Table IV. Comparison of Some M-M Distances (Å) and Torsion Angles (deg) in $M_2(RNXNR)_4$ Molecules (R = C_6H_5, p-$CH_3C_6H_4$; X = N, CH, CC_6H_5)

M_2^{4+}	PhNCPhNPh	(tol)NCH-N(tol)	(tol)NNN(tol)	PhNNNPh
Ru_2^{4+}			2.417 (2)[a]	
Rh_2^{4+}	2.389[b]	2.4336 (4)[c]		
	17.3	16.7		
Pd_2^{4+}		2.622 (3)[d]		2.563 (1)[e]
		15		15

[a] This work. [b] Le, J. C.; Chavan, M. Y.; Chau, L. K.; Bear, J. L.; Kadish, K. M. *J. Am. Chem. Soc.* **1985**, *107*, 7195. No esd given. [c] Piraino, P.; Bruno, G.; Lo Schiavo, S.; Laschi, F.; Zanello, P. *Inorg. Chem.* **1987**, *26*, 2205. [d] Cotton, F. A.; Matusz, M.; Poli, R.; Feng, X. *J. Am. Chem. Soc.* **1988**, *110*, 1144. [e] Corbett, M.; Hoskins, B. F.; McLeod, N. J.; O'Day, B. P. *Aust. J. Chem.* **1975**, *28*, 2377.

this conclusion in two ways. The eclipsed configuration indicates that a net δ bond is present. In all comparable structures (see Table IV) where the δ^* orbital must contain two electrons, thus abolishing the δ bond, there are torsion angles of ca. 16°.

The Ru-Ru bond length is also in excellent accord with the $\sigma^2\pi^4\delta^2\pi^{*4}$ configuration. For $Ru_2(O_2CR)_4^+$ species with three unpaired electrons, the configuration must be $\sigma^2\pi^4\delta^2(\pi^*\delta^*)^3$, where we have case II, $E(\pi^*) \approx E(\delta^*)$.[9] In these compounds there are two π^* electrons, and the Ru-Ru distances are about 2.26 Å. The very much larger distance in $Ru_2[(tol)NNN(tol)]_4$, 2.417 (2) Å, is in accord with the addition of another two strongly antibonding π^* electrons. The concomitant loss of one very weakly antibonding δ^* electron is comparatively negligible. Since the $Ru_2(O_2CR)_4L_2$ compounds[3] all have magnetic moments of ca. 2.9 μ_B, indicating two unpaired electrons, they must have either $\delta^{*2}\pi^{*2}$ or $\pi^{*3}\delta^*$ configurations. From the fact that their Ru-Ru distances[4] are virtually the same as those of the $Ru_2(O_2CR)_4^+$ species, the former would seem to be indicated. Finally, as shown in Table IV, when the similarity of the Ru-Ru distance in $Ru_2[(tol)NNN(tol)]_4$ to the Rh-Rh distances in similar Rh_2^{4+} species (where both the π^* and δ^* orbitals must be filled) is taken into consideration, the case for a π^{*4} configuration is supported. It is also seen in Table IV that the further addition of two σ^* electrons (as in the Pd_2^{4+} species) again causes a sizeable increase in the M-M distance.

Our results and conclusions are in excellent accord with the theoretical and photoelectron spectroscopic studies[10] recently reported for $Rh_2[(tol)NCHN(tol)]_4$. This molecule has two more electrons than our $Ru_2[(tol)NNN(tol)]_4$, and the calculation, supported by the measured UV-PES, assigns them to an orbital of b_{1u} symmetry that is primarily a δ^* (Rh-Rh) orbital. This orbital (the HOMO) lies about 8000 cm^{-1} above the π^* orbital. Thus, if we were to deduce the electron configuration of $Ru_2[(tol)NNN(tol)]_4$ from that established for $Rh_2[(tol)NCHN(tol)]_4$ by removing two electrons (which seems an eminently reasonable thing to do), we should arrive at the $\sigma^2\pi^4\delta^2\pi^{*4}$ configuration, which is exactly the one indicated directly by experimental data for $Ru_2[(tol)NNN(tol)]_4$. The similarity of the Ru-Ru and Rh-Rh distances in these two compounds shows that the δ^* orbital is not a major factor in determining M-M bond strength. The major result of losing the two δ^* electrons is the reestablishment of a net δ bond, and this imposes an eclipsed configuration in $Ru_2[(tol)NNN(tol)]_4$ instead of the twisted one (16.7°) found in $Rh_2[(tol)NCHN(tol)]_4$.

