—	—	0,717	—	0,36
$^2J_{56}$	$^2J_{43}$	1,743	6,40	0,886	0,17	0,99
$^3J_{53}$	$^3J_{42}$	—	—	0,127	—	0,39
$^1J_{66}$	$^1J_{33}$	1,284	−25,44	0,965	0,94	9,28
$^2J_{65}$	$^2J_{34}$	1,123	2,06	0,872	0,15	0,85
$^3J_{64}$	$^3J_{35}$	0,864	0,37	0,911	0,16	0,95
$^4J_{63}$	$^4J_{36}$	1,226	0,77	0,899	0,09	0,63

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a) Range of measurement of J^{pyr}.

an example, Fig. 1 gives the experimental and calculated spectra of 2-cyanopyridine. The values of the chemical shifts of the ^{13}C nuclei and the ^{13}C—^1H SSCCs in the 2- and 3-substituted pyridines are given in Tables 3 and 4. The majority of ^{13}C—^1H SSCCs obtained are accurate to within 0.1 Hz. The deviation of the ^{13}C—^1H SSCCs in pyridine and 2-bromopyridine from the values given in [4] amount to 0.3-1.4 Hz for the direct $^1J_{CH}$ SSCCs and are of the order of 0.1 Hz for the $^nJ_{CH}$ long-range SSCCs, which is possibly connected with the influence of the medium.

A certain difficulty in the study of the NMR spectra of nitrogen-containing compounds is presented by the quadrupole broadening of the lines caused by interaction with the ^{14}N nuclei. Calculations made from the equations of Kintzinger and Lehn [15] have shown that in the ^{13}C NMR spectra of pyridine such broadening of the lines does not amount to more than 0.1 Hz [4]. Similar values of the spectral broadening of the ^{13}C NMR lines may also be expected in the case of the monosubstituted pyridines. In the PMR spectra, the signals of the 2-H and 6-H protons, which are close to the nitrogen, undergo pronounced broadening. This is connected with the large values of the ^{14}N—^1H SSCCs for these protons (10-12 Hz [16]). Consequently, in the present work, to determine the ^1H—^1H SSCCs we used mainly the signals of 3-H, 4-H, and 5-H protons the broadening of the lines of which is insignificant and is within the limits of error of the experiment.

The values of the ^{13}C—^1H SSCCs in the 2- and 3-substituted pyridines obtained were compared with the corresponding constants in monosubstituted benzenes [10]. The lacking information in the monosubstituted benzene series [with the substituents $COCH_3$, $COOCH_3$, and $N(CH_3)_2$], which we obtained under conditions similar to those in [10], is given in Table 5. The results of the comparison are given in Tables 6 and 7.

A linear interrelationship of the ^{13}C—^1H SSCCs in the 2- and 3-substituted pyridines and in the monosubstituted benzenes was found. The tangents of the angles of slope of the majority of relationships that are given in Tables 6 and 7 are between 0.7 and 1.3, which shows the moderate influence of the heterocycle on the ^{13}C—^1H spin—spin coupling in this series. Complete absence of a correlation was found only for some long-range SSCCs $^nJ_{CH}$, characterized by a small range of change under the influence of the substituent (<0.6 Hz). Furthermore, it is not excluded that some deviations from linearity in the relations presented may be connected with the influence of the solvent on the concentration of the ^{13}C—^1H SSCCs, since in [10] the results were obtained for highly concentrated solutions of compounds in different solvents.

Earlier, for the case of halogen-substituted benzenes [17], an additivity of the influence of substituents on the ^{13}C—^1H SSCCs was established. In the light of the results that

TABLE 7. Parameters of the ^{13}C—^{1}H Correlation in the 3-Substituted Pyridines and Monosubstituted Benzenes[a]

