Intramolecular Nitrene Insertions into Aromatic and Heteroaromatic Rings. Part 8.[1] Flash Vacuum Pyrolysis of 2-Azidobenzylpyridines

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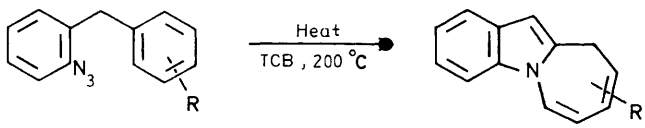
Flash vacuum pyrolysis of 2-azidobenzylpyridines (**9**)—(**11**) at temperatures from 350 to 700 °C gave mixtures of benzonaphthyridines and their dihydro derivatives as major products. The 3-pyridyl derivative (**10**) also gave 2-(3-cyanoprop-1-enyl)indole (**19**). Benzonaphthyridines were also obtained by pyrolysis of 2-aminophenyl(*x*-pyridyl)methanols (**4**), (**5**), and (**6**), [the 2-pyridyl derivative (**4**) also gave 2-aminobenzaldehyde and pyridine]. Treatment of the azides (**9**)—(**11**) with aluminium chloride gave the corresponding 2-amino-5-chlorobenzylpyridines (**21**)—(**23**). The mechanism of the reaction is discussed.

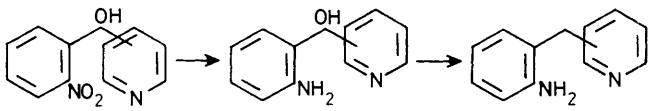
We have reported that 2-azidodiphenylmethanes (**1**) decompose in solution at 190—200 °C to give 10*H*-azepinoindoles (**2**) as major products.[1-3] When we attempted similar decompositions on 2-azidobenzylpyridines, no diazepinoindoles were obtained; indeed the major products appeared to be polymeric![1] We



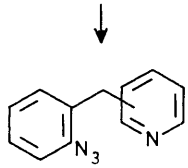
(**1**) (**2**)

reasoned that polymerisation would be inhibited under the conditions of flash vacuum pyrolysis (f.v.p.; vapour phase under low pressures). Preliminary experiments with 2-azidodiphenylmethane (**1**; R = H) showed a different pathway from the solution experiments;[4] we have now pyrolysed the three 2-azidobenzylpyridines (**9**)—(**11**) and we report below the results.

The synthesis of the 4- and 3-pyridyl derivatives (**9**) and (**10**) has been reported previously.[1] The 2-pyridyl derivative (**11**) has been prepared by a similar sequence. Reaction between 2-pyridyl-lithium and 2-nitrobenzaldehyde at −70 °C gave 2-nitrobenzyl(2-pyridyl)methanol (**3**), reduced catalytically to the amino alcohol (**4**); further reduction to the aminobenzylpyridine (**7**) required hydriodic acid. Diazotisation of amine (**7**) followed by treatment with buffered sodium azide solution gave



(**3**) 2-Pyridyl (**4**) 2-Pyridyl (**7**) 2-Pyridyl
(**5**) 4-Pyridyl (**8**) 4-Pyridyl
(**6**) 3-Pyridyl



(**9**) 4-Pyridyl
(**10**) 3-Pyridyl
(**11**) 2-Pyridyl

Table 1. Yields of products from decomposition of azide (**9**)[a]

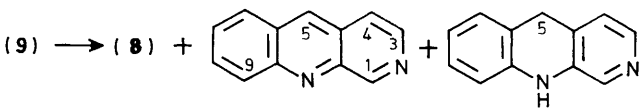
Temp. of tube (°C)	% (**8**)	% (**12**)	% (**13**)	Total % (**12**) + (**13**)
350	11	13	5	18
500	9	18	23	41
700	5	41	22	63

[a] Yields of pyrolysate were calculated by capillary g.c., using integration, with calibration using pure products.

the azide (**11**). The overall yield from 2-pyridyl-lithium was 20%, principally due to a poor (43%) yield in the first stage.

Decomposition Results

The apparatus used for flash vacuum pyrolysis was essentially that of Manley, Rees, and Storr,[5] with a vertical quartz tube (25 cm long, 17 mm inside diameter). Pressures were kept below 10^{-2} mmHg by adjusting the temperature of sublimation of the azide into the tube. Samples were collected on a cold finger (−70 °C), and analysed by n.m.r., then accurately by capillary g.c. Pure samples of products were obtained by separation on a Chromatotron. All azides were decomposed at three tube temperatures (350, 500, and 700 °C). Decomposition of 4-(2-azidobenzyl)pyridine (**9**) gave the same three products at each temperature, although in differing proportions. The yields are given in Table 1 and are discussed later but the overall yield at 700 °C was 63%. The first product eluted on g.c. was 4-(2-aminobenzyl)pyridine (**8**) the second was a benzonaphthyridine, and the third a dihydrobenzonaphthyridine. The predicted benzo[*b*][1,7]naphthyridine would have structure (**12**); this compound has not been reported previously. The ^{1}H n.m.r. spectrum of our product agree well with that calculated for compound (**12**) notably in the broadened singlet at δ 9.75 (1-H), the sharp singlet at δ 8.79 (5-H), the broadened doublet at δ 8.57 (3-H), and the broadened doublet at δ 8.34 (9-H). The dihydro derivative equally clearly had structure (**13**), the broadened



(**12**) (**13**) 5,5-^{1}H
(**14**) 5,5-^{2}H

singlet due to 1-H being upfield at δ 8.1, and the doublet due to 3-H being at δ 7.98; the methylene singlet was at δ 4.06.

The pyrolysis of 3-(2-azidobenzyl)pyridine (**10**) was less

Table 2. Yields of products from decomposition of azide (**10**)[a]

Temp. of tube (°C)	% (**15**)	% (**16**)	% (**17**)	% (**18**)	%(**19**)	Total % (**15**) + (**18**)
350	3	2	2	9	4	12
500	4	1	1	21	12	25
700	13	3	2	22	12	35

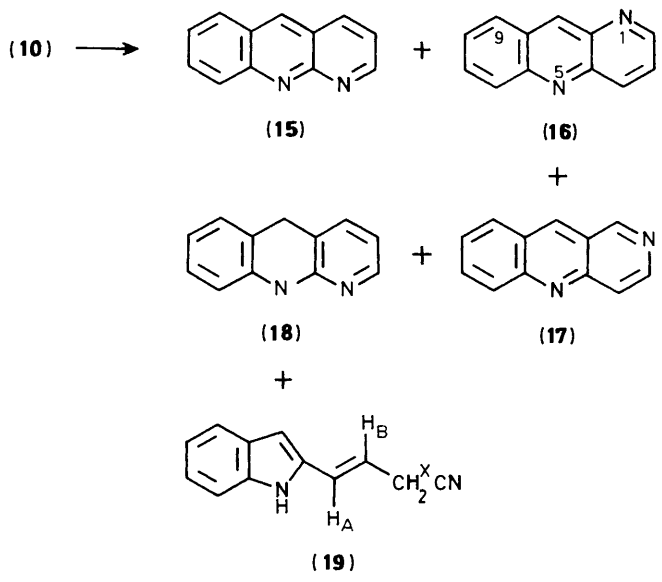
[a] See footnote to Table 1.