Another important result given by the calculations on the rhodium compounds[10] is that the large (ca. 1 eV) separation of the δ^* and π^* orbitals in the $Rh_2(RNCHNR)_4$ type compound is in sharp contrast to the small (<0.1 eV) difference in $Rh_2(O_2CH)_4$. Again when the Rh_2^{4+} compound minus two electrons is used as a model for the corresponding Ru_2^{4+} compound, it is clear that for $Ru_2(O_2CR)_4$ compounds the presence of two unpaired electrons is to be expected. We note once again that the large decrease in the Ru-Ru distance on going from $Ru_2[(tol)NNN(tol)]_4$ to $Ru_2(O_2CR)_4L_2$ compounds, viz., 2.42-2.26 = 0.16 Å, leads us to prefer a $\delta^{*2}\pi^{*2}$ configuration rather than a $\pi^{*3}\delta^*$ configuration for the carboxylates.

Acknowledgment. This work was supported by the National Science Foundation.

Supplementary Material Available: Full listings of bond distances, bond angles, and anisotropic displacement parameters (B's) (4 pages); table of observed and calculated structure factors (8 pages). Ordering information is given on any current masthead page.

(9) For the most detailed study of the magnetic properties, see: Cotton, F. A.; Pedersen, E. *Inorg. Chem.* **1975**, *14*, 388. For detailed spectroscopic information, see: Miskowski, V. M.; Loehr, T. M.; Gray, H. B. *Inorg. Chem.* **1987**, *26*, 1098.

(10) Rizzi, G. A.; Casarin, M.; Tondello, E.; Piraino, P.; Granozzi, G. *Inorg. Chem.* **1987**, *26*, 3406.

An Unusually Facile Formation of Substituted 1,2-Dihydropyridine Derivatives: The Reversible Condensation of Pyridines with Reactive Carbonyl Groups

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Abstract: Temperature-variable spectroscopic examination (^1H and ^{13}C NMR and IR) of the reaction of pyridine with a number of acid halides and anhydrides indicates the reversible formation of novel 2-pyridinyl-1,2-dihydropyridine structures (**1**). The structure results from a nucleophilic attack at the ortho position of the transient 1:1 pyridinium adduct. The reaction is observed to be general for 3- and 4-substituted pyridines. The formation of structures analogous to **1** are favored by electron-withdrawing groups substituted on either the pyridine or carbonyl. Electron-donating substituents favor the production of the simple 1:1 pyridinium salts. The 3-substituted pyridines produce the corresponding 6-addition product (2:1 pyridine–carbonyl).

Interest in a fundamental understanding of the interrelationship of pyridinium–dihydropyridine chemistry continues to be an area of considerable experimental and theoretical effort.[1] Such activity is particularly acute in research directed toward the study of

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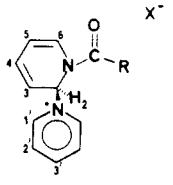
biologically important nicotinamide derivatives[1b,2] and the preparation of enamides.[3] Although the chemical literature is replete with examples of dihydropyridine syntheses starting from the corresponding pyridines, none is reversible without the aid of some secondary agent.[1b,e,4] We report here the first example of the reversible, regiospecific formation of 2-dihydropyridinylpyridinium salts (2-DHPP, structure **1**) from 3- and 4-substituted pyridines under extremely mild conditions.



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Experimental Section

Instruments. Nuclear magnetic resonance spectra were taken on either a Varian XL 200 (^{1}H spectra) or a Varian XL 300 (^{13}C spectra) spectrometer. Chemical shifts were measured relative to tetramethylsilane (TMS). The temperature range examined in all cases was between 20 and −90 °C. The samples were monitored at 10 ± 0.1 °C increments within this temperature range.

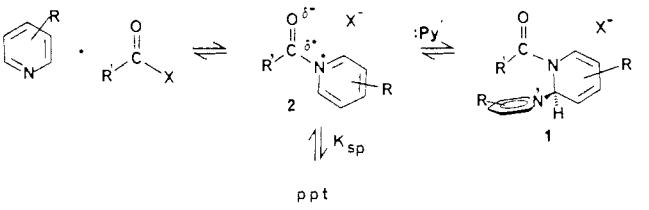
The infrared work was performed an a Nicolet 7199 FTIR spectrometer with an MCT (HgCdTe) detector. The system was outfitted with a Class II Imw HeNe laser and a Nicolet IR-80 data processor. The data were taken at a 1 wavelength resolution. A total of 256 scans were acquired prior to transformation, and the resulting spectra were plotted without smoothing or using a baseline correction routine. The variable temperature IR cell was a SPECAC P/N 21.000 low-temperature solution cell containing 0.1-mm AgCl windows. All nonvariable temperature infrared measurements were made with a Perkin-Elmer Model 598 IR spectrometer. The samples were observed at 20, −20, −50, and −70 °C; all measurements were made with an accuracy of ±2 °C.

