1-Methylcyclopropyl Ethyl Ketone (3d).[47]—Ketone **3d** was isolated from pyrolysates of **1d** and was identified by the following data: ir (CCl_4) 3.24 (cyclopropyl CH), 5.92 μ (C═O); nmr δ^{CCl_4} 0.48–0.73 (m, 2, cyclopropyl CH cis or trans to C═O), 0.81–1.28 (m, 2, cyclopropyl CH trans or cis to C═O), 0.98 (t, 3, J = 7.5 Hz, $CH_2\mathbf{CH_3}$), 1.35 (s, 3, CH_3C), 2.43 (q, 2, J = 7.5 Hz, $\mathbf{CH_2}CH_3$).

Anal. Calcd for $C_7H_{12}O$: C, 74.95; H, 10.78. Found: C, 75.09; H, 10.87.

The 2,4-dinitrophenylhydrazone derivative had mp 120.5–121°.

Anal. Calcd for $C_{13}H_{16}N_4O_4$: C, 53.42; H, 5.52; N, 19.17. Found: C, 53.17; H, 5.47; N, 19.23.

Cyclopropyl Isopropyl Ketone (14).[42]—Ketone **14** was isolated from the pyrolysates of **13** and was identified by the following data: ir (CCl_4) 3.24 (cyclopropyl CH), 5.88 (C═O), 7.20 7.33 μ (>$C(CH_3)_2$); nmr δ^{CCl_4} 0.56–1.02 (m, 4, cyclopropyl CH_2), 1.13 (d, 6, J = 7 Hz, $CH(\mathbf{CH_3})_2$), 1.68–21.6 (m, 1, cyclopropyl methine), 2.45–2.99 (q, 1, J = 7 Hz, degenerate $\mathbf{CH}(CH_3)_2$).

Anal. Calcd for $C_7H_{12}O$: C, 74.95; H, 10.78. Found: C, 74.85; H, 10.65.

The 2,4-dinitrophenylhydrazone derivative had mp 183° (sharply);

Anal. Calcd for $C_{13}H_{16}N_4O_4$: C, 53.42; H, 5.52; N, 19.17. Found: C, 53.25; H, 5.51; N, 19.22.

Cyclopentanone (6).[34]—Cyclopentanone was recovered in 96% yield from the pyrolysate[55] of cyclopentanone and was produced in 48% yield by pyrolysis[55] of α-carbethoxycyclopentanone (**5**). The compound was identified with a commercial sample by comparison of glpc retention times, ir and nmr spectra, and mixture melting point of the 2,4-dinitrophenylhydrazone derivatives. No cyclopentenone was observed in either pyrolysate.[18]

3-Cyclopropanecarbonyl-6-cyclopropyl-2*H*-pyran-2,4(3*H*)-dione (10b).—This dehydroacetic acid analog was obtained by pyrolysis of **1a** at 760 mm. The keto ester was carried through the hot tube by stream of prepurified nitrogen (25 ml/min). Part of the pyrolysate solidified and, upon filtration and recrystallization (ethanol), afforded a white solid, mp 66–66.5°, in 20% yield. This material gave a positive ferric chloride test: ir (CCl_4) 3.24 (cyclopropyl CH), 5.82, 6.16, 6.52, 10.19 μ; uv $\lambda_{max}^{C_2H_5OH}$ 319 nm (ϵ 14,200), 233.5 (13,500); $\lambda_{max}^{C_2H_5OH,\ pH\ 12}$ 298 nm (ϵ 15,200), 232 (20,200);[56] nmr δ^{CDCl_3} 0.94–1.37 (m, 8, cyclopropyl CH_2), 1.56–2.05 (m, 2, cyclopropyl methine), 3.29–3.80 (dd, 1, J = 2.7 Hz, vinyl H), 5.99 (s, 1, enolic H).

Anal. Calcd for $C_{12}H_{12}O_4$: C, 65.45; H, 5.49. Found: C, 65.39; H, 5.43.

