Investigation of Electronic Effects in the Reaction of Diazodiphenylmethane with Pyridine and Pyridine N-Oxide Carboxylic Acids

By Djordje M. Dimitrijević, Živorad D. Tadić, Milica M. Mišić-Vuković, and M. Muškatirović,* Department of Organic Chemistry, University of Beograd, Karnegijeva 4, 1100, Beograd, Yugoslavia

The empirical Hammett treatment has been applied to the investigation of structure–reactivity relationships for pyridine and pyridine N-oxide carboxylic acids in the reaction with diazodiphenylmethane. The values obtained for the pyridine aza-group (σ_2 0·878. σ_3 0·740. σ_4 1·105) are in good agreement with the literature values for the alkaline hydrolysis of the corresponding esters. For the N-oxide group. the σ values for the 3- and 4-positions (σ_3 1·312.σ_4 1·140) indicate that the overall effect is electron withdrawing. The negative value for the 2-position (σ_2 −0·395) can be explained on the basis of intramolecular hydrogen bonding. It is also shown that the Hammett relationship holds for pyridinecarboxylic acids with a fixed ortho-substituent as well.

THE reactivity of pyridine and pyridine N-oxide systems is of much interest in connection with the electronic effects operating in the ring. Numerous investigations, including electrophilic and nucleophilic substitution in the ring and reactivity of side chains, as well as the study of spectra and dipole moments, indicate the complexity of effects caused by nitrogen in the pyridine nucleus and even more so by the N-oxide function in pyridine N-oxide, which is both an electron donor and an electron acceptor.

The reaction of carboxylic acids with diazodiphenyl-methane (DDM) has been used by numerous authors for quantitative structure–reactivity studies.[1-5] The mechanism of this reaction, suggested by Roberts,[6] was later proved [1,7-10] to involve proton transfer from molecular acids to DDM in the rate-determining step. Therefore, in the transition state, there is partial breaking of the O–H bond, and the structural factors involved are closely related to those that govern the pK_a values of the acids.[11] Low activation energies for the reaction of carboxylic acids with DDM indicate the small influence of the approaching agent on the polarization of the molecule. In our opinion, the electronic effects which operate in the acid molecule in the transition state are very close to those operating in the ground state.

As one of the most convenient methods, the same reaction has been used as a measure of the effect of substituents on the reactivity of heterocyclic carboxylic

[1] R. A. More O'Ferrall, W. K. Kwok, and S. I. Miller, *J. Amer. Chem. Soc.*, 1964, **86**, 5553.

[2] K. Bowden, *Canad. J. Chem.*, 1966, **44**, 661; K. Bowden, M. Hardy, and D. C. Parkin, *ibid.*, 1968, **46**, 2929; K. Bowden, and D. C. Parkin, *ibid.*, p. 3909; 1969, **47**, 177, 185.

[3] Z. Lasocki and S. Piechucki, *Bull. Acad. Pol. Sci. Ser. Sci. Chim.*, 1967, **15** (10), 461.

[4] A. Buckley, N. B. Chapman, and J. Shorter, *J. Chem. Soc.* (B), 1969, 195; N. B. Chapman, J. R. Lee, and J. Shorter, *ibid.*, p. 769; N. B. Chapman, M. R. J. Dack, and J. Shorter, *ibid.*, 1971, 834.

[5] E. J. Grubbs, R. Fitzgerald, R. E. Phillips, and R. Petty, *Tetrahedron*, 1971, **27**, 935.

[6] J. D. Roberts and W. Watanabe, *J. Amer. Chem. Soc.*, 1950, **72**, 4869; J. D. Roberts, W. Watanabe, and R. E. McMahon, *ibid.*, 1951, **73**, 760, 2521.

[7] K. Bowden, A. Buckley, N. B. Chapman, and J. Shorter, *J. Chem. Soc.*, 1964, 3580.

[8] A. F. Diaz and S. Winstein, *J. Amer. Chem. Soc.*, 1966, **88**, 1318.