Materials. All the pyridines and acid halides used in these experiments, except for the 3-(trimethylsilyl)pyridine, 3-phenylpyridine and 3-(*tert*-butyldimethylsiloxy)pyridine, were purchased from Aldrich. All reagents were purified by distillation prior to their use.

The 3-(trimethylsilyl)pyridine and 3-phenylpyridine were donated by Professor D. L. Comins and Dr. E. F. V. Scriven, respectively. The 3-(*tert*-butyldimethylsiloxy)pyridine was prepared by the condensation of *tert*-butyldimethylsilyl chloride with 3-hydroxypyridine (3-pyridinol).[5c]

Solution Methods. The purified pyridines and acid halides were combined stoichiometrically by using standard syringe techniques. All solution manipulations were carried out under a nitrogen atmosphere in a Vacuum Atmospheres' Model HE-43-2 Dri-Lab glovebox. The reagents were initially combined at room temperature with either methylene chloride-d_2 or acetonitrile-d_3 as solvents. The concentration range of pyridinium salts studied was from 0.005 to 0.70 M. In all cases, the pyridine:carbonyl ratios were varied between 1:1 and 2:1 in order to verify the stoichiometric dependence of the observed structures as well as their equilibrium constants.

Scheme I[a]



[a] R = H, methyl, ethyl, phenyl, 4-*tert*-butyl, 3-trimethylsilyl, 3-*tert*-butyldimethylsiloxy; R′ = C_6F_5, *m,p*-$NO_2C_6H_4$, *m,p*-$CF_3C_6H_4$, C_6H_5, *m,p*-NCC_6H_4, CCl_3, CF_3; X = Cl, Br, $C_2O_2Cl_3$, $C_2O_2F_3$.

Results and Discussion

In the course of studies directed toward a detailed mechanistic understanding of carbonyl activation via pyridinium salt formation, we had occasion to prepare a number of species derived from the condensation of 3- and 4-substituted pyridines with various acid halides, carbamoyl halides, and anhydrides. Consistent with earlier observations, no net reaction was detectable spectroscopically[5] when these functional groups were reacted with pyridine in aprotic, nonpolar media at ambient temperatures.[6] These results are in distinct contrast to those observed for similar reactions in an aqueous environment.[7] It was hoped that by appending electron-withdrawing groups to the carbonyl moiety, pyridinium salt formation might be induced (structural type **2**), allowing for the study of such species in nonpolar media. Furthermore, monitoring these systems through the use of temperature-variable NMR techniques would allow any temperature-dependent equilibria and/or structural changes to be determined readily.

To our surprise, rather than enhance the simple onium salt formation, the inclusion of electron-withdrawing groups induce a remarkable second nucleophilic addition of an equivalent of the starting pyridine to the α-position of the transient pyridinium ion (**2**). This second addition generates the corresponding 2-DHPP adduct (**1**) shown in Scheme I.

This novel transformation is both reversible and quite general. The displacement of equilibrium favors the components at ambient temperatures, while structures analogous to **1** are the dominant species below −50 °C in methylene chloride-d_2. No degradation of material is detectable on cycling the solution temperature between −90 °C and room temperature; the DHPP adducts do exhibit slow degradation on exposure to air. The efficiency and facility with which this nucleophilic addition takes place is rather phenomenal considering the 19 kcal mol^{-1} of resonance energy postulated to be lost on formation of a dihydropyridine moiety (DHP) from its corresponding pyridine.[1c,f,8] The generation of structural type **1**, we believe, results from a large charge–dipole destabilization effect induced upon formation of the 1:1 pyridinium

(1) See, for example, the following reviews: (a) Eisner, U.; Kutan, J. *Chem. Rev.* **1972**, *72*, 1. (b) Stout, D. M.; Meyers, A. I. *Chem. Rev.* **1982**, *82*, 223. (c) Bunting, J. W. In *Adv. Heterocycl. Chem.* **1979**, *25*, 42. (d) Keay, J. G. *Adv. Heterocycl. Chem.* **1986**, *39*, 1. (e) Kröhnke, F. *Angew. Chem.* **1953**, *65*, 605. (f) Dewar, M. J. S.; Gleicher, G. J. *J. Chem. Phys.* **1966**, *44*, 759.