Pyrandione **10b** was also prepared in 80% yield by passing 39.2 g (0.25 mol) of keto ester **1a**, on a stream of prepurified nitrogen at 1 atm, over a 6-in. segment of pumice[27] at 400°. The pyrolysate was distilled under reduced pressure giving 11.7 g (29.8%) of unreacted **1a** and 15.2 g (55.5%) of **10b**, bp 125–126° (0.05 mm), which solidified upon cooling, mp 65–66°. This material was identified with the above sample by comparison of ir spectra.

Gases.—Carbon monoxide, carbon dioxide, and ethylene were identified in the untrapped pyrolysis product stream (1–3 mm) by comparison of glpc retention times with those of commercial samples. A 6 ft × 0.25 in. column packed with Porapak Q at room temperature was used for these analyses in a Gow-Mac, Model 69–100, thermal conductivity instrument. A gas sample volume of 7.5 ml was used.

Registry No.—**1a** methyl ester, 32249-35-7; **1a** ethyl ester, 24922-02-9; **1b,** 32249-37-9; **1b** thiouracil derivative, 32249-38-0; **1c,** 21741-37-7; **1c** thiouracil derivative, 32249-40-4; **1d,** 32249-41-5; **1d** thiouracil derivative, 32249-42-6; **2a,** 930-30-3; **2b,** 2758-18-1; **2c,** 1120-73-6; **2d,** 1121-05-7; **3d,** 25111-31-3; **3d** 2,4-DNPH, 32249-48-2; **10b,** 32249-49-3; **13,** 32249-50-6; **14,** 6704-20-7; **14** 2,4-DNPH, 32304-06-6.

Acknowledgments.—We gratefully acknowledge the support of Public Health Service Research Grant NIH ROI-AM11226 and of Queens College General Research Support Grant NIH 5-S05-FR-07064-03. The authors are also grateful to Professor N. L. Goldman of Queens College for useful discussions.

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[55] The pyrolysis was done at 575° (1–3 mm) with glass wool packing.

[56] Dehydroacetic acid: $\lambda_{max}^{95\%\ C_2H_5OH}$ 310 nm (ϵ 11,200); $\lambda_{max}^{C_2H_5OH,\ pH\ 12}$ 294 nm (ϵ 8150) [J. A. Berson, W. M. Jones, and L. F. O'Callaghan, *J. Amer Chem. Soc.*, **78**, 622 (1956)].

Nuclear Magnetic Resonance Spectroscopy. Proton Spectra of 2-Pyridones[1a]

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The proton magnetic resonance spectra of 2-pyridone, 1-methyl-2-pyridone, and 1-(2′-pyridyl)-2-pyridone in deuteriochloroform solution were recorded at 100 and 220 MHz. A computer-assisted analysis of these spectra yielded the chemical shifts and consistent sets of coupling constants. Some regularities in the effects of structure and concentration on the chemical shifts were observed. The spectra of 2-pyridone in deuterium oxide and benzene-d_6 were briefly explored.

The purpose of this study was to complete and refine the existing pmr data of 2-pyridone (**1**) and 1-methyl-2-pyridone (**2**) and to determine the spectral parameters of 1-(2′-pyridyl)-2-pyridone (**3**).[2] It is now commonly assumed[3] that the 2-pyridone, usually written as **1a**, is the predominant species in a tautomeric equilibrium with 2-hydroxypyridine (**1c**). Compounds **2** and **3** can only exist in the lactam form, represented as the resonance hybrid **1a** and **1b**. The numbering used in all tables and discussions is as shown in these structures. The spectral analysis of **3** was of interest because it possesses both the 2-pyridone ring (A) and the pyridine ring (B) as an aromatic N substituent.

Assuming fast chemical exchange for the N-H proton, the ring protons of 2-pyridone represent an asymmetric four-spin system whose pmr spectrum is characterized by four chemical shifts and six coupling constants. The 60-MHz spectra of other 2-substituted pyridines have been analyzed rigorously as ABCD and, sometimes to a good approximation, as ABKL and AA′KL systems.[4]

The 100-MHz and 220-MHz spectra discussed in this paper approximate ABKX types but were treated as

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[1] (a) Supported by the National Science Foundation. (b) On leave from Youngstown State University.