[9] D. Bethell and R. D. Howard, *Chem. Comm.*, 1966, 96.

[10] A. Buckley, N. B. Chapman, M. R. J. Dack, J. Shorter, and H. M. Wall, *J. Chem. Soc.* (B), 1968, 631.

[11] R. A. More O'Ferrall and S. I. Miller, *J. Amer. Chem. Soc.*, 1963, **85**, 2940; 1964, **86**, 4016.

acids.[12-14] The results of our previous investigation of the reaction of DDM with pyridine and pyridine N-oxide carboxylic acids, rechecked and recalculated (k_2 values at 30°), together with the results of our present work, are given in Table 1.

TABLE 1

Rate constants for the reaction of DDM with pyridine and pyridine N-oxide carboxylic acids

	k_2/l mol^{-1} min^{-1}				E_A/ kcal mol^{-1}
Acid	20°	30°	40°	50°	
Pyridine-2-carboxylic acid	3·54	7·3	10·5	17·5	10·6
Pyridine-3-carboxylic acid	3·08	5·4	8·9	14·8	10·7
Pyridine-4-carboxylic acid	4·75	11·9	13·2	22·2	10·1
2-Carboxypyridine N-oxide	0·001	0·465	1·96	1·58	28·8
3-Carboxypyridine N-oxide	13·1	19·1	27·9	40·5	7·5
4-Carboxypyridine N-oxide	7·7	12·9	21·0	33·0	9·7

A crucial point for the applicability of the DDM reaction to the investigation of compounds which can exist as zwitterions is their state in the solutions used. Specifically for pyridinecarboxylic acids, study of u.v. spectra showed that no dissociation occurs in 95% ethanol and consequently no zwitterions can be formed.[15]

The work of Jaffé and Doak [16] and Jaffé [17] on the basicities of substituted pyridines and pyridine N-oxides, u.v. spectra, and tautomeric equilibria indicate that zwitterions are practically non-existent in water and 50% ethanol solutions of 3- and 4-carboxypyridine N-oxides.

Product analysis of the reaction of equimolar amounts of 3-carboxypyridine N-oxide with DDM proved that it is the undissociated acid which reacts. Microanalysis and i.r. data showed that the main product is the benzhydryl ester, and also some benzhydryl ethyl ether (see Experimental section). Therefore, it is certain that in absolute ethanol pyridine and pyridine N-oxide carboxylic acids exist in the neutral form.

In this paper, on the basis of rate constants determined at 30°, considering nitrogen as a ring substituent in benzene, Hammett σ values for the ring nitrogen in 2-, 3-, and 4-substituted pyridines and pyridine N-oxides

have been calculated. The application of the Hammett equation to the reactivity of pyridine and pyridine N-oxide compounds has already been reported by several authors [15,16,18-22] (for reviews see refs. 23—25). The most compatible results for pyridine derivatives were obtained using alkaline hydrolysis of substituted pyridinecarboxylates [22] while other values vary widely with the type of reaction used.[25] The pyridine N-oxides have been investigated to a much lesser extent using different methods.[17,20,26]

The results of our calculations using the values ρ 0·937 and log k_0 0·039 (from ref. 27), for the same experimental conditions (EtOH; 30°), are given in Table 2. Our values are in rather poor agreement with the mean values calculated by Blanch,[25] based on the reactions of 11 series of pyridine derivatives. We believe that the validity of these mean values is questionable owing to the fact that eight out of 11 reactions whose results were incorporated, were the ionizations of species whose state under the experimental conditions was uncertain.