(2) (a) Bunting, J. W.; Bolton, J. L. *Tetrahedron* **1986**, *42*, 1007. (b) Ohno, A.; Kashiwagi, M.; Ishihara, Y.; Ushida, S.; Oka, S. *Ibid.* **1986**, *42*, 961. (c) Verhoeven, J. W.; Gerresheim, W. v.; Martens, F. M.; Kerk, S. M. v. d. *Ibid.* **1986**, *42*, 975. (d) Kok, P. M. T. d.; Donkersloot, M. C. A.; Lier, P. M. v.; Meulendijks, G. H. W. M..; Bastiaansen, L. A. M.; Hooff, H. J. G. v.; Kanters, J. A.; Buck, H. M. *Ibid.* **1986**, *42*, 941.

(3) (a) Krow, G. R.; Henz, K. J.; Szczepanski, S. W. *J. Org. Chem.* **1985**, *50*, 1888. (b) Campbell, A. L.; Lenz, G. R. *Synthesis* **1987**, 421. (c) Raucher, S.; Lawrence, R. F. *Tetrahedron Lett.* **1983**, *24*, 2927 and references therein.

(4) See, for example: (a) Comins, D. L.; Mantlo, N. B. *Tetrahedron Lett.* **1987**, *28*, 759. (b) Comins, D. L.; Abdullah, A. H. *J. Org. Chem.* **1982**, *47*, 4315. (c) Lyle, R. E. *Chem. Heterocycl. Compd.* **1974**, *14*, 137. (d) Sundberg, R. J.; Hamilton, G.; Trindle, C. *J. Org. Chem.* **1986**, *51*, 3672 and references therein.

(5) Site-specific broadening was observed occasionally in some of the NMR spectra, but the equilibrium distributions of all these structures were determined, by peak position, to favor the unassociated pyridines and carbonyl-containing compounds, at room temperature, as per earlier work: (a) Johnson, S. L.; Rumon, K. A. *J. Phys. Chem.* **1964**, *68*, 3149. (b) Höfle, G.; Steglich, W.; Vorbrüggen, H. *Angew. Chem., Int. Ed. Engl.* **1978**, *17*, 569. (c) King, J. A., Jr., manuscript in preparation.

(6) The solutions were monitored by IR, ^{1}H NMR, and/or ^{13}C NMR spectroscopy. The solvents used were either methylene chloride or chlorform. Occasionally acetonitrile was used for comparative purposes. These results were found to be valid for the less basic pyridines (aqueous pK_a's < 7) up to the solubility limit (K_{sp}) of their respective pyridinium salts in the chosen solvent.

(7) (a) Fersht, A. R.; Jencks, W. P. *J. Am. Chem. Soc.* **1969**, *91*, 2125. (b) Bond, P. M.; Castro, E. A.; Moodie, R. B. *J. Chem. Soc., Perkin Trans. 2* **1976**, 68. (c) Chrysiuk, E.; Williams, A. *J. Am. Chem. Soc.* **1987**, *109*, 3040. (d) Castro, C.; Castro, E. A. *J. Org. Chem.* **1981**, *46*, 2939. (e) Fersht, A. R.; Jencks, W. P. *J. Am. Chem. Soc.* **1970**, *92*, 5432.

(8) A factor that might promote this unique transformation could be a large charge–dipole destabilization effect; this would arise during the incipient onium ion formation developing adjacent to an electron-deficient carbonyl. Consistent with a charge–dipole destabilization effect is the observation that neither cyanide nor hydroxide (pseudobase) form stable addition products with simple N-alkylated pyridinium salts.[1] This type of interaction, coupled with other solvolytic electroconstrictive phenomena common to ion-forming reactions in nonpolar media (ion-pairing, aggregation, etc.) may be sufficient to explain our observations.