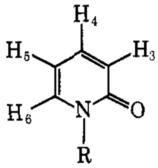
[2] (a) K. Takeda, K. Hamamoto, and H. Tone, *J. Pharm. Soc. Jap.*, **72**, 1427 (1952); *Chem. Abstr.*, **47**, 8071 (1953). (b) F. Ramirez and P. W. von Ostwalden, *J. Amer. Chem. Soc.*, **81**, 156 (1959).

[3] See, *e.g.*, A. Albert, "Heterocyclic Chemistry," 2nd ed, Athlone Press, London, 1968, p 92.

[4] V. J. Kowalewski and D. G. de Kowalewski, *J. Chem. Phys.*, **37**, 2603 (1962).

TABLE I

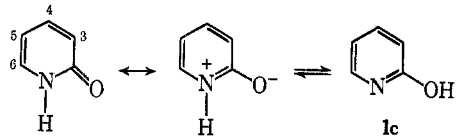
SPECTRAL PARAMETERS OF 2-PYRIDONE AND N-SUBSTITUTED 2-PYRIDONES[a,b]



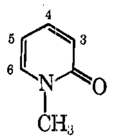
	2-Pyridone (R = H)		1-Methyl-2-pyridone (R = CH$_3$)		1-(2′-Pyridyl)-2-pyridone, ring A (R = C$_5$H$_4$N),
	c, d	e	f	g	h
ν_{H_3C-N}			3.59	3.59	
ν_5	6.30	6.4	6.17	6.15	6.29
ν_3	6.60	6.7	6.57	6.57	6.63
ν_4	7.49	7.7	7.34	7.26	7.38
ν_6	7.41	7.8	7.32	7.31	7.86
ν_{H-N}	13.65	11.43			
J_{34}	9.15 ± 0.05[i]	~10	9.12 ± 0.05		9.11 ± 0.05[i]
J_{35}	1.02	<1	1.38		1.29
J_{36}	0.70	0	0.70		0.71
J_{45}	6.64	~7	6.66		6.52
J_{46}	2.07	~2	2.07		2.03
J_{56}	6.46	~7	6.67		6.79

[a] Chemical shifts, in δ (parts per million). [b] Coupling constants, J (hertz). [c] 0.5 M in CDCl$_3$. [d] Chemical shifts of 2-pyridone, $\nu_6 = 7.53$, $\nu_3 = 6.62$, $\nu_5 = 6.59$; shifts in C$_6$D$_6$ (0.2 M); $\nu_5 = 5.47$. [e] Brügel,[10] 30% in DMSO. [f] 0.65 M in CDCl$_3$. [g] Elvidge and Jackman,[6] 5% in CDCl$_3$. [h] 1.2 M in CDCl$_3$. [i] In a few cases, analysis of the 100-MHz spectrum of the ±0.05 range: 2-pyridone, $J_{35} = 1.16$; 1-(2′-pyridyl)-2-pyridone, 8.15, $J_{4'5'} = 7.47$ (*cf.* Table II).

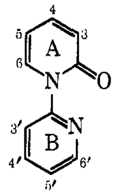
ABCD systems. Theory predicts for such systems 56 possible transitions,[5] 24 of which are combination bands of weak intensity, leaving 32 observable lines to be expected. Most of these lines (27 in the case of 2-pyridone) could be observed.



1a **1b** **1c**



2



3

The 56.4-MHz spectrum of 1-methyl-2-pyridone (**2**) as a 5% solution in deuteriochloroform had first been studied by Elvidge and Jackman[6] who, with the aid of an empirical equation and the proton line positions in pyridine and several lutidines, assigned the chemical shifts in Table I. The main features of the spectrum, aside from the high-field singlet due to the *N*-methyl protons, were a triplet at δ 6.15 ppm assigned to ring proton H-5, a doublet at 6.57 assigned to H-3, and a complex band at 7.3 due to H-4 and H-6. In this multiplet, the lowest field chemical shift (δ 7.31 ppm) was assigned to H-6, and the shift difference $\nu_6 - \nu_4$ amounted to 0.05 ppm. Other authors have confirmed these assignments,[7] studied the chemical shift of the *N*-methyl group in different solvents,[8] and calculated the ring-current contributions to the chemical shifts.[9] No coupling constants were reported.