Table 3. Yields of products from decomposition of azide (**11**)[a]

Temp. of tube (°C)	% (**7**)	% (**16**)	% (**20**)	Total % (**16**) + (**20**)
350	17	15	1	16
500	19	25	7	32
700	3	57	5	62

[a] See footnote to Table 1.

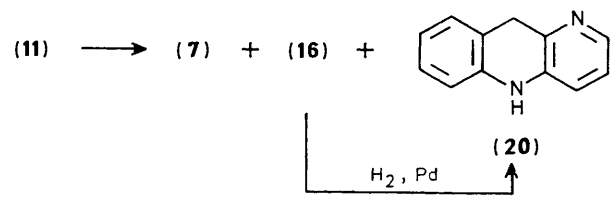
satisfactory in total yield, the maximum being 35% at 700 °C as estimated by g.c. (Table 2). Five products were successfully identified, three of the four possible benzonaphthyridines (**15**)—(**17**), a dihydro derivative (**18**), and a product identified spectroscopically as a cyanopropenylindole (**19**). Two of the benzonaphthyridines [the 1,8-derivative (**15**) and the 1,6-derivative (**17**)] were previously reported[6,7] and our compounds agreed in properties with the literature values. The dihydrobenzonaphthyridine (**18**) was identified by its n.m.r. spectrum and by its ready dehydrogenation to benzonaphthyridine (**15**). The fourth compound, (**16**) another new benzonaphthyridine, was identical with one isolated from the decomposition of azide (**11**) (see later); the quantity isolated was in all cases small. The most interesting compound had a ^{1}H n.m.r. spectrum quite different from the other products. Notable features were a broad singlet (indole NH) at δ 10.9, a broadened singlet at δ 6.54 (indole 3-H), and an ABX_2 system at δ 6.8, 6.2,



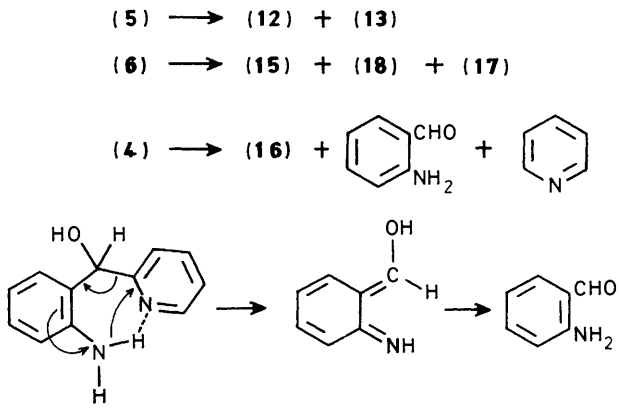
and 3.5, with J_{AB} 16, J_{BX} 6, and J_{AX} 1.4 Hz. The i.r. spectrum showed a peak at 2 250 cm^{-1} (C≡N), and the spectrum is in accord with structure (**19**).

From the pyrolysis of the 2-pyridyl derivative (**11**), three products were obtained, the amine (**7**), benzo[*b*]-1,5-naphthyridine (**16**), and its dihydro derivative (**20**) (Table 3). The compounds (**16**) and (**20**) were not previously reported. The ^{1}H n.m.r. spectrum of compound (**16**) showed a downfield doublet of doublets (*J* 4 and 2 Hz) at δ 9.07 (2-H), a singlet at δ 9.02 (10-H), and a multiplet at δ 8.53 (major coupling at 9 Hz) due to 9-H. Catalytic hydrogenation of compound (**16**) gave a dihydro derivative identical with the third pyrolysis product (**20**). The ^{1}H n.m.r. spectrum showed a doublet of doublets at δ 7.98 (2-H); the methylene singlet was at δ 4.16.

The formation of azaxylylenes from 2-aminophenylmethanols



has been reported by Bowen *et al.*,[8] and this prompted us to pyrolyse the three 2-aminophenyl(pyridyl)methanols (**4**)—(**6**), for comparison with the pyrolysis of the azides (**9**)—(**11**). The alcohols were prepared by catalytic hydrogenation of the corresponding nitro alcohols, and were all obtained in excellent yield. The pyrolyses were performed at one temperature only (750 °C). From the alcohol (**5**) two products were obtained, the major (almost 90% isolated yield) was benzo[*b*][1,7]naphthyridine (**12**) and the minor the dihydro derivative (**13**). From the 3-pyridylmethanol (**6**) the total yield was less than those from the other two alcohols [as noted also for the 3-pyridyl azide (**10**)]; three products were isolated. The major part of the pyrolysate (about 80%) was benzo[*b*][1,8]naphthyridine (**15**) and its dihydro derivative (**18**); the minor product was benzo[*b*][1,6]naphthyridine (**17**). No trace of the indole (**19**) was observed. The pyrolysis of the 2-pyridylmethanol (**4**) took a different course. Three products were obtained, two in approximately equal weight, the first being benzo[*b*]-1,5-naphthyridine (**16**) and the second 2-aminobenzaldehyde. An amount of pyridine roughly equivalent to the 2-aminobenzaldehyde was also identified. We understand[9] that similar cleavage occurs in other cases where a substituent heterocycle with the heteroatom next to the methanol carbon allows hydrogen transfer and the subsequent cleavage of the heterocycle–methanol bond (Scheme 1). These pyrolyses are summarized in Table 4.



Scheme 1.