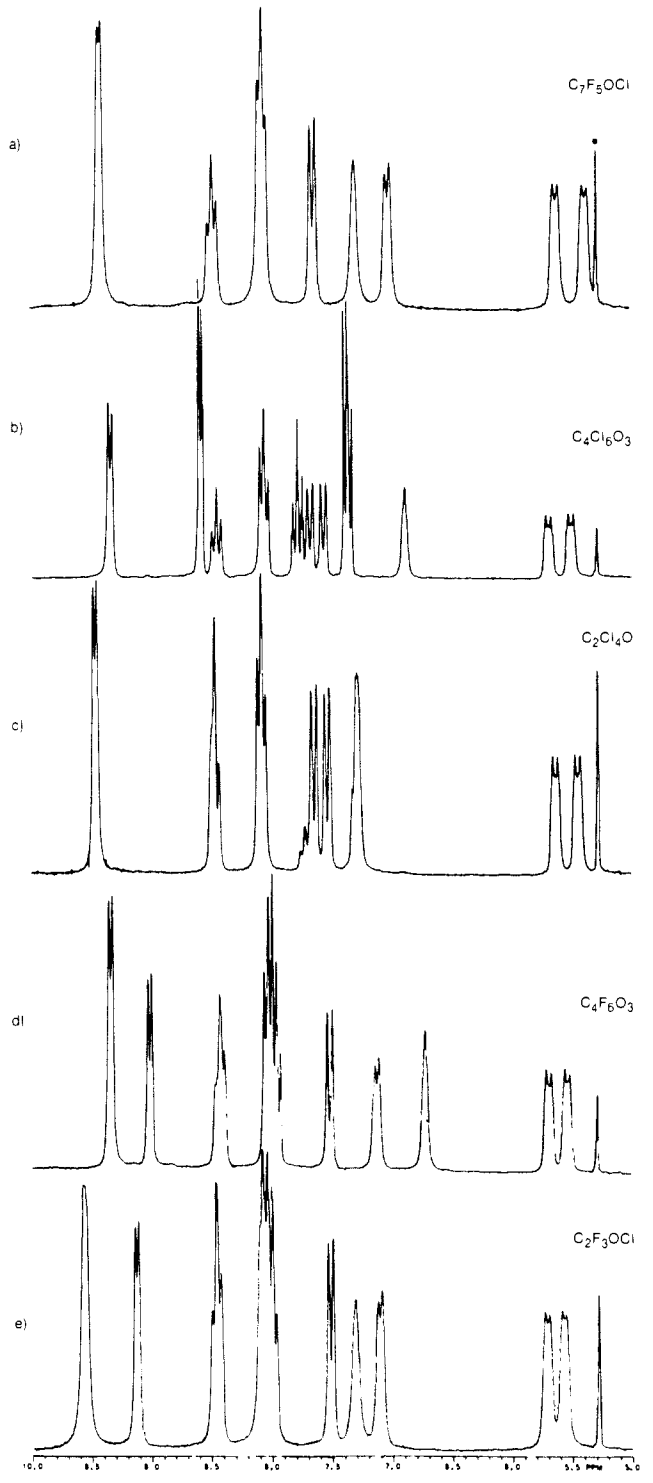


Figure 1. Low-temperature ^1H NMR spectra (200 MHz, CD_2Cl_2, −90 °C, 0.3 M) of the 2-DHPP adducts formed from the reaction of pyridine with (a) pentafluorobenzoyl chloride (**1a**), (b) trichloroacetic anhydride (**1b**), (c) trichloroacetyl chloride (**1c**), (d) trifluoroacetic anhydride (**1d**), and (e) trifluoroacetyl chloride (**1e**).

salt.

The presence of the 2-DHPP adducts can be discerned readily from their distinctive ^1H NMR spectra (Figure 1).[9] Figure 1a

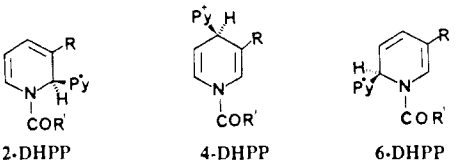


Figure 2.

shows the proton spectrum of the 2-DHPP adduct derived from pentafluorobenzoyl chloride (**1a**) with 2 equiv of pyridine. The 2-dihydropyridinyl ring exhibits two characteristic 3- andd 5-positional proton patterns at δ 5.63 and 5.38, respectively.[10] In general, the resonances for these two proton sites are observed in the region δ 5.2–5.8, with the 5-position resonance always occurring at higher field relative to that of the 3-position. The 2-, 4-, and 6-^1H resonances all appear at much lower field (δ 7.65, 7.32, and 7.02, respectively); their relative positions are observed to be dependent on both the group attached to the carbonyl as well as the gegenion.[11] The low-field resonances of the pyridinium moiety can be used as an indication of the formation of these structures.[12] The 2-DHPP adducts exhibit a unique peak by ^{13}C NMR spectroscopy in the region between 62 and 70 ppm.[10] This resonance corresponds to the point of attachment of the pyridinium nitrogen to the DHP ring and can be used as a signature for the formation of such species. Furthermore, variable-temperature solution IR spectroscopy shows a number of new carbonyl absorptions at 50–200 cm^{-1} lower energy relative to the unassociated carbonyl.[10] This shift to lower energy can be contrasted with

(9) All configurational assignments were verified by homonuclear proton–proton decoupling experiments (^1H {^1H}), and further by 2D-^1H:^{13}C HETCOR experiments when necessary. Attempted isolation of these materials by forced precipitation at low temperature gave amorphous solids. These solids were found to undergo a reversion to their individual component upon either warming to room temperature or on drying under vacuum at −90 °C. Precipitation (or crystallization) of the salts using either a less soluble or a less nucleophilic anion (such as BF_4^- or PF_6^-), proved fruitless in our hands.