The proton spectrum of 2-pyridone (**1**) as a 30% solution in dimethyl sulfoxide was reported by Brügel[10] who, with less detailed reasoning, made shift assignments for the ring protons in analogy to those proposed earlier by Elvidge and Jackman[6] for 1-methyl-2-pyridone. The N-H proton signal was found to be a broad peak at δ 11.4 ppm, and an approximate set of coupling constants, included in Table I, was reported.

Experimental Section

Practical grade 2(1*H*)-pyridone (Matheson Coleman and Bell) was recrystallized twice from benzene-cyclohexane using decolorizing carbon and dried *in vacuo*, mp 107-108°. 1-Methyl-2-pyridone (Aldrich) was dried over sodium hydroxide and distilled *in vacuo*, bp 60-62° (~1 torr). The clear distillate, when kept under nitrogen in the refrigerator, remained colorless for longer than a week. 1-(2′-Pyridyl-2-pyridone was prepared from 2-bromopyridine and pyridine *N*-oxide in toluene as solvent,[2b] and recrystallized twice from hexane-petroleum ether, mp 53-55°.

The pmr spectra were taken of solutions in deuteriochloroform containing 1% TMS ("Silanor C," Merck Sharp and Dohme). Those at 220 MHz were recorded on a Varian HR-220 spectrometer at a probe temperature of ~18°; all line positions were measured relative to TMS as internal standard. Similarly, the 100-MHz spectra[11] were obtained on a Varian HA-100 instrument at a probe temperature of ~28°.

Results and Discussion

Considering only the ring proton signals, both the 100-MHz and 220-MHz spectra of 2-pyridone (**1**) and 1-methyl-2-pyridone (**2**) as well as of 1-(2′-pyridyl)-

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(5) J. W. Emsley, J. Feeney, and L. H. Sutcliffe, "High Resolution Nuclear Magnetic Resonance Spectroscopy," Pergamon Press, Vol. 1, 1956, p 425.

(6) J. A. Elvidge and L. M. Jackman, *J. Chem. Soc.*, 859 (1961).

(7) D. W. Turner, *J. Chem. Soc.*, 847 (1962).

(8) J. S. N. Ma and E. W. Warnoff, *Can. J. Chem.*, **43**, 1849 (1965).

(9) G. G. Hall, A. Hardisson, and L. M. Jackman, *Tetrahedron*, **19**, Suppl. 2, 101 (1963).

(10) W. Brügel, *Z. Elektrochem.*, **66**, 159 (1962); the reported chemical-shift data refer to water as external standard with $\nu_{TMS} = 5.23$ ppm.

(11) We are grateful for the help in recording these spectra from Dr. P. W. Sprague, California State College at San Bernardino.

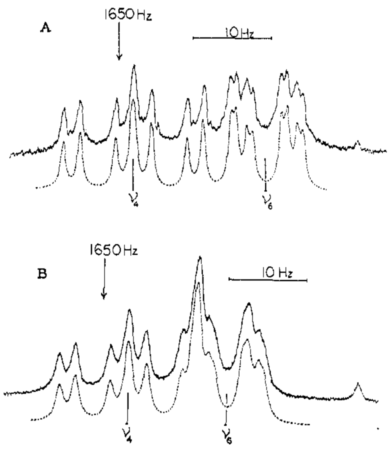

Figure 1.—Experimental and calculated 220-MHz spectra of 2-pyridone. Multiplet C: A, 0.5 *M;* B, 2.2 *M*. In this and the other figures, the solid lines are the experimental spectra recorded in $CDCl_3$ solution at 50-Hz sweep width; the dashed lines are calculated spectra based on the parameters given in Tables I and II. The reference point on each experimental spectrum is downfield from TMS.