TABLE 2

σ Values for reaction of DDM with pyridine and pyridine N-oxide carboxylic acids

Substituent	σ_2	σ_3	σ_4	$\sigma_4 - \sigma_3$
$-N=$	0·878	0·740	1·105	0·365
$N^+ - O^-$	$-0·395$	1·312	1·140	$-0·172$

Our values for the constants for the pyridine azagroup are in good agreement with the values for corresponding ester hydrolyses obtained by different authors (Table 3). The positive σ values for the $-N=$ ' substituent ' are in agreement with the known electron-withdrawing ability of the pyridine ring. The alternating values of these constants, which are the sum of inductive and resonance components, show that in this case the last one predominates. It is considered that inductive effects almost entirely determine the σ value in the 3-position,[28] although it includes the resonance component relayed to carbons in the 2- and 4-positions by intranuclear resonance. If we assume that the contribution of the inductive effect in the value σ_4 is equal to σ_3, although it is slightly larger in the 3-position, owing to the proximity of the ring nitrogen, then the difference $\sigma_4 - \sigma_3$ could be considered as a semi-

[12] D. M. Dimitrijević, Ž. D. Tadić, and M. D. Muškatirović Glasnik Hem. društva Beograd, 1962, 27, 397; 1963, 28, 83; Ž. D. Tadić, M. M. Mišić, and D. M. Dimitrijević, ibid., 1962, 27, 407.

[13] W. K. Kwok, R. A. More O'Ferrall, and S. I. Miller, Tetrahedron, 1964, 20, 1913.

[14] K. Bowden and D. C. Parkin, Canad. J. Chem., 1966, 44, 1493.

[15] H. P. Stephenson and H. Spooner, J. Amer. Chem. Soc., 1957, 79, 2050.

[16] H. H. Jaffé and G. O. Doak, J. Amer. Chem. Soc., 1955, 77, 4441.

[17] H. H. Jaffé, J. Amer. Chem. Soc., 1955, 77, 4445, 4451; J. Org. Chem., 1958, 23, 1790.

[18] R. C. Elderfield and M. Siegel, J. Amer. Chem. Soc., 1951, 73, 5622.

[19] P. R. Falkner and D. Harrison, J. Chem. Soc., 1960, 1171.

[20] A. R. Katritzky, C. R. Palmer, F. J. Swinbourne, T. T. Tidwell, and R. D. Topsom, J. Amer. Chem. Soc., 1969, 91, 636.

[21] A. D. Campbell, S. Y. Chooi, L. W. Deady, and R. A. Shanks, J. Chem. Soc. (B), 1970, 1063; A. D. Campbell, E. Chan, S. Y. Chooi, L. W. Deady, and R. A. Shanks, ibid., p., 1068.

[22] A. D. Campbell, S. Y. Chooi, L. W. Deady, and R. A. Shanks, Austral. J. Chem., 1970, 23, 203.

[23] H. H. Jaffé, Chem. Rev., 1953, 53, 191.

[24] H. H. Jaffé and H. L. Jones, Adv. Heterocyclic Chem., 1964, 3, 209.

[25] J. H. Blanch, J. Chem. Soc. (B), 1966, 937.

[26] J. H. Nelson, R. G. Garvey, and R. O. Ragsdale, J. Heterocyclic Chem., 1967, 4, 591.

[27] J. D. Roberts, E. A. McElhill, and R. Armstrong, J. Amer. Chem. Soc., 1949, 71, 2923.

[28] K. B. Wiberg, ' Physical Organic Chemistry,' Wiley, New York, 1964, p. 289.

quantitative measure [29] of the resonance effect in the 4-position. Its positive value (Table 2) points out the predominance of electron-acceptor resonance structures in 4-substituted pyridine derivatives.

Owing to the possibility of hydrogen-bond type interactions, the values of σ_2 based on the ionization of pyridine derivatives must be considered unreliable.[18,19,25] We believe that except for alkaline hydrolysis of alkyl

value for compound (I) must be attributed to steric hindrance to hydrogen bonding. All limitations expressed for the σ_2 constant for the 2-carboxypyridine N-oxide also hold here.