(10) The sharp peak at approximately 5.26 ppm in Figure 1 is the residual $HCDCl_2$ resonance from the solvent. For examples of DHPP structural data derived form pyridine with, 1a: ^1H NMR (200 MHz, CD_2Cl_2) δ 5.38 (br d, J = 7.8 Hz, 1 H), 5.63 (br d, J = 8.6 Hz, 1 H), 7.02 (br d, J. = 7.8 Hz, 1 H), 7.32 (br s, 1 H), 7.65 (d, J = 8.6 Hz, 1 H), 8.06 (dd, J = 3.8, 2.6 Hz, 2 H), 8.48 (t, J = 3.8 Hz, 1 H), 9.42 (d, J = 2.6 Hz, 2 H); ^{13}C NMR (300 MHz, CD_2Cl_2, −90 °C) δ 63.51, 104.65, 106.56, 106.72 (t, J_{CF} = 18 Hz), 124.99, 127.66, 128.02, 137.15 (ddd, J_{CF} = 254.5, 14.0, 14.0 Hz), 142.60 (br d, J_{CF} = 246.9, 14 Hz), 142.78 (br d, J_{CF} = 246.9, 14 Hz), 142.95, 145.77, 155.51; IR (CH_2Cl_2, −70 °C) 1702 (m), 1692 (s), 1655 (m), 1628 (m) cm^{-1}. **1b**: ^1H NMR (200 MHz, CD_2Cl_2 −90 °C) δ 5.50 (br d, J = 8.8 Hz, 1 H), 5.69 (br d, J = 8.6 Hz, 1 H), 6.89 (br s, 1 H), 7.57 (d, J = 8.8 Hz, 1 H), 7.67 (d, J = 8.6 Hz, 1 H), 8.05 (t, J = 7.3 Hz, 2 H), 8.45 (dd, J = 6.2, 7.3 Hz, 1 H), 9.33 (d, J = 6.2 Hz); ^{13}C NMR (300 MHz, CD_2Cl_2, −90 °C) δ 65.93, 88.10, 90.10, 104.10, 107.27, 127.24, 127.77, 128.13, 143.32, 145.70, 151.25, 155.96. **1c**: ^1H NMR (200 MHz, CD_2Cl_2, −90 °C) δ 5.40 (br d, J = 8.7 Hz, 1 H), 5.59 (br d, J = 8.7 Hz, 1 H), 7.23 (br s, 1 H), 7.49 (d, J = 8.7 Hz, 1 H), 7.60 (d, J = 8.7 Hz, 1 H), 8.06 (dd, J = 6.1, 7.7 Hz, 2 H), 8.45 (t, J = 7.7 Hz, 1 H), 9.42 (d, J = 6.1 Hz, 2 H); ^{13}C NMR (300 MHz, CD_2Cl_2, −90 °C) δ 63.42, 91.10, 105.18, 108.27, 128.28, 128.77, 129.19, 144.19, 146.85, 157.03; IR (CH_2CL_2, −70 °C) 1711 (s) 1687 (s), 1626 (w) cm^{-1}. **1d**: ^1H NMR (200 MHz, CD_2Cl_2, −90 °C) δ 5.55 (br d, J = 7.7 Hz, 1 H), 5.71 (br d, J = 8.6 Hz, 1 H), 6.78 (br s, 1 H), 7.13 (br d, J = 7.7 Hz, 1 H), 7.55 (d, J = 8.6 Hz, 1 H), 8.02 (dd, J = 5.9, 7.2 Hz, 2 H), 8.43 (t, J = 7.2 Hz, 1 H), 9.33 (d, J = 5.9 Hz, 2 H); ^{13}C NMR (300 MHz, CD_2Cl_2, −90 °C) δ 63.02, 105.72, 107.59, 114.76 (q, J_{CF} = 289.2 Hz), 116.08 (q, J_{CF} = 292.7 Hz), 125.18, 126.89, 128.12, 143.45, 145.82, 148.81 (br), 152.72 (q, J_{CF} = 39.1 Hz); IR (CH_2Cl_2, −70 °C) 1780 (m), 1730 (s), 1668 (m) cm^{-1}. **1d** (pyridinium salt, **2**): ^1H NMR (200 MHz, CD_2Cl_2, −90 °C) δ 7.99 (dd, J = 6.1, 6.6 Hz, 2 H), 8.41 (t, J = 6.6 Hz, 1 H), 9.01 (d, J = 6.1 Hz, 2 H); ^{13}C NMR (300 MHz, CD_2Cl_2, −90 °C) δ 114.76 (q, J_{CF} = 289.2 Hz), 116.08 (q, J_{CF} = 292.7 Hz), 125.50, 140.68, 145.41, 148.81 (br), 152.72 (q, J_{CF} = 39.1 Hz). **1e**: ^1H NMR (200 MHz, CD_2Cl_2, −90 °C) δ 5.62 (br d, J = 7.2 Hz, 1 H), 5.76 (br d, J = 8.0 Hz, 1 H), 7.14 (br d, J = 7.2 Hz, 1 H), 7.36 (br s, 1 H), 7.55 (d, J = 8.0 Hz, 1 H), 8.07 (br, 2 H), 8.48 (t, J = 7.2 Hz, 1 H), 9.63 (br s, 2 H); ^{13}C NMR (300 MHz, CD_2Cl_2, −90 °C) δ 62.40, 106.15, 107.89, 114.67 (q, J_{CF} = 284.4 Hz), 125.11, 125.24, 128.02, 143.35, 145.76, 152.60 (q, J_{CF} = 39.3 Hz). **1e** (pyridinium salt, **2**): ^1H NMR (200 MHz, CD_2Cl_2, 90 °C) δ 7.98 (dd, J = 5.9, 7.2 Hz, 2 H), 8.46 (t, J = 7.2 Hz, 1 H), 9.13 (d, J = 5.9 Hz, 2 H); ^{13}C NMR (300 MHz, CD_2Cl_2, −90 °C) δ 114.67 (q, J_{CF} = 284.4 Hz), 126.40, 141.36, 145.32, 152.60 (q, J_{CF} = 39.3 Hz).