J^{pyr}	J^{bz}	*A*	*B*	*r*	*s*	ΔJ^{pyr}
$^{1}J_{22}$	$^{1}J_{22}$	1,165	−5,89	0,993	0,62	14,03
$^{3}J_{24}$	$^{3}J_{26}$	0,960	−0,46	0,991	0,32	3,01
$^{3}J_{26}$	$^{3}J_{24}$	1,241	1,80	0,899	0,11	0,89
$^{4}J_{25}$	$^{4}J_{25}$	—	—	0,855	—	0,40
$^{2}J_{32}$	$^{2}J_{12}$	0,901	7,01	0,977	0,36	4,55
$^{2}J_{34}$	$^{2}J_{12}$	0,954	−0,01	0,999	0,10	4,48
$^{3}J_{35}$	$^{3}J_{13}$	0,793	0,65	0,979	0,23	2,94
$^{4}J_{36}$	$^{4}J_{14}$	—	—	0,796	—	0,50
$^{1}J_{44}$	$^{1}J_{22}$	1,021	1,31	0,996	0,42	11,89
$^{2}J_{45}$	$^{2}J_{23}$	0,805	−0,17	0,921	0,08	0,67
$^{3}J_{42}$	$^{3}J_{26}$	0,787	0,26	0,982	0,14	2,46
$^{3}J_{46}$	$^{3}J_{24}$	1,148	−2,42	0,887	0,11	0,68
$^{1}J_{55}$	$^{1}J_{33}$	1,139	−16,96	0,994	0,32	9,72
$^{2}J_{54}$	$^{2}J_{32}$	1,136	−0,29	0,993	0,07	1,66
$^{2}J_{56}$	$^{2}J_{34}$	1,609	6,49	0,961	0,11	1,11
$^{4}J_{52}$	$^{4}J_{36}$	—	—	0,672	—	0,34
$^{1}J_{66}$	$^{1}J_{44}$	1,364	−38,61	0,959	0,52	5,24
$^{2}J_{65}$	$^{2}J_{43}$	1,268	1,78	0,977	0,05	0,65
$^{3}J_{62}$	$^{3}J_{42}$	—	—	0,848	—	0,53
$^{3}J_{64}$	$^{3}J_{42}$	—	—	0,315	—	0,25

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a) Analogous to the parameters of Table 6.

TABLE 8. Correlation Parameters of the Direct $^{1}J_{CH}$ SSCCs in 2- and 3-Substituted Pyridines (J^{pyr}) with the F and R Constants of Substituents from the Equation $J^{pyr} = A \cdot F + B \cdot R + C$, Hz

N[a]	J^{pyr}	*A*	*B*	*C*	*r*	*s*
2	J_{33}	17,90	1,17	162,63	0,934	1,84
	J_{44}	8,57	4,52	163,13	0,988	0,54
	J_{55}	6,19	0,14	164,17	0,964	0,45
	J_{66}	11,84	3,64	177,46	0,966	1,05
3	J_{22}	19,97	1,62	176,52	0,952	1,74
	J_{44}	16,08	2,89	161,85	0,951	1,54
	J_{55}	9,54	3,93	163,56	0,990	0,48
	J_{66}	7,89	0,22	178,09	0,983	0,38

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a) Position of the substituent.

we have obtained one may probably expect the appearance of an analogous effect for the substituted pyridines. In actual fact, an additivity of the influence of substituents on the $^{1}J_{CH}$ in polysubstituted pyridines (deviations from the calculated values not exceeding 2 Hz) has been reported [6]. The hypotheses put forward probably extend to more complex nitrogen-containing aromatic heterocycles. Thus, a study of the ^{13}C—^{1}H SSCCs in methyl- and amino-substituted pyrimidines [18] has also shown the existence of an additivity of the influence of the substituents.

With the aim of making a detailed study of the influence of substitution on the ^{13}C—^{1}H SSCCs in 2- and 3-substituted pyridines, a correlation has been made between these parameters and the resonance and inductive constants of the substituents (Swain—Lupton F and R constants in the interpretation of Hansch et al. [19]). As a result, satisfactory correlations have been obtained for all the direct $^{1}J_{CH}$ SSCCs (Table 8). However, for the majority of long-range SSCCs, $^{n}J_{CH}$, no similar correlation was found, which confirms the conclusion made previously [8] on the basis of results from monosubstituted benzenes that it is impossible in general to describe the ^{13}C—^{1}H SSCCs satisfactorily within the framework of linear two-parameter relations.