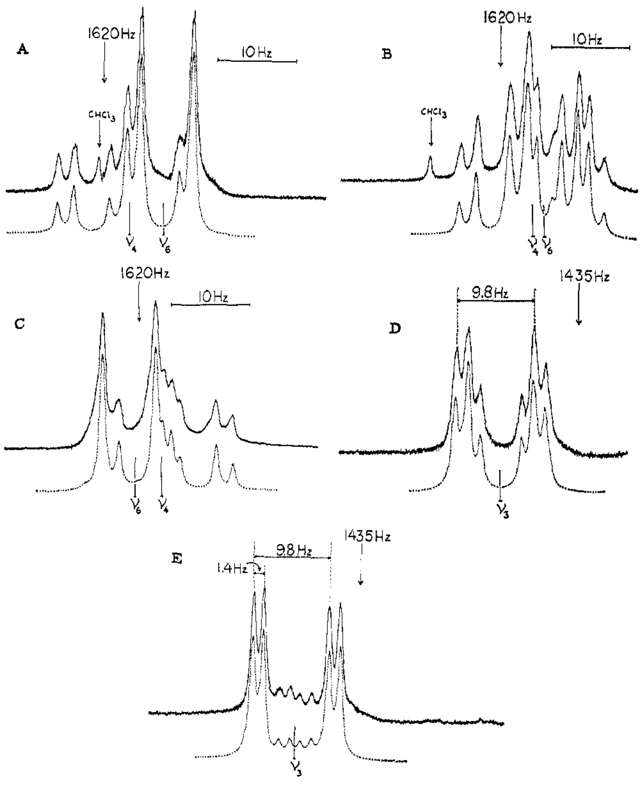

Figure 2.—Experimental and calculated 220-MHz spectra of 1-methyl-2-pyridone. Multiplet C: A, 0.65 *M;* B, 0.9 *M;* C, 1.3 *M*. Doublet B: D, 0.65 *M;* E, 0.9 *M*.

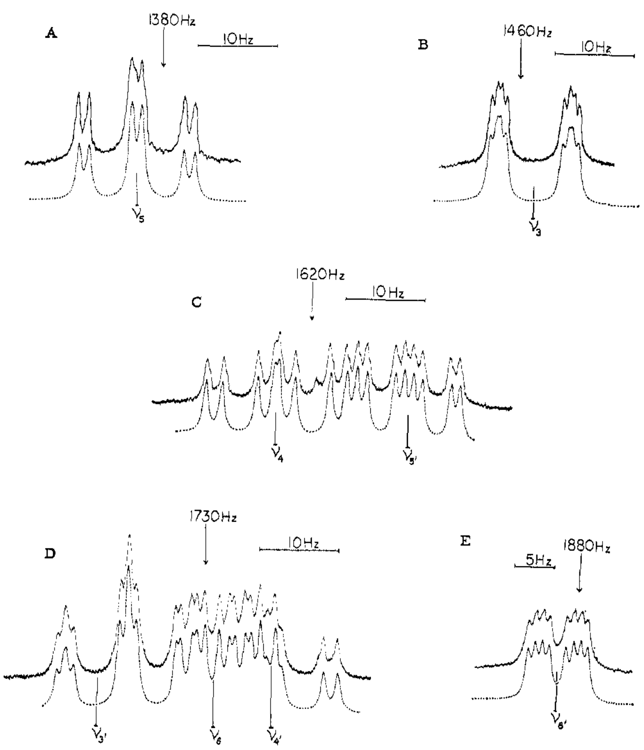

Figure 3.—Experimental and calculated 220-MHz spectra of 1-(2′-pyridyl)-2-pyridone (1.2 *M*): A, triplet A; B, doublet B; C, multiplet C; D, multiplet D; E, doublet E.

2-pyridone (**3**) show the distinctive features mentioned above, namely a low field multiplet (C) at $\delta \sim 7.5$ ppm, a higher field doublet (B) at ~ 6.6, and a triplet (A) at ~ 6.3. These have different fine structures for each compound. In addition to these signals, the 1-(2′-pyridyl)-2-pyridone (**3**) spectrum shows a second multiplet (D) at $\delta \sim 7.9$ ppm and another, lowest field doublet (E) at ~ 8.5. All parts of the 220-MHz spectrum of 1-(2′-pyridyl)-2-pyridone and representative examples of the spectra of 2-pyridone and 1-methyl-2-pyridone are shown in Figures 1–3. Also shown are the calculated spectra resulting from iterative fitting of the experimental line positions using the program LAOCN3,[12] modified to include CalComp plotting and plot accumulation. The root mean square errors in the overall fitting were in the range of 0.03–0.06 Hz.