(11) Note the carbonyl functional pairs in Figure 1b,c (free pyridine is detectable) and in 1d,e, (the simple acyl pyridinium salt is present also). Within each pair, the carbonyl moiety attached to the dihydropyridine ring is identical, while the counterion is changed from the chloride to the corresponding acetate.

(12) There is a characteristic 0.9 ± 0.1 ppm shift to lower field, relative to the free pyridine, for each type of pyridinium proton upon onium salt formation. As expected for the DHPP salts, the pyridinium/dihydropyridine ratio by ^1H NMR integration is found to be 1:1. This ratio is observed to be invariant as a function of temperature.

simple acyl pyridinium salts, which exhibit a corresponding shift of 25–80 cm^{-1} to higher energy upon formation.[5a,b]

Substitution at the 3- or 4-position of the pyridine with electron-donating groups, diminished the tendency toward additional nucleophilic attack in favor of the simple pyridinium salt formation. This tendency was observed to correlate roughly with the basicity of the pyridine.[13] Simple alkyl substitution (methyl, ethyl, propyl, or butyl; pK_a's ≤ 6.5) readily exhibit diaddition products. The more basic pyridines (e.g. 4-dimethylamino; pK_a's ≥ 8) gave essentially exclusive formation of the 1:1 pyridinium salts (type **2**).[14] Conversely, electron-withdrawing substituents were observed to produce only species analogous to **1**.[15]

In the case of the 3-substituted pyridines, the addition of the second pyridine has the possibility of producing three regioisomers (Figure 2). Surprisingly, when either trichloroacetyl chloride (**1c**) or pentafluorobenzoyl chloride (1a) reacts with 3-substituted pyridines, only the 6-adduct is observed. The regiospecificity could be determined by examining the relative ratio of proton absorptions in the region between δ 5.2 and 5.8.[16] The NMR data did indicate the presence of two 6-DHPP conformers that do not interconvert on the NMR time scale. Furthermore, models indicate that, within these two conformers, the pyridinium and carbonyl moieties should be highly conjested.[17] Indeed, as a result, the proton and carbon NMR absorptions for the ortho positions on the pyridinium ring broaden as the temperature is decreased below −50 °C. A temperature-dependent study for the observed spectra give the following free energies of activation: 3-picoline with (a) trichloroacetyl chloride); $\Delta G^{\ddagger} = 9.2 \pm 0.4$ kcal mol^{-1}, (b) pentafluorobenzoyl chloride; $\Delta G^{\ddagger} = 8.9 \pm 0.3$ kcal mol^{-1}, (c) 3-ethylpyridine with trichloroacetyl chloride; $\Delta G^{\ddagger} = 9.0 \pm 0.3$ kcal mol^{-1}. To our knowledge, these constitute the first examples of an observable restricted rotation of a pyridinium group bound to an sp^3-hybridized carbon.