In the present work we have investigated the possibility of describing the other parameters of the PMR spectra and of the protein-coupled ^{13}C NMR spectra of the 2- and 3-substituted pyridines with the aid of the inductive and resonance constants of the substituents. As a result, satisfactory correlations with the F and R constants have been obtained for all the chemical shifts of the protons ($r \geq 0.96$) and the chemical shifts of the ^{13}C nuclei present in the para position to the substituent ($r \geq 0.99$), which confirms the conclusions drawn by Smith and Proulx [3]. To improve the description of the parameters of the spectra these authors [3] have proposed to use additional data characterizing the electronic nature of the substituents (parameters of Schaefer's ortho effects). However, the use of these parameters (together with the F and R constants) within the framework of three-parameter relations gives definite improvement only for the description of the chemical shifts of the ^{13}C nuclei and is of little significance for the interpretation of the $^1H-^1H$ and $^{13}C-^1H$ SSCCs.

EXPERIMENTAL

The PMR and ^{13}C NMR spectra were recorded on a Bruker WP 200 SY spectrometer working in the pulsed regime (working frequency for protons 200.13 MHz and for ^{13}C nuclei 50.33 Hz) at 23 ± 2°C for solutions of the pyridines in DMSO-D_6 (1 M) containing 3-5% (by volume) of TMS. Stabilization was effected with respect to the NMR signal of the deuterium of the solvent.

Conditions for Recording the Spectra. PMR spectra: 5-mm ampul, 4-10 accumulations; widths of the full spectrum 2 kHz, numerical resolution 0.25 Hz; aromatic region of the spectrum: width 400 Hz, numerical resolution 0.05 Hz. ^{13}C NMR spectra: 10-mm ampul; width of the full spectrum 10 kHz, numerical resolution 0.6 Hz, number of scans >100, regime of complete spin decoupling from protons; aromatic region of the spectrum: 2-3 kHz, numerical resolution 0.12-0.18 Hz, number of scans >2000, delay between pulses 15-20 sec, regime of "proton-pumping" between the pulses.

In order to simplify the proton-coupled ^{13}C spectra for the methylpyridines we used selective spin decoupling from methyl protons (amplitude of the irradiating field 10-15 Hz, which led to errors in the measurement of the $^{13}C-^1H$ SSCCs under our conditions of not more than 0.01% [10]). A similar regime was used for compounds containing methyl groups within the substituent.

The width of the lines (at half-height) in the PMR spectrum was 0.2-0.3 Hz (for the 2-H and 6-H protons, 0.4-0.8 Hz), and in the proton-coupled ^{13}C NMR spectra it was 0.3-0.5 Hz.

The NMR spectra of the monosubstituted benzenes (Table 5) were recorded for 50% (by volume) solutions of the compounds in acetone-D_6 under conditions similar to those given above.

All the spectra were calculated with the aid of the PANIC iteration program (in the LAOCOON version) on an ASPECT-2000 minicomputer. The ^{13}C NMR spectra were calculated as ABCDX five-spin systems, where X is a ^{13}C nucleus (for pyridine and benzenes, six-spin systems). The initial values of the $^{13}C-^1H$ SSCCs were taken from the literature [4, 5] and from a comparison with the parameters for benzenes [10]. The number of lines assigned in the calculations was 21-24 (PMR spectra of the 2-substituted pyridines; signals of the 3-H, 4-H, and 5-H protons), 14-16 (PMR spectra of the 3-substituted pyridines; signals of the 4-H and 5-H protons); or 12-17 (^{13}C NMR spectra; for the signals of each ^{13}C nucleus); in the case of pyridine and the benzenes, for all the different transitions in the spectra.

The values of the mean square deviations of the experimental and calculated transition frequencies obtained are given in the tables. The standard deviations for the calculated parameters (taking the numerical resolution into account, were about 0.02 Hz for the $^1H-^1H$ SSCCs and 0.03-0.05 Hz for the $^{13}C-^1H$ SSCCs, apart from the constants for the substituted carbon atoms $C_{(2)}$ and $C_{(3)}$, which were determined with an accuracy of 0.2 Hz ($^3J_{24}$ and $^3J_{26}$ in 2-nitropyridine, 0.5 Hz). The error in the determination of the J_{26} SSCCs from the PMR spectra of the 3-substituted pyridines was 0.05 Hz. The chemical shifts of the nuclei were determined from the full PMR and $^{13}C-\{^1H\}$ NMR spectra with accuracies of $1 \cdot 10^{-3}$ and $2 \cdot 10^{-2}$ ppm, respectively (the correction for infinite dilution did not exceed $4 \cdot 10^{-2}$ and 0.1 ppm).