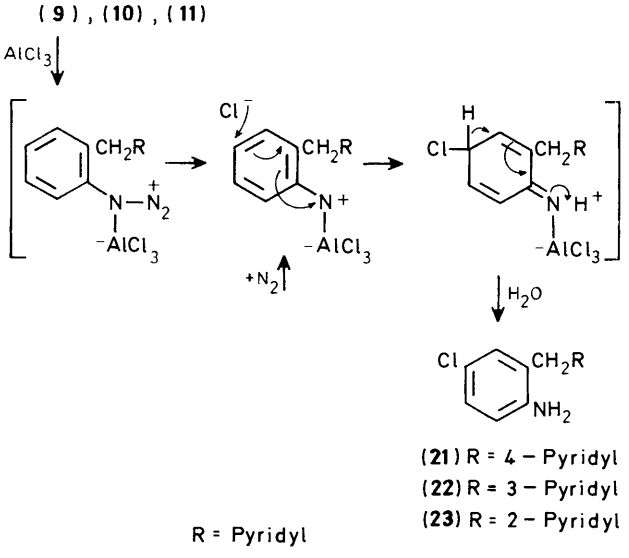
Finally, the observation of cyclisation of nitrenium species generated by aluminium chloride-catalyzed decomposition of azides[10] led us to examine briefly the effect of aluminium

Table 4. Yields of products from decomposition of amino alcohols at 700 °C

Alcohol	Products and yields (%)[a]
(5)	(12) (87) + (13) (1)
(6)	(15) (29) + (18) (13) + (17) (7)
(4)	(16) (32) + *o*-Aminobenzaldehyde (45) + Pyridine (31)

[a] See footnote to Table 1.

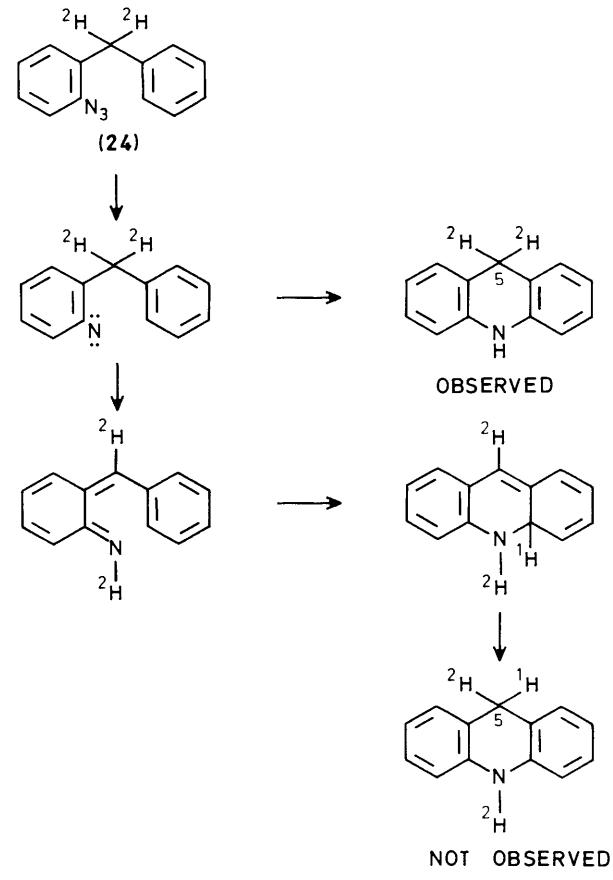
chloride on our azides (9)—(11), although the low reactivity of pyridines towards electrophiles was discouraging. Indeed, treatment of the azide (9) with aluminium chloride in dichloromethane produced an evolution of gas; work-up gave, as the major product, compound $C_{12}H_{11}ClN_2$ (up to 70% yield). The spectral data showed it to be 4-(2-amino-5-chlorobenzyl)pyridine (21). From azides (10) and (11) the corresponding chloroanilines (22) and (23) were obtained, although in poorer yields. No evidence of any cyclised products was obtained. Examples are available of similar substitutions by nucleophiles *para* to nitrenium ions.[11] A simple mechanism for the conversion of the azides (9)—(11) into compounds (21)—(23) is shown in Scheme 2.



Scheme 2.

Discussion

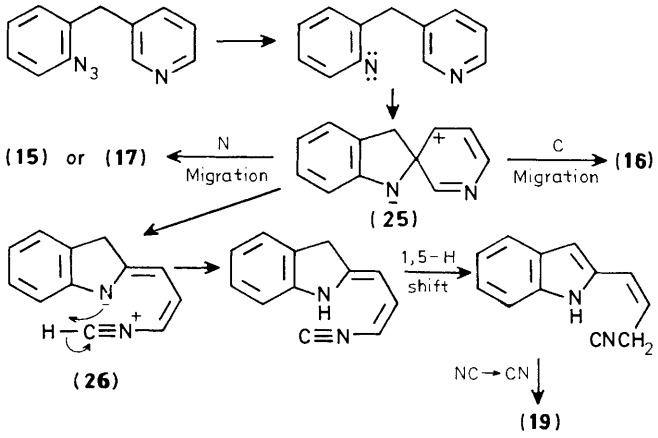
Inspection of Tables 1—3 which show the variation in the amount of each product over three temperatures (350, 500, and 700 °C) reveal similar patterns for the 2- and 4-pyridyl derivatives (11) and (9). The 3-substituted pyridine (10) differs in a number of ways and will be discussed separately, but it shares with the others a trend towards increasing amounts of benzonaphthyridine (and dihydro derivative) with increasing temperature. In the case of the azides (9) and (11), appreciable amounts of the corresponding 2-aminobenzylpyridines are obtained at 350 °C, these amounts decreasing up to 700 °C. We confirmed that the amines are unchanged by further passage through a tube at 700 °C, so that the increase in benzonaphthyridine products is not due in part to the cyclisation of the amine. The same pattern of benzonaphthyridines and dihydro derivatives was obtained from the amino alcohols (4)—(6), (Table 4) although the 2-pyridyl derivative (4) gave substantial amounts of 2-aminobenzaldehyde and pyridine. This fragmentation is characteristic of a 2-aminophenylmethanol substituted in the methanol carbon atom by a heterocycle, if the heterocycle is α-substituted.[9] Our flash vacuum pyrolyses gave results different from those expected from our previous solution pyrolyses. A direct comparison is possible only in the previously studied 2-azidodiphenylmethane (1; R = H) which in solution gives an azepinoindole[2] but on flash vacuum pyrolysis gives mainly acridan, acridine, and 2-aminodiphenylmethane.[4] The possibility must be considered that the nitrene is transformed into an azaxylylene by a hydrogen shift. Such azaxylylenes have been suggested as intermediates in the formation of acridines by f.v.p. of 2-aminophenylmethanols and their derivatives.[8] We can exclude this possibility by the isotopic labelling experiments shown in Scheme 3. The dideuterio derivative (24),[12] when pyrolysed,



Scheme 3.

must lead *via* an azaxylylene to an acridan with one ^1H and one ^2H atom on C-5. Our observation is of no ^1H incorporation at C-5.