Conclusions

In conclusion, a facile, reversible, and regiospecific formation of novel dihydropyridinylpyridinium species has been demonstrated. Their formation is believed to result from a large charge–dipole destabilization effect between the pyridinium ring and the carbonyl moiety.[8] Furthermore, structures analogous to those discussed herein, may be common intermediates in a number of organic reactions involving pyridines. In particular, the "ortho effect", commonly observed in pyridine addition chemistry,[4] can readily be explained by invoking such sterically demanding intermediates.[18] Future work is oriented toward extension of this chemistry.

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(13) Basicity values were approximated from the listed aqueous pK_a's tabulated in: *Handbook of Tables for Organic Compound Identification*, 3rd ed.; Rappoport, Zvi, Ed.: CRC: Boca Raton, FL, 1967; p 436, Table XXIX.

(14) Pyridinoid bases, such as 4-(dimethylamino)pyridine, are sufficiently basic or resonance stabilized that DHPP formation could not be induced. The nonpolar solution equilibria for the simple pyridinium salts of this type and basicity were observed to be favored at ambient temperatures.

(15) Pyridines with pK_a values of less than ca. 4 gave no indication that any type of interaction was occurring with these carbonyls, under our reaction conditions. The more sterically demanding 2-substituted pyridines (ie. 2-methyl, -ethyl, or -chloro and 2,6-lutidines) also gave no sign of either simple pyridine or DHPP salt formation.

(16) The proton absorptions for the ring positions adjacent (α) to the appended pyridinium group are observed always to resonate at a lower field position compared to those of the transannular (γ) protons. These relative assignments were confirmed by both $^1H\langle^1H\rangle$ and 2D-^1H:^{13}C HETCOR experiments. The 3-substituents studied were the methyl, ethyl, phenyl, trimethylsilyl, and *tert*-butyldimethylsiloxy groups; the integrated ratios for these two resonances (with **1a**) were measured to be (low field:high field): 1:1.7, 1:2.4, 1:2.4, 1:3, and 1:10, respectively. The conclusion one reaches on examination of these ratios is that, as the substituent becomes more sterically demanding, addition to the 2-position is increasingly favored relative to 6-addition. The alternative analysis is that there are two conformational isomers generated upon addition to the 6-position. *Note*: At no time could we detect products indicative of addition to the 4-position. This alternative is further supported by 2D-^1H:^{13}C HETCOR analysis which indicate the site of pyridinium attachment, for each species, is adjacent a carbon bearing a hydrogen. The two conformers were not observed to intercovert on the NMR time scale in the temperature region where they are detectable (−50 to −90 °C).

(17) See: Krow, G. R.; Raghavachari, R.; Siatkowski, R.; Chodosh, D. F. *J. Org. Chem.* **1986**, *51*, 1916 for an example of a similarly structured but much less conjested 1,2-dihydropyridine compound.

(18) Currently, there is no clear-cut explanation for this effect. If the intermediacy of structures analogous to **1** are involved in systems exhibiting the "ortho effect", an initially formed 6-addition DHPP would convert the 2-position into the less demanding site. Subsequent nucleophilic addition at the 2-position, with concomitant release of the appended pyridine, would generate the observed materials. The final 2-/6- product ratios could then simply result from the "intended" nucleophiles' ability to competitively add to a pyridinium species (6-addition sterically preferred) versus a 6-DHPP derivative (2-addition sterically preferred). Although there is no electonic bias favoring either site,[4d] precoordination by the "intended" nucleophile may be important in determining the final product distribution. This analysis may only be applicable to the "ortho effect" under acylating conditions such as during Fowler reduction: e.g., Fowler, F. W. *J. Org. Chem.* **1972**, *37*, 1321. In the case of the "ortho effect" observed for N-alkylated or N-arylated pyridinium salts, trace amounts of nonalkylated pyridines may be responsible for producing similar intermediates. The possibility of multiple mechanistic pathways for these two reaction types must also be considered.