An intramolecular hydrogen bond between the 2-carboxy and N-oxide groups could also explain the extremely high σ value for 2,6-dicarboxypyridine N-oxide (III). Analysis of the products from the reaction

TABLE 3

Hydrolysis of alkyl pyridinecarboxylates

Alkyl group	Solvent	Temp. (°C)	σ_2	σ_3	σ_4	Ref.
Ethyl 83·83%	EtOH–H$_2$O (w/w)	30	0·81	0·62	0·93	23
Ethyl 85%	EtOH–H$_2$O (w/w)	25	0·77	0·64		a
Methyl 85%	MeOH–H$_2$O (w/w)	25	0·75	0·65	0·96	22

a Y. Otsuji, Y. Koda, M. Furukawa, and E. Imoto, Nippon Kagaku Zasshi, 1959, 80, 1293 (Chem. Abs., 1961, 55, 6476).

pyridinecarboxylates, the DDM reaction is the only one which makes the estimation of σ_2 possible.

For the N-oxide group positive σ values for the 3- and 4-positions indicate that its overall effect is electron withdrawing. However, if we try to separate the polar and resonance components of this effect using the same approximation as for the $-N=$ ' substituent,' taking $\sigma_4 - \sigma_3$ as a semiquantitative measure of the contribution of the resonance component, the value obtained is negative. This means that direct electron-release conjugation of the N-oxide group, ring, and the carboxy-group is operative in this case. This is particularly facilitated by the low polarity of the solvent used in our experiments.

The negative value for σ_2 cannot be explained on the basis of electronic effects. Electron-releasing conjugation which could be the reason for it, should also cause a negative value for σ_4, which is evidently not the case. This type of conjugation of the pyridine N-oxide nucleus with a 2-substituent was previously shown to be improbable, on the basis of spectroscopic data.[19] Therefore the unexpected value for σ_2 is most probably due to intramolecular hydrogen bonding between the carboxy and N-oxide groups which has already been suggested on the basis of i.r. data.[30] Since this type of interaction does not fit the Hammett relationship, the value for σ_2 has to be accepted as a semiquantitative measure of the electronic effect of the N-oxide group specifically for 2-carboxypyridine N-oxide. If the idea of the intramolecular hydrogen bond is correct, steric hindrance of the coplanarity of carboxy-group and the nucleus, as a prerequisite for hydrogen bond formation, should strongly affect the magnitude of the rate constant. The difference in the Hammett constants for compounds (I) and (II) in Table 4 (calculated on the basis of rate constants with DDM in ethanol at 30°) indicates the existence of a hydrogen bond.

The polar substituent effects in the ortho- and para-position being approximately the same,[29] the far greater

of the acid (III) with DDM showed that only one of the carboxy-groups reacted, giving the monobenzhydryl

TABLE 4

Hammett constants for compound (I)—(III)

Acid	$k_2/$ l mol^{-1} min^{-1}	σ
2-Carboxy-3-methoxycarbonyl-pyridine N-oxide (I)	39·6	1·465 *
2-Carboxy-5-methoxycarbonyl-pyridine N-oxide (II)	2·94	0·450
2,6-Dicarboxypyridine N-oxide (III)	55·6	1·820

* Calculated on the basis of ρ 1·078.

ester. Therefore, the value of the σ_2 constant for 2,6-dicarboxypyridine N-oxide is a consequence of the strong polar effect of positively charged ring nitrogen due to hydrogen bond formation (structure A).
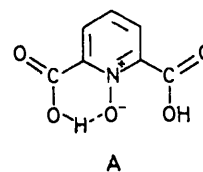

A

Table 5 gives the values for log k_2 for the reaction of DDM with o-methoxycarbonylpyridinecarboxylic acids, which, together with the σ values for the $-N=$ ' substituent' in the 2-, 3-, and 4-positions, were used to calculate the reaction constant ρ for the reaction of o-methoxycarbonylpyridinecarboxylic acids with DDM in absolute ethanol at 30°. The value of ρ (1·078) calculated by the least squares method (Figure) was already used for the calculation of one σ constant in Table 4. The linearity of this plot proves that the Hammett equation holds for pyridinecarboxylic acids

[29] R. W. Taft, ' Steric Effects in Organic Chemistry,' ed. M. S. Newman, Wiley, New York, 1958, ch. 13.

[30] A. R. Katritzky and J. M. Lagowski, ' Chemistry of the Heterocyclic N-Oxides,' Academic Press, London, 1971, pp. 10, 377.

with a fixed *ortho*-substituent. It also proves the assumption that ring nitrogen can be considered as a substituent in the benzene ring, about which certain doubts have been expressed.[19,24]
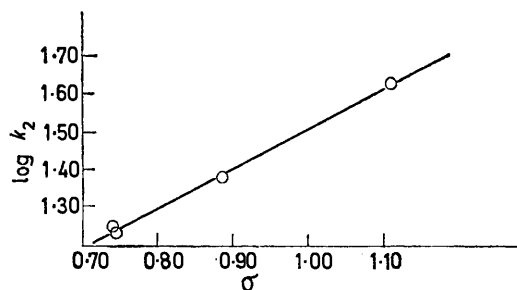
Plot of σ against log k_2 for the reaction of DDM with *o*-methoxycarbonylpyridinecarboxylic acids

The σ values given in Table 5 were calculated using Hammett's equation and the values ρ 1·078 and log k_0

TABLE 5

Hammett constants for the reaction of DDM with *o*-methoxycarbonylpyridinecarboxylic acids

Acid	k_2	log k_2	σ	$\sigma - \sigma_N$
3-Methoxycarbonyl-pyridine-2-carboxylic acid	24·2	1·381	1·265	0·387
2-Methoxycarbonyl-pyridine-3-carboxylic acid	17·1	1·233	1·128	0·388
4-Methoxycarbonyl-pyridine-3-carboxylic acid	17·3	1·238	1·133	0·393
3-Methoxycarbonyl-pyridine-4-carboxylic acid	42·6	1·630	1·495	0·417

0·017 measured for benzoic acid.[27] These values are the sum of the substituent constants for *o*-methoxycarbonyl and $-N=$ ' substituents ' in the 2-, 3-, and 4-positions. The values in the last column obtained by subtracting the σ values for the $-N=$ ' substituent ' stand for the net effect of the *o*-methoxycarbonyl group. Almost identical values for the 2- and 3-positions and good agreement for the 4-position show that this effect is independent of the position of the carboxy-group. The somewhat larger effect of the *o*-methoxycarbonyl group on a 4-carboxy-group probably indicates steric inhibition of direct conjugation between the nitrogen atom and the carboxy-group. This effect was also mentioned as possible in ref. 15.

The *o*-methoxycarbonyl group affects 2- and 3-carboxy-groups almost identically. Therefore, qualitatively, the same effects influence the reactivity of carboxy-groups in both positions. In our opinion this verifies the magnitude of σ_2 (Table 2) as a measure of the

electronic effects in the 2-position of the pyridine nucleus.

An analogous attempt to calculate ρ for the corresponding *N*-oxides, from the data given in Table 6, had to be

TABLE 6

Hammett constants for the reaction of DDM with *ortho*-disubstituted pyridine *N*-oxides

Acid	k_2	log k_2	σ	$\sigma - \sigma_{NO}$
2-Carboxy-3-methoxy-carbonylpyridine *N*-oxide	39·6	1·598	1·465	1·860
3-Carboxy-2-methoxy-carbonylpyridine *N*-oxide	47·5	1·677	1·540	0·228
3-Carboxy-4-methoxy-carbonylpyridine *N*-oxide	49·5	1·695	1·562	0·250
4-Carboxy-3-methoxy-carbonylpyridine *N*-oxide	44·0	1·643	1·505	0·365

abandoned since the value of σ_2 due to hydrogen bonding could not be used. The remaining three values were insufficient for a reliable plot.