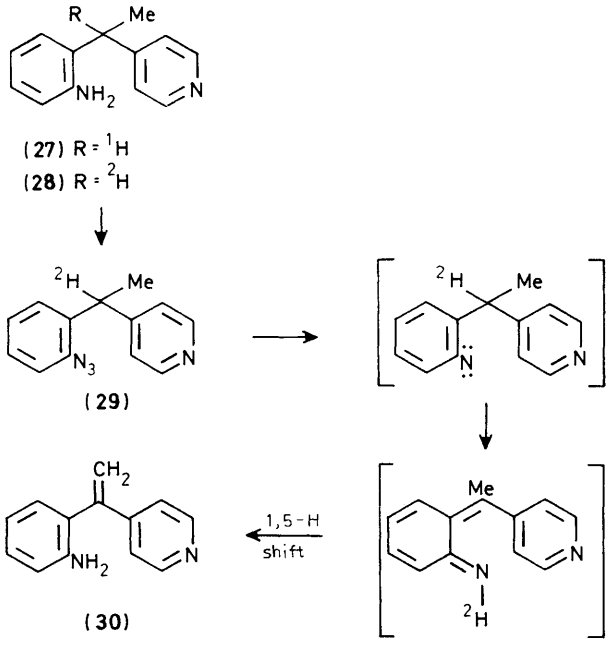
For our experiments with 2-azidobenzylpyridines it now appears that a spirodiene provides the most satisfactory general intermediate. We have prepared azidobenzylpyridine (9) with two ^2H atoms on the methano bridge and found that the C-5 of the dihydrobenzonaphthyridine (14) carries two ^2H atoms; thus an azaxylylene is again excluded. If we consider 3-(2-azidobenzyl)pyridine (10) the products can all be satisfactorily explained by the spirodiene intermediate (25) in Scheme 4. Migration of the N–C bond gives dihydrobenzonaphthyridines (15) and (17) while migration of the CH_2–C bond gives 'rearranged' product (16). More importantly, fragmentation of the pyridine 2,3 bond in the spirodiene intermediate gives the protonated isonitrile (26). Hydrogen transfer, a 1,5-hydrogen



Scheme 4.

shift, and an isonitrile to nitrile rearrangement gives the indole (**19**).

We have also synthesized the homologue (**27**) of amine (**8**) and labelled it on the bridge with ^2H, giving compound (**28**). Decomposition of the derived azide (**29**) gave a mixture of six products, of which only one is firmly characterised, the vinyl derivative (**30**). In this case it is difficult to see a mechanism which does not involve an azaxylylene (Scheme 5), so that here it is necessary to assume a mixture of competing mechanisms.



Scheme 5.

Experimental

M.p.s are determined on a Kofler heated stage, and are uncorrected. Chromatography was performed on columns of alumina (Woelm, activity IV). Smaller scale separations were performed on Chromatotron plates (2 mm, Merck silica). Unless otherwise stated, n.m.r. spectra were determined for solutions in $CDCl_3$, i.r. spectra in chloroform, and u.v. spectra in 95% ethanol.

4-(2-*Azidobenzyl*)*pyridine* (**9**).—Prepared as previously described.[1] By hydrogenation of 2-nitrophenyl(4-pyridyl)-methanol under neutral conditions, it was possible to isolate 2-*aminophenyl*(4-*pyridyl*)*methanol* (**5**) in 94% yields, m.p. 140—141 °C (from benzene) (Found: C, 71.95; H, 6.05; N, 13.65. $C_{12}H_{12}N_2O$ requires C, 71.95; H, 6.0; N, 14.0%); $\nu_{max.}$ 3 400 cm^{-1}; $\lambda_{max.}$ 237 and 289 nm (log ε 3.74 and 3.25); δ 4.0 (3 H, NH_2 and OH), 5.82 (1 H, s, C*H*OH), 6.6—7.5 (6 H, m), and 8.5 (2 H, d, *J* 6 Hz); *m/z* 200 (M^+, 20%), 180 (30), 181 (77), 180 (75), 126 (41), 92 (42), 86 (52), 78 (52), 77 (41), 75 (100), and 65 (49).

2-*Nitrophenyl*(2-*pyridyl*)*methanol* (**3**).—A cooled (−70 °C) solution of 2-bromopyridine (5 g) in anhydrous ether (29 ml), under a nitrogen atmosphere, was treated with butyl-lithium (1.8M in hexane; 17.5 ml) and the solution stirred for 10 min. A solution of 2-nitrobenzaldehyde (4.83 g) in ether (40 ml) was added over 10 min, the resultant mixture stirred at −70 °C for 30 min and then allowed to warm to room temperature over 2 h. The reaction mixture was treated with an ice-cold solution of sodium metabisulphite saturated with brine, separated, and the aqueous layer extracted with ether. The combined ethereal extracts were dried (Na_2SO_4), filtered, and evaporated. The crude product (6.2 g) was purified on a column of alumina (250 g), eluting with ethyl acetate–light petroleum (b.p. 40—60 °C) (1:4) to give the 2-*pyridylmethanol* (**3**) (3.1 g, 43%), m.p. 71—72 °C (from light petroleum, b.p. 40—60 °C) (Found: C, 62.45; H, 4.15; N, 12.05. $C_{12}H_{10}N_2O_3$ requires C, 62.6; H, 4.35; N, 12.15%); $\nu_{max.}$ 3 360 cm^{-1}; $\lambda_{max.}$ 245, 256, and 350 nm (log ε 3.62, 3.63, and 2.72); δ 5.5 (1 H, br, OH), 6.4 (1 H, s, C*H*OH), 7.15—7.75 (6 H, m), 7.92 (1 H, d, *J* 8 Hz, 2′-H), and 8.55 (1 H, d, *J* 5 Hz, 6-H).