In the interpretation of these spectra, the assumption was made that there is essentially no coupling between the ring protons of the 2-pyridone ring and the N–H, $N–CH_3$, or $N–C_5H_4N$ protons. Simple first-order analysis was partly applicable, but several of the spectral parameters could only be found by computer analysis. The coupling constants were estimated from the 220-MHz spectra, except for J_{34} and J_{36} in the case of 1-methyl-2-pyridone,[13] then refined in the iterative procedure, and finally confirmed by fitting the 100-MHz spectra. A summary of the parameters for **1**, **2**, and **3** is presented in Tables I and II.

As for the assignment of the chemical shifts of the pyridone ring protons, the doublet B and the triplet A were assigned to H-3 and H-5, respectively, in accord with the literature.[6,10] Inspection and computer simulation of multiplet C of 2-pyridone (Figure 1) revealed that the lowest field signal[14] pertains to H-4 and the slightly higher field doublet of quartets, featuring line spacings of 0.7 Hz, to H-6. This order of shifts is opposite to that reported by Brügel[10] for more concentrated solutions in dimethyl sulfoxide. However, a decrease in the shift difference $\nu_4 - \nu_6$ is observed with an increase in concentration from 0.5 to 2.2 *M* (Table III).

[12] A. A. Bothner-By and S. M. Castellano, "Computer Programs for Chemistry," Vol. 1, D. F. DeTar, Ed., New York, N. Y., W. A. Benjamin, Inc., 1968, p 10.

[13] In the doublet B (H-3 signal) of **2** (Figure 2D and 2E), there is a frequency (9.8 Hz) corresponding to the sum of J_{34} and J_{36}. This appears to be a case of "virtual coupling:" J. J. Musher and E. J. Corey, *Tetrahedron*, **18**, 791 (1962).

[14] The center of this signal is the center of a quartet of doublets with the two centermost lines merged to produce an apparent triplet, and its upfield portion obscured by the H-6 signal in the more concentrated solutions.

TABLE II

SPECTRAL PARAMETERS OF RING B OF 1-(2′-PYRIDYL)-2-PYRIDONE AND OF 2-AMINOPYRIDINE[a,b]

1-(2′-Pyridyl)-2-pyridone (ring B)	c, d	2-Aminopyridine	e
		ν_{NH_2}	6.21
$\nu_{5'}$	7.31	ν_5	6.60
$\nu_{4'}$	7.83	ν_4	7.44
$\nu_{3'}$	7.92	ν_3	6.70
$\nu_{6'}$	8.56	ν_6	8.11
$J_{3'4'}$	7.94 ± 0.05	J_{34}	8.3
$J_{3'5'}$	1.01	J_{35}	1.8
$J_{3'6'}$	0.88	J_{36}	1.0
$J_{4'5'}$	7.27	J_{45}	6.9
$J_{4'6'}$	1.86	J_{46}	1.7
$J_{5'6'}$	4.81	J_{56}	5.0

[a] Chemical shifts, in δ (parts per million). [b] Coupling constants, J (hertz). [c] 1.2 M in $CDCl_3$. [d] These shifts, except $\nu_{3'}$ and $\nu_{4'}$ which are at somewhat lower fields, and the coupling constants also fall within the usual range for the corresponding quantities in pyridine; see J. R. Dyer, "Applications of Absorption Spectroscopy of Organic Compounds," Prentice Hall, Inc., Englewood Cliffs, N. J., 1965, pp 89, 99. [e] Brügel,[10] 30% in DMSO.

TABLE III

EFFECT OF STRUCTURE AND CONCENTRATION ON THE CHEMICAL SHIFTS AT 220 MHz OF H-4 AND H-6 IN 2-PYRIDONES

Compound	Concn, mol/l.	ν_4[a]	ν_6[a]	$\nu_4 - \nu_6$, Hz
2-Pyridone	2.2	1646	1634	+12.3
	1.2	1648	1633	+14.5
	0.5	1648	1631	+16.8
1-Methyl-2-pyridone	1.3	1617	1620	−3.4
	0.9	1615	1614	+1.4
	0.65	1615	1611	+4.0
1-(2′-Pyridyl)-2-pyridone	1.2	1624	1729	−104.7

[a] Rounded values.