The compounds investigated were obtained by known methods [20], and the values of their physical constants agreed with those given in the literature. The prepared samples, before the recording of the spectra, were subjected to additional purification, and their purity was checked by TLC and GLC.

LITERATURE CITED

1. J. B. Stothers, Carbon-13 NMR Spectroscopy, Academic Press, New York (1972), p. 250.
2. G. Miyajima, Y. Sasaki, and M. Suzuki, Chem. Pharm. Bull., 20, 429 (1972).

3. W. B. Smith and T. W. Proulx, Org. Magn. Reson., 8, 567 (1976).
4. M. Hansen and H. J. Jakobsen, J. Magn. Reson., 10, 74 (1973).
5. Y. Takauchi and N. Dennis, Org. Magn. Reson., 7, 244 (1975).
6. Y. Takauchi and K. Aoki, J. Chem. Soc., Perkin Trans. II, No. 3, 285 (1979).
7. N. M. Sergeev, NMR Spectroscopy [in Russian], Izd. MGU, Moscow (1979), p. 94.
8. V. A. Chertkov, Dissertation for the degree of Candidate of Chemical Sciences, Moscow (1982).
9. S. A. T. Long and J. D. Memory, J. Magn. Reson., 44, 355 (1981).
10. L. Ernst, V. Wray, V. A. Cherkov, and N. M. Sergeyev, J. Magn. Reson., 25, 123 (1977).
11. W. B. Smith and J. L. Roark, J. Phys. Chem., 73, 1049 (1969).
12. T. J. Batterham, NMR Spectra of Simple Heterocycles, Wiley, New York (1973), p. 27.
13. Y. Sasaki and M. Suzuki, Chem. Pharm. Bull., 17, 1104 (1969).
14. D. W. Aksnes and H. Kryvi, Acta Chem. Scand., 26, 2255 (1972).
15. J. P. Kintzinger and J. M. Lehn, Mol. Phys., 14, 133 (1968).
16. W. Städeli, P. Bigler, and W. Philipsborn, Org. Magn. Reson., 16, 170 (1981).
17. A. R. Tarpley and J. H. Goldstein, J. Phys. Chem., 76, 515 (1972).
18. M.-T. Chenon and J. Riand, Org. Magn. Reson., 15, 18 (1981).
19. C. Hansch, A. Leo, S. H. Unger, K. M. Kim, D. Nikaitani, and E. J. Lien, J. Med. Chem., 16, 1207 (1973).
20. The Chemistry of Heterocyclic Compounds, A. Weissberger (ed.), Interscience, New York, Vol. 14 (1960).

NEW METHOD OF SYNTHESIZING PYRIDYL- AND QUINOLYLCARBONYLARENECARBOXYLIC ACIDS

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An original method has been developed for the synthesis of a number of pyridyl- and quinolylcarbonylarenecarboxylic acids by condensing anhydrides of aromatic dicarboxylic acids with picolinic and quinaldic acids. The characteristics of the IR spectra of the compounds synthesized are given, and their ring-chain equilibrium transformations are discussed. It has been shown that the protonation of the nitrogen atom of the heterocycle stabilizes the cyclic form.

We have previously detected the stabilization of the ring form of 2-(imidazol-2-ylcarbonyl)benzamides by the protonation of the imidazole ring [1, 2]. It appeared of interest to investigate the influence of this effect on ring-chain equilibrium systems of keto carboxylic acids and their derivatives having other nitrogen heterocycles attached to the keto group.

The aim of the present work was to synthesize and investigate pyridyl- and quinolylcarbonylarenecarboxylic acids.

2-(2-Pyridylcarbonyl)benzoic acid (Ia) has long been known, but the methods previously used for its preparation [3, 4] involve many stages and are laborious. We [5] have obtained the acid (Ia) by condensing phthalic anhydride with picolinic acid at the temperature of decarboxylation of the latter (160-165°C) in a high-boiling organic solvent (nitrobenzene, benzonitrile, cymene, diethyleneglycol diethyl ether). This method is favorably distinguished from those known previously [3, 4] by the fact that it is a single-stage process, by the use of readily available reactants, and by the simplicity of its practical performance.

We have studied the possibility of expanding the boundaries of this method by using carboxylic acids of other nitrogen heterocycles, and also the anhydrides of other aromatic dicarboxylic acids. Thus, in the analogous reaction of naphthalic and diphenic anhydrides with

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