2-*Aminophenyl*(2-*pyridyl*)*methanol* (**4**).—A solution of the nitro compound (**3**) (1.07 g) in 95% ethanol (25 ml) was hydrogenated at atmospheric temperature and pressure over 10% Pd–C catalyst (0.25 g) until 3 equiv. of hydrogen had been absorbed. Filtration and evaporation gave a dark oil (0.86 g), purified by passage through a short column of alumina to give the *amino alcohol* (**4**) (0.81 g, 87%) (Found: C, 71.45; H, 6.05; N, 13.55. $C_{12}H_{12}N_2O$ requires C, 71.95; H, 6.05; N, 14.0%); $\nu_{max.}$ 3 400 cm^{-1}; δ 4.19 (2 H, NH_2), 4.96 (1 H, OH), 5.77 (1 H, C*H*OH), 6.58—6.81 (2 H, m), 7.03—7.37 (4 H, m), 7.63 (1 H, m, 4-H), and 8.55 (1 H, d, *J* 6 Hz, 6-H); *m/z* 200 (M^+, 37%).

2-(2-*Aminobenzyl*)*pyridine* (**7**).—A solution of the amino alcohol (**4**) (1.71 g) in freshly distilled hydriodic acid (22 ml) was boiled for 5 h. The cooled mixture was added to an aqueous solution of sodium metabisulphite (14 g in 85 ml). A tarry insoluble material was left when the solution was decanted, and was treated with boiling 50% aqueous sodium hydroxide over 5 min. The combined aqueous solutions were basified with ammonia (*d* 0.88) and extracted by dichloromethane (4 × 100 ml). The dried (Na_2SO_4) solution was filtered and evaporated to give a residue (1.27 g), which was purified by distillation. The *aminobenzylpyridine* (**7**) had b.p. 144 °C/0.01 mmHg (1.09 g, 70%), m.p. 64 °C (Found: C, 77.8; H, 6.65; N, 15.0. $C_{12}H_{12}N_2$ requires C, 78.2; H, 6.55; N, 15.2%); $\nu_{max.}$ 3 400 cm^{-1}; $\lambda_{max.}$ 236 and 285 nm (log ε 4.0 and 3.59); δ 4.02 (2 H, s), 4.1 (2 H, br, NH_2), 6.59—6.78 (2 H, m), 6.97—7.23 (4 H, m), 7.54 (1 H, m, 4-H), and 8.45 (1 H, d, *J* 5 Hz, 6-H); *m/z* 184 (M^+, 28%).

2-(2-*Azidobenzyl*)*pyridine* (**11**).—A solution of the amine (**7**) (1.27 g) in water (3.2 ml), concentrated hydrochloric acid (3.2 ml), and dioxane (8.5 ml) was treated at 0 °C with sodium nitrite (0.52 g) in water (12 ml). The diazonium salt solution was added slowly with stirring to a solution of sodium azide (0.52 g) and sodium acetate (5.3 g) in water (24 ml) at 0—5 °C; the combined solutions were allowed to warm to room temperature and kept there for 30 min. The mixture was extracted with dichloromethane (4 × 20 ml), the extracts dried ($MgSO_4$), filtered, and

evaporated to give the crude azide (1.3 g). Separation on an alumina column (eluant CH_2Cl_2–light petroleum, 1:4) gave the *azide* (**11**), (1.21 g, 84%), further purified for analysis on the Chromatotron (Found: C, 68.8; H, 4.85; N, 26.35. $C_{12}H_{10}N_4$ requires C, 68.55; H, 4.8; N, 26.65%); $\nu_{max.}$ 2 150 cm^{-1}; $\lambda_{max.}$ 214 and 256 nm (log ε 4.36 and 4.12); δ 4.11 (2 H, CH_2), 7.0—7.38 (5 H, m), 7.48—7.66 (2 H, m), and 8.52 (1 H, d, *J* 5 Hz, 6-H); *m/z* 182 ($M^+ - N_2$, 37%) and 181 ($M^+ - N_2H$, 100%).

Standard Procedure for Flash Vacuum Pyrolyses.—The apparatus used has been described;[5] the pyrolysis section of the silica tube was 25 cm long and had an internal diameter of 17 mm. Samples were vaporized at bath temperatures sufficiently low to prevent pressure rising above 2×10^{-2} mmHg. Samples were collected on a cold finger (−70 °C) and washed off with dichloromethane. Samples from the top of the column were similarly removed and worked up separately. In most cases some azide was recovered from the flask and the bottom section of the column (that below the oven). Calculated yields take into account the amount of azide recovered. Appreciable amounts of material were lost by carbonisation in the tube or decomposition before the tube. An aliquot of the solution was used for quantitative gas chromatography (g.c.) using a Perkin-Elmer 8320 with capillary column (OV1), with integrator, and thus yields were calculated. The products were separated using a Chromatotron (2 mm silica plates); for many separations multiple runs were required. Quantitative results for azide decompositions are recorded in Tables 1—3.

Decomposition of 4-(2-*Azidobenzyl*)*pyridine* (**9**).—Three compounds were separated by Chromatotron (eluant ethyl acetate–light petroleum, 1:1). Their retention times on g.c. were 18.8, 19.6, and 21.0 min. The first was 4-(2-aminobenzyl)pyridine (**8**), the second *benzo*[b][1,7]*naphthyridine* (**12**), m.p. 134—135 °C (from cyclohexane), b.p. 60 °C/0.02 mmHg (Found: C, 80.15; H, 4.35; N, 15.25. $C_{12}H_8N_2$ requires C, 80.0; H, 4.45; N, 15.55%); $\lambda_{max.}$ 230, 248, 349, 370, and 388 nm (log ε 4.41, 4.84, 3.62, 3.56, and 3.44); δ 7.57—8.09 (4 H, m, 4-, 6-, 7-, and 8-H), 8.34 (1 H, br d, *J* 8 Hz, 9-H), 8.57 (1 H, d, *J* 6 Hz, 3-H), 8.79 (1 H, s, 5-H), and 9.75 (1 H, s, 1-H); *m/z* 181 (*M*H, 23%) and 180 (M^+, 100%). The third component was 5,10-*dihydrobenzo*[b][1,7]*naphthyridine* (**13**), m.p. 140—141 °C (from cyclohexane) (Found: C, 79.0; H, 5.25; N, 15.2. $C_{12}H_{10}N_2$ requires C, 79.1; H, 5.55; N, 15.35%); $\nu_{max.}$ (DMSO) 3 480 cm^{-1}; δ 4.06 (2 H, s, 5- and 5′-H), 7.14—6.73 (6 H, m), 7.98 (1 H, d, *J* 5 Hz), and 8.1 (1 H, s, 1-H).