Computer simulation of the multiplet (C) of 1-methyl-2-pyridone (**2**) (Figure 2) showed that, in 0.65 M solution, the lower field signal again is to be attributed to H-4, contrary to what has been reported for the 56.4-MHz spectrum.[6] The shift difference is small ($\nu_4 - \nu_6 \sim 4$ Hz), however, and in more concentrated solutions (1.3 M) the order is inverted and the lowest field signal is due to H-6 (Figure 2C and Table III).[15]

The downfield half of multiplet C at 220 MHz of 1-(2′-pyridyl)-2-pyridone (**3**) (Figure 3C) resembled the corresponding portion of the 2-pyridone spectrum; hence, this was assumed to be the H-4 signal. The upfield portion of this multiplet was different in appearance and was attributed to H-5′ of ring B because (a) the analogously situated H-5 in 2-aminopyridine has the highest field chemical shift (Table II) and (b) there is a similarity in the chemical environments of H-5 ring A which has highest field chemical shift, and H-5′ of ring B (both are meta to their respective ring nitrogens and para to >C═O or ⩾C—N<, respectively). The 22-line lower field multiplet (D) (Figure 3D) of **3**, known by integration to correspond to three protons, featured a prominent doublet of triplets on the downfield side. Because of the resemblance of this signal to the signal of H-3 (doublet B) of the 2-pyridones and, again, the analogous environment of H-3 and H-3′ in **3**, this signal was assigned to H-3′. Inspection of the remaining 16 peaks reveals that there is a quartet of doublets with a line spacing of 0.7 Hz in each doublet as expected for H-6 of ring A. The downfield shift of this signal, compared with that of 2-pyridone, is thought to be caused by the ring current of the neighboring pyridine ring B; H-6 is situated in the deshielding zone extending around ring B. Another quartet of doublets, interspaced with the H-6 signal, was assigned to H-4′ by exclusion. The lowest field doublet of quartets (E) in the spectrum of 1-(2′-pyridyl)-2-pyridone (Figure 3E) is a prominent feature in the 220-MHz as well as in the 100- and 60-MHz spectra of this compound. In analogy to the assignments for 2-aminopyridine[10,16] this lowest field signal is attributed to H-6′ of ring B. Table II summarizes the chemical shifts and coupling constants for the protons of ring B together with literature values of 2-aminopyridine for comparison.

The concentration effects on the shift difference $\nu_4 - \nu_6$, which have been mentioned above, are documented in more detail in Table III. Small changes in this shift difference produced pronounced changes in the appearance of the spectra, especially of multiplet C. It is likely that **1** is already so highly associated by hydrogen bonding at the concentration used, that ν_6 (which is most sensitive to concentration) is changed only by 3 Hz when the concentration is changed by a factor of more than four. In contrast, ν_6 for **2** changes by 9 Hz when the concentration is doubled, indicating that its degree of association (not, of course, involving hydrogen bonding) is changing more rapidly in the concentration range studied.

The spectra of 2-pyridone show pronounced solvent effects which were explored to some degree. The analysis of the deuteriochloroform solution 100-MHz spectrum led to a shift difference $\nu_4 - \nu_6$ of 5.9 Hz (0.06 ppm) and spectral parameters generally in good agreement with those listed in Table I. The iterative fitting of the acetone-d_6 solution spectrum, on the other hand, yielded a value of −0.6 Hz for $\nu_4 - \nu_6$, indicating that in this solvent the two chemical-shift positions have interchanged and the H-6 resonance is at the low field end. The chemical shifts observed, but not computer analyzed, in deuterium oxide and benzene-d_6, are presented in footnote *d* of Table I. Again, we fixed the H-6 resonance at the lowest field in the case of the benzene-d_6 solution.

Registry No.—**1**, 142-08-5; **2**, 694-85-9; **3**, 3480-65-7.

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(15) A peak at δ 7.30–7.40 ppm often appeared in the multiplets (C) of 2-pyridone and 1-methyl-2-pyridone (*cf.* Figure 2) which arose from the ordinary chloroform present in the deuteriochloroform. In the solvent itself, this peak was found at δ 7.27 ppm.

(16) "High-Resolution NMR Spectra Catalogue," Varian Associates, Vol. 2, 1963, Spectrum No. 431.