2-Azaallyl anions: key models for the elaboration of alkyl-, amino- and hydroxy-1,7-naphthyridine derivatives

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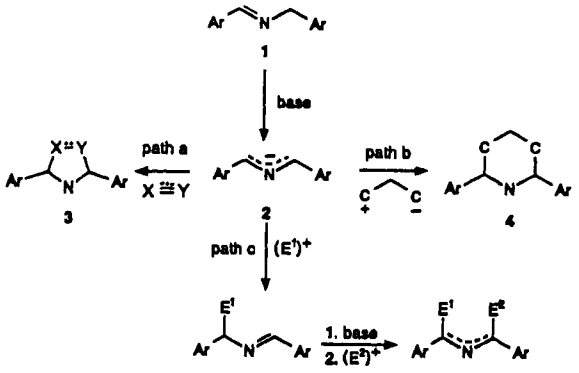
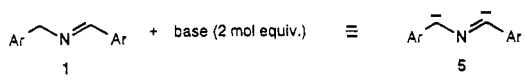
A variety of 5-alkyl-, 5-amino- and 5-hydroxy-6,8-diaryl-1,7-naphthyridines have been efficiently prepared by the treatment of suitable 2-azaallyl anions with diversely functionalized 2-halogenopyridines.

Synthetic methods based on carbanion chemistry have enjoyed increasing popularity in recent years and are now commonplace in rationally designed synthetic endeavours.[1] During the last two decades, for example, stabilized 2-azaallyl anions have proved to be useful synthons for the preparation of nitrogen containing heterocycles.[2] Indeed such carbanionic species may behave as 4π electron partners in [π4s + π2s] cycloaddition processes as defined by Woodward and Hoffman and the construction of a wide array of five-membered heterocyclic frameworks has been successfully achieved by treatment of the anionic species **2** with extremely diverse anionophiles such as imines,[3] azo compounds,[2a] nitriles,[4] alkenes,[2a,d] heterocumulenes,[3d,5] allenes,[3b,6] polyenes[7] and acetylenes[8] (Scheme 1, path



Scheme 1

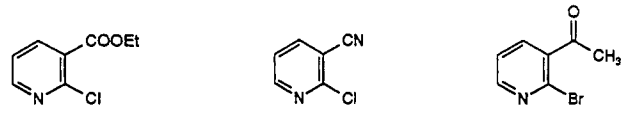
a). However, the use of **2** for the construction of six- and seven-membered heterocyclic rings by a [3 + 3] annulation mode, also known as [1 − 3 − 1] condensation,[9] or a [4 + 3] cycloaddition process is quite rare.[10] A striking illustration of the [3 + 3] annulation (Scheme 1, path b) is the synthesis of polysubstituted piperidines and pyridines as a result of the combination of azaallyl anions **2** with iodomethylallyl silane.[11] It is only very recently that the azepine ring system has been assembled by the [4 + 3] approach with **2** and s-*cis*-fixed dienes.[12] In all these reactions the 2-azaallyl anions **2** behave as 1,3 dipoles. Paradoxically, to our knowledge, these conjunctive reagents have not been used as 1,3 dianion equivalents. However, due to the ambident character of 2-azaallyl anions **2** derived from arylmethylidene(arylmethyl)amines **1**, one can reasonably envisage the connection of suitable electrophiles on the carbon atoms adjacent to the nitrogen of the parent models **1** by two sequential reactions (i) base-induced deprotonation and (ii) electrophilic attack (Scheme 1, path c), a property cleverly used thus far for α-alkylated arylmethylamine synthesis.[13] Consequently, in the presence of two equivalents of base the aldimines **1** may be regarded as synthetic equivalents of aza-1,3-dianions **5** (Scheme 2). We reasoned that such bis-



Scheme 2

anionic species would participate in polar cycloadditions and the present study deals with a new construction of fused heterocycles which hinges upon the reaction of nitrogen centred dianions **5** with a variety of 'bis-anionophile' partners. From a synthetic point of view it was found judicious to perform the annulation reaction with models incorporating anionophiles of very different natures. For this purpose compounds with ester, nitrile and acyl functions which are ideally suited to nucleophilic attack, vicinal to a sensitive halogenocarbon centre on a pyridine ring, were employed.

Initially, the required ethyl 2-chloropyridine-3-carboxylate **6** was obtained from the commercially available 2-chloroisonicotinic acid *via* the corresponding acid chloride or by direct esterification (DCC, DMAP, EtOH, DMF). 2-Chloropyridine-3-carbonitrile **7** was readily synthesized by treatment of nicotinamide 1-oxide with $POCl_3$–PCl_5 and 2-bromo-3-acetylpyridine **8** was prepared in two steps by orthometallation of