Decomposition of 3-(2-*Azidobenzyl*)*pyridine* (**10**).—Five products were isolated; the pyrolysis was extremely slow (up to 10 h). The retention times were 11.71 [compound (**16**)], 11.75 [compound (**17**)], 12.05 [compound (**18**)], 13.1 [compound (**19**)], and 13.3 [compound (**15**)]. Separation by Chromatotron was difficult, requiring careful gradient elution; the order of elution was (**19**), (**18**), (**16**), (**17**), and (**15**).

Benzo[*b*][1,8]naphthyridine (**15**) had m.p. 190—192 °C (lit., m.p. 190—192 °C). The u.v. and ^1H n.m.r. spectral data were identical with those reported by Hamada, Takeuchi, and Hirota.[6]

Benzo[b]-1,5-*naphthyridine* (**16**) had m.p. 106—107 °C (sublimed at 65 °C/0.08 mmHg) (Found: C, 80.0; H, 4.55; N, 15.5. $C_{12}H_8N_2$ requires C, 80.0; H, 4.45; N, 15.55%); $\lambda_{max.}$ 244 and 356 nm (log ε 4.59 and 3.8); δ 7.52—7.93 (3 H, m), 8.03—8.32 (2 H, m), 8.53 (1 H, dd, *J* 9 and 1 Hz, 6-H), 9.02 (1 H, s, 10-H), and 9.07 (1 H, dd, *J* 4 and 2 Hz, 2-H); *m/z* 180 (M^+, 100%).

Benzo[*b*][1,6]naphthyridine (**17**) had spectra similar to those reported.[7] δ 7.55—7.9 (4 H, m), 8.35 (1 H, dd, *J* 8 and 1.5 Hz, 9-H), 9.15 (1 H, d, *J* 1.5 Hz, 4-H), 9.2 (1 H, d, *J* 5 Hz, 2-H), and 9.3 (1 H, s, 5-H).

5,10-*Dihydrobenzo*[b][1,8]*naphthyridine* (**18**) had m.p. 150—151 °C (from 60% ethanol), b.p. 85 °C/0.06 mmHg (Found: C, 79.05; H, 5.35; N, 15.25. $C_{12}H_{10}N_2$ requires C, 79.1; H, 5.55; N, 15.35%); $\lambda_{max.}$ 312 and 335 nm (log ε 3.62 and 3.58); δ 4.09 (2 H, s), 7.8 (1 H, br, NH), 6.65—7.4 [6 H, m, $J_{8,9}$ 8 Hz, revealed by Eu(fod)$_3$], and 8.0 (1 H, dd, *J* 4 and 1 Hz, 2-H); *m/z* 182 (M^+, 6%) and 180 ($M^+ - 2$, 100%).

The cyanopropenylindole (**19**) had $\nu_{max.}$ 3 460 and 2 250 cm^{-1}; $\lambda_{max.}$ 244 and 293 nm; δ 3.5 (2 H, dd, *J* 6 and 1.4 Hz, CH_2C=), 6.2 (1 H, dd, *J* 16 and 6 Hz, 3-H), 6.54 (1 H, s, 3′-H), 6.8 (1 H, d, *J* 16 Hz, 4-H), 6.95—7.7 (4 H, m), and 10.9 (1 H, br, NH).

Decomposition of 2-(2-*Azidobenzyl*)*pyridine* (**11**).—Three products were isolated, having g.c. retention times of 11.31 (**7**), 11.71 (**16**), and 12.16 (**20**). On Chromatotron plates, with increasing amounts of ethyl acetate in light petroleum, the order of elution was (**20**), (**7**), and (**16**). The *dihydrobenzonaphthyridine* (**20**) had m.p. 164—165 °C (from cyclohexane) (Found: C, 79.0; H, 5.3; N, 15.1. $C_{12}H_{10}N_2$ requires C, 79.1; H, 5.55; N, 15.35%); $\nu_{max.}$ 3 150 cm^{-1}; $\lambda_{max.}$ 288 nm (log ε 4.11); δ 4.16 (2 H, s), 6.6—7.15 (7 H, m), 7.98 (1 H, dd, *J* 4 and 2 Hz, 3-H); *m/z* 182 (M^+, 19%).

Decomposition of 2-*Aminophenyl*(x-*pyridyl*)*methanols* (**4**)—(**6**).—All were pyrolysed at 750 °C. The work-up procedures were as described for the azide decompositions. For compound (**4**), three products were isolated, the benzo[*b*]-1,5-naphthyridine (**16**), 2-aminobenzaldehyde, identical with a synthetic sample, and pyridine. The products and yields are summarized in Table 4.

Aluminium Chloride-catalyzed Decomposition of Azides (**9**)—(**11**).—A solution of the azide (0.15 g) in anhydrous dichloromethane (1 ml) was added slowly and with stirring to aluminium chloride (0.38 g) under dichloromethane (7 ml). As drops entered the mixture nitrogen evolution was observed (*N.B.* When sublimed aluminium chloride was used *no reaction was observed.*) The purple mixture was cooled (ice-bath) while aqueous sodium hydroxide was added, after which the organic layer was separated and combined with dichloromethane washings of the aqueous layer. The combined organic layers were dried ($MgSO_4$), filtered, evaporated, and separated on a Chromatotron (eluant, dichloromethane), to give starting material and the chloroaniline.

(*a*) From the azide (**9**) was obtained 4-(2-*amino*-5-*chlorobenzyl*)*pyridine* (**21**), [61% (64% on unrecovered azide)], m.p. 142—143 °C (from cyclohexane) (Found: C, 65.9; H, 5.0; N, 12.45. $C_{12}H_{11}ClN_2$ requires C, 65.9; H, 5.05; N, 12.8%); δ 3.46 (2 H, br s, NH_2), 3.84 (2 H, s), 6.63 (1 H, d, *J* 8 Hz, 3′-H), 7.42 (1 H, d, *J* 1.5 Hz, 6′-H), 6.95—7.15 (3 H, m), and 8.52 (2 H, m, 2- and 6-H); $\nu_{max.}$ 3 400 and 3 200 cm^{-1}.

(*b*) From the azide (**10**) was obtained 3-(2-*amino*-5-*chlorobenzyl*)*pyridine* (**22**) [70% (virtually quantitative on unrecovered azide)], m.p. 78 °C (from light petroleum, b.p. 40—60 °C) (Found: C, 65.75; H, 5.05; N, 12.85%); δ 3.52 (2 H, br s, NH_2), 3.82 (2 H, s), 6.6 (1 H, d, *J* 8 Hz, 3′-H), 6.95—7.5 (2 H, m), 7.44 (1 H, d of t, *J* 2 and 8 Hz, 4-H), and 8.49 (2 H, m); $\nu_{max.}$ 3 400 and 3 200 cm^{-1}; $\lambda_{max.}$ 243 and 299 nm (log ε 3.94 and 3.29).