EXPERIMENTAL

Rate Measurements.—Second order rate constants k_2 for the reaction of pyridine and pyridine *N*-oxide carboxylic acids with DDM were determined by the spectroscopic method, proposed by Roberts and his co-workers, using a Unicam SP 600 spectrophotometer.[6,27] Optical density measurements were performed at 525 nm with 1 cm cells in absolute ethanol at 30°, for the calculation of the rate constants. Measurements at three other temperatures were also performed (Table 1) for the determination of activation energies. The concentration of both acid and DDM was 0·006M in all experiments.

Materials.—Diazodiphenylmethane was prepared by the method of ref. 31 and was recrystallized from absolute methanol. Stock solutions (*ca.* 0·06M) were stored in a refrigerator and diluted for use. Absolute ethanol was prepared by known procedures. Pyridinemonocarboxylic acids were commercial samples from Koch–Light, and after recrystallization from suitable solvents had the following m.p.s: 2-, 133—135°; 3-, 230—231°; 4-, 315—317°. 2-Methoxycarbonylpyridine-3-carboxylic acid, m.p. 122° (lit., 123°), 3-methoxycarbonylpyridine-2-carboxylic acid, m.p. 106°, 3-methoxycarbonylpyridine-4-carboxylic acid, m.p. 182°, and 4-methoxycarbonylpyridine-3-carboxylic acid, m.p. 172°, were prepared according to methods proposed by Kirpal.[32] 2-,[33] 4-,[34] and 4-Carboxypyridine *N*-oxides [35] were prepared by the action of peracetic acid on the corresponding pyridinemonocarboxylic acids. The m.p.s were 161, 249, and 266° respectively. 2,6-Dicarboxy-pyridine *N*-oxide was commercial (Fluka) and after recrystallization from water and ethanol had m.p. 160°.

2-Carboxy-5-methoxycarbonylpyridine N-oxide. This was synthesized by the method of ref. 36 and after recrystalliz-ation from water–ethanol had m.p. 162° (lit.,[36] 151°)

[31] L. I. Smith and K. L. Howard, *Org. Synth.*, Coll. Vol. III, 1955, p. 351.

[32] A. Kirpal, *Monatsh*, 1899, **20**, 766; 1900, **21**, 439; 1906, **27**, 363; 1907, **28**, 439.

[33] O. Diels and K. Alder, *Annalen*, 1933, **505**, 103.

[34] G. R. Clemo and H. Koenig, *J. Chem. Soc.*, 1949, 231.

[35] E. Ghigi, *Ber.*, 1942, **75**, 1318.

[36] M. L. Peterson, *J. Org. Chem.*, 1960, **25**, 565.

Found: C, 48·5; H, 3·4; N, 7·1. Calc. for C₈H₇NO₅: C, 48·7; H, 3·55; N, 7·15%).

2-Carboxy-3-methoxycarbonylpyridine N-*oxide.* This was synthesized by the method proposed for the synthesis of 2,3-dicarboxypyridine *N*-oxide by Bain and Saxton.[37] 3-Methoxycarbonylpyridine-2-carboxylic acid (0·5 g),[32] glacial acetic acid (4 ml), and hydrogen peroxide (2 ml) were mixed, the ester dissolved immediately, and the mixture was left at room temperature for 7 days. The mixture was then evaporated to dryness under vacuum without heating to avoid the very easy decarboxylation observed in previous experiments. The last traces of peracetic acid were removed by blowing air through the flask and storing it in a vacuum desiccator over KOH. Recrystallization from ethanol yielded *needles*, m.p. 110°, test for *N*-oxide group positive[38] (Found: C, 49·0; H, 3·7; N, 7·4%).

3-Carboxy-2-methoxycarbonylpyridine N-*oxide.* This was prepared by the standard method of Ochiai[39] from the corresponding pyridine derivative[32] and peracetic acid. Work-up gave *plates* (from methanol), m.p. 202—203°, test for *N*-oxide group positive[38] (Found: C, 48·5; H, 3·5; N, 6·85%). An identical sample was obtained by the partial hydrolysis (0·5N-KOH in methanol) of 2,3-bis-methoxycarbonylpyridine *N*-oxide.

2,3-Bismethoxycarbonylpyridine N-*oxide.* This was prepared by Ochiai's method[39] from the pyridine derivative and also by the action of diazomethane on the corresponding acid,[37] giving *crystals*, m.p. 140—141° (from methanol), test for *N*-oxide group positive[38] (Found: C, 51·3; H, 4·3; N, 6·55. C₉H₉NO₅ requires C, 51·15; H, 4·2; N, 6·65%).

3-Carboxy-4-methoxycarbonylpyridine N-*oxide.* This was prepared by the same procedure[39] from the acid[32] and peracetic acid, giving *needles* (from methanol), m.p. 204—205°, test for *N*-oxide group positive[38] (Found: C, 49·0; H, 3·7; N, 7·4%).

4-Carboxy-3-methoxycarbonylpyridine N-*oxide.* This was prepared as above[39] giving *needles*, m.p. 130—131° (decomp.) (from methanol), test for *N*-oxide group positive[38] (Found: C, 49·05; H, 3·55; N, 7·05%).

Benzhydryl Ester of 3-*Carboxypyridine* N-*Oxide.*—The reaction of equimolecular amounts of 3-carboxypyridine *N*-oxide and diazodiphenylmethane yielded two products, a solid substance whose analysis corresponded to the expected ester and an oily substance which did not contain nitrogen and whose i.r. spectrum corresponded to that of benzhydryl ethyl ether. The *benzhydryl ester* had m.p. 117° (from benzene–light petroleum), test for *N*-oxide group positive,[38] δ_{max.} (KBr) 1295 (N→O[40]) and 1720 cm⁻¹ (C=O[41]). The carboxy-band (3000—2500 cm⁻¹), noticeable in the spectrum of the acid, was completely absent (Found: C, 74·3; H, 4·4; N, 5·05. C₁₉H₁₅NO₃ requires C, 74·8; H, 4·9; N, 4·6%).

Monobenzhydryl Ester of 2,6-*Dicarboxypyridine* N-*Oxide.* —2,6-Dicarboxypyridine *N*-oxide (0·5 g) was dissolved in absolute ethanol (20 ml) and an excess of DDM solution (0·06M) was added slowly with mixing. A white fluffy precipitate formed immediately, with evolution of nitrogen. The *solid* was recrystallized from benzene–light petroleum (b.p. 40—70°), m.p. 146—148°, test for the *N*-oxide group positive.[38] The i.r. spectrum was similar to the spectrum of the corresponding monomethyl ester[42] and showed interesting characteristics, ν_{max.} 1235 and 1275 (N→O[43]) and 1750 cm⁻¹ (C=O[43]). There is also a weak band at 1700 cm⁻¹, probably due to C=O stretching of the remaining carboxylic group (Found: C, 68·7; H, 4·2; N, 4·55. C₂₀H₁₅NO₅ requires C, 68·75; H, 4·3; N, 4·0%).

[37] B. M. Bain and J. E. Saxton, *J. Chem. Soc.*, 1961, 5216.
[38] N. A. Coats and A. R. Katritzky, *J. Org. Chem.*, 1959, **24**, 1836.
[39] E. Ochiai, *J. Org. Chem.*, 1953, **18**, 534.
[40] A. R. Katritzky, J. A. T. Beard, and N. A. Coats, *J. Chem. Soc.*, 1959, 3680.
[41] A. R. Katritzky, A. M. Monro, J. A. T. Beard, D. P. Dearnaley, and N. J. Earl, *J. Chem. Soc.*, 1958, 2182.
[42] J. Kolarik, unpublished data.
[43] A. R. Katritzky and A. R. Hands, *J. Chem. Soc.*, 1958, 2195.