(*c*) From the azide (**11**) was obtained 2-(2-*amino*-5-*chlorobenzyl*)*pyridine* (**23**) [63% (70% on unrecovered azide)], m.p. 49—50 °C (from light petroleum, b.p. 40—60 °C) (Found: C, 65.6; H, 5.3; N, 12.55%); δ 3.97 (2 H, s), 4.3 (2 H, br s, NH_2), 6.55 (1 H, d, *J* 2.5 Hz, 6′-H), 6.95 (1 H, dd, *J* 8 and 2.5 Hz, 4′-H), 7.08 (1 H, d, *J* 2.5 Hz, 6′-H), 7.05—7.25 (2 H, m), 7.56 (1 H, d of t, *J* 7.5 and 2 Hz, 4-H), and 8.45 (1 H, br d, 2-H); $\nu_{max.}$ 3 400 and 3 200 cm^{-1}; $\lambda_{max.}$ 246 and 298 nm (log ε 3.9 and 3.24).

4-(2-*Nitrobenzoyl*)*pyridine*.—A mixture of dichloromethane (70 ml) and oxalyl chloride (2.97 ml) was placed in a 500 ml round-bottomed flask fitted with a thermometer, a stirrer, and a pressure-equalized dropping funnel, and cooled to −50 to −60 °C. A solution of dimethyl sulphoxide (5.09 g) in dichloromethane (15 ml) was added, the mixture stirred for 10 min and a solution of 2-(2-nitrophenyl)-4-pyridylmethanol (7 g) in dichloromethane (70 ml) added over 5 min. Stirring was continued for 15 min, triethylamine (21 ml) added, and stirring continued for a further 5 min at −60 °C and at room temperature for 1.5 h. Addition of water (180 ml) and separation of the organic phase was followed by further extraction (dichloromethane). The combined organic layers were washed with saturated brine, 1% hydrochloric acid, water, aqueous sodium carbonate (5%), and again with water, dried ($MgSO_4$), and evaporated to give a dark red oil (6.6 g). Separation on an alumina column (eluant ethyl acetate–light petroleum, 2:3) gave 4-(2-*nitrobenzoyl*)*pyridine* (5.65 g, 81.5%), m.p. 77–78 °C (from cyclohexane) (Found: C, 62.85; H, 3.45; N, 12.1. $C_{12}H_8N_2O_3$ requires C, 63.15; H, 3.55; N, 12.25%); $\nu_{max.}$ 1 740, 1 580, 1 390, and 1 320 cm^{-1}; δ 7.46—7.94 (5 H, m), 8.29 (1 H, d of d, *J* 7 and 1.8 Hz), 8.8 (2 H, d of d, *J* 5.8 and 1.3 Hz, 2- and 6-H).

4-(2-*Aminobenzoyl*)*pyridine*.—A solution of the nitrobenzoylpyridine (10.5 g) in 95% ethanol (250 ml) with Pd on charcoal catalyst (2.1 g, 10%) hydrogenated at room temperature and pressure until uptake ceased. Filtration and evaporation of the filtrate gave a bright yellow solid separated on alumina into three products. In order of elution, using increasing percentages of ethyl acetate in light petroleum, the products were (i) the azo compound from 4-(2-aminobenzoyl)pyridine (3.5 g, 19.4%), (ii) 4-(2-*aminobenzoyl*)*pyridine*, (6.3 g, 69.2%), m.p. 160—161 °C (yellow crystals from cyclohexane) (Found: C, 72.8; H, 4.8; N, 14.2. $C_{12}H_{10}N_2O$ requires C, 72.7; H, 5.1; N, 14.15%); $\nu_{max.}$ 3 520, 3 380, and 1 640 cm^{-1}; δ 6.3 (2 H, br s, NH_2), 6.49—6.79 (2 H, m), 7.25—7.46 (4 H, m), and 8.76 (2 H, d of d, *J* 5 and 1.5 Hz, 2- and 6-H); *m/z* 198 (M^+, 100%), and (iii) 2-aminophenyl-4-pyridylmethanol (**5**), which was identical with a specimen prepared previously.

1-(2-*Aminophenyl*)-1-(4-*pyridyl*)*ethane* (**27**).—(*a*) A solution of 4-(2-aminobenzoyl)pyridine (4.0 g) in tetrahydrofuran (THF) (70 ml) was added at room temperature to the Grignard reagent from iodomethane (12.04 g) and magnesium (2.21 g) in ether–THF (1:1, 60 ml), with stirring, and the mixture boiled under reflux for 30 min. The dark red mixture was decomposed with a mixture of ammonium chloride, ice, and aqueous ammonia, the organic layer separated, and the aqueous layer extracted with dichloromethane (2 × 100 ml). The combined organic extracts were dried and evaporated leaving a cream coloured solid, recrystallized from carbon tetrachloride to give 1-(2-*aminophenyl*)-1-(4-*pyridyl*)*ethanol* (3.79 g, 87.6%), m.p. 197—198 °C (Found: C, 72.35; H, 6.8; N, 12.95. $C_{13}H_{14}N_2O$ requires C, 72.85; H, 6.6; N, 13.05%); $\nu_{max.}$($CHCl_3$) 3 640, 3 450, 1 605, 1 220, and 1 050 cm^{-1}; δ 1.84 (3 H, s), 3.65 (3 H, br s, NH_2 and OH), 6.63 (1 H, d of d, *J* 7.7 and 1.3 Hz), 6.84 (1 H, d of t, *J* 7.4 and 1.3 Hz), 7.07—7.43 (4 H, m), and 8.43 (2 H, d of d, *J* 5 and 1.5 Hz, 2- and 6-H).

(*b*) The aminophenylpyridylethanol (2 g) was dissolved in constant boiling hydriodic acid (28 ml) and the solution boiled under reflux for 2 h. The cooled mixture was poured into an excess of aqueous sodium metabisulphite (17 g in 100 ml), and subsequently basified using 50% aqueous sodium hydroxide. The organic material was extracted with dichloromethane, the extracts dried ($MgSO_4$), and evaporated to give almost pure product. Chromatography on alumina (eluant CH_2Cl_2–light petroleum, 1:4) gave the *title compound* (**27**) (1.6 g, 87%), m.p. 96—97 °C (from light petroleum, b.p. 40—60 °C) (Found: C, 78.55; H, 6.8; N, 13.8. $C_{13}H_{16}N_2$ requires C, 78.75; H, 7.1; N, 14.1%); $\nu_{max.}$ 3 460 and 3 400 cm^{-1}; δ 1.61 (3 H, d, *J* 7.2 Hz), 3.28 (2 H, br s), 4.06 (1 H, q, *J* 7.2 Hz), 6.66 (1 H, d of d, *J* 7.6 and 1.1 Hz), 6.83 (1 H, d of t, *J* 7.4 and 1.4 Hz), 7.0—7.27 (4 H, m), and 8.47 (2 H, d of d, *J* 5.4 and 1 Hz); *m/z* 198 (M^+, 97%) and 183 (M − 15, 100%).

Deuterium Exchange on Compound (**27**).—Sodium metal (0.75 g) was added to a solution of the amine (**27**) (0.6 g) in methan[^{2}H]ol (8 ml), and the resulting solution boiled for 3 h. The cooled mixture was poured into deuterium oxide (30 ml) and the organic product extracted with dichloromethane. Purification on alumina (dichloromethane–light petroleum; 3:7) gave a product whose ^{1}H n.m.r. spectrum showed almost complete loss of the signal at δ 4.06 due to the ^{1}H of the ethane.

[1-^{2}H]-1-(2-*Azidophenyl*)-1-(4-*pyridyl*)*ethane* (**29**).—The amine (**28**) (1 g) in a mixture of water (3 ml), concentrated hydrochloric acid (2.5 ml), and dioxane (7 ml) at −5 °C was diazotized by addition of a solution of sodium nitrite (0.4 g) in water (10 ml). The diazonium salt solution was added to a cooled solution of sodium azide (0.4 g) and sodium acetate (4 g) in water (20 ml), and the mixture stirred while it came to room temperature over 0.75 h. Extraction by dichloromethane, and purification of the crude organic product on alumina (eluant dichloromethane–light petroleum, 1:4) gave the *azide* (**29**) as a pale yellow oil (0.84 g, 75%) (Found: C, 69.05; H, 5.2; N, 24.45. $C_{13}{}^1H_{11}{}^2HN_4$ requires C, 69.31; H, 5.35; N, 24.85%); $\nu_{max.}$ 2 540 and 2 200 cm^{-1}; δ 1.4 (3 H, s), 6.75—7.3 (6 H, m), and 8.35 (2 H, d, *J* 5.5 Hz, 2-and 6-H).

Pyrolysis of Azide (**29**).—Performed as previously described for the azides (**9**)—(**11**) at 350 °C. Gas chromatography of the crude product showed six peaks of which only the major one corresponded to a product which could be obtained in a pure form after Chromatotron treatment (eluant ethyl acetate–light petroleum, 4:1), and proved to be the vinyl derivative (**30**); *m/z* 197, M + 1, 33%) and 196 (M^+, 100%); $\nu_{max.}$ 3 480 and 3 390 cm^{-1}; δ 3.4 (2 H, br s), 5.4 (1 H, d, *J* 1 Hz), 5.9 (1 H, d, *J* 1 Hz), 6.55—6.75 (2 H, m), 6.85—7.2 (4 H, m), and 8.45 (2 H, d of d, *J* 5 and 1 Hz, 2- and 6-H).

Decomposition of Azide (**24**).—The azide (**24**) (0.3 g) was decomposed as described at a tube temperature of 350 °C; the crude product was separated by Chromatotron [eluant light petroleum, (b.p. 60—80 °C) with increasing amounts of ethyl acetate], to give 2-aminodiphenylamine (25%), [9,9-$^2H_2$]-acridan (0.083 g, 33%), and [9-^{2}H]acridine (0.035 g, 14%). The dideuterioacridan had m.p. 168—169 °C, and the n.m.r. spectrum was identical with that of acridan except for the absence of the signal (2 H) at δ 3.9; *m/z* 184 (M + 1$^+$, 26%), 183 (M^+, 69%), 182 (M − 1$^+$, 51%), and 181 (M − 2$^+$, 100%) (Found: C, 85.05; H, 6.15; N, 7.75. $C_{13}{}^1H_9{}^2H_2N$ requires C, 85.2; H, 6.05; N, 7.65%). The deuterioacridine had m.p. 111 °C, and the n.m.r. spectrum was identical with that of acridine except for the absence of the signal (1 H, s) at δ 8.4; *m/z* 181 (M^+, 22%), 180 (M − 1$^+$, 100%) (Found: C, 86.35; H, 5.4; N, 7.65. $C_{13}{}^1H_8{}^2HN$ requires C, 86.65; H, 5.1; N, 7.75%).

Preparation and Decomposition of 4-(2-*Azido*[α,α-$^2H_2$]-*benzyl*)*pyridine*.—The amine (**8**) (0.72 g) in methan[^{2}H]ol (4 ml) was treated with a catalytic amount of sodium, and the mixture boiled under reflux for 2.5 h. After basification the deuteriated amine was recovered in 89% yield, identical with the amine (**8**) except for the absence of the peak at δ 3.8. The amine was converted without further purification into the azide [procedure as for the azide (**9**)], in 56% yield after purification

by alumina column. The dideuterioazide had an n.m.r. spectrum identical with that of the azide (**9**) except for the absence of the peak (2 H) at δ 3.8; *m/z* 184 ($M^+ - N_2$, 100%) [azide (**9**) has *m/z* 182 (100%)]. Flash vacuum pyrolysis at 350 °C of the deuteriated azide (0.3 g) gave the pyrolysate (0.12 g) separated by Chromatotron to give two major products. Compound (**14**) (30 mg, 25%) had an n.m.r. spectrum identical with that of compound (**13**) but for the absence of the signal (2 H) at δ 4.0; *m/z* 185 ($M^+ + 1$, 24%), 184 (M^+, 62%), 183 ($M^+ - 1$, 100%), and 182 ($M^+ - 2$, 98%). The second product was [5-^{2}H]benzo[*b*][1,7]naphthyridine, m.p. 134—135 °C, n.m.r. spectrum identical with that of compound (**12**) except for the absence of the peak (1 H) at δ 8.8; *m/z* 182 ($M^+ + 1$, 19%) and 181 (M^+, 100%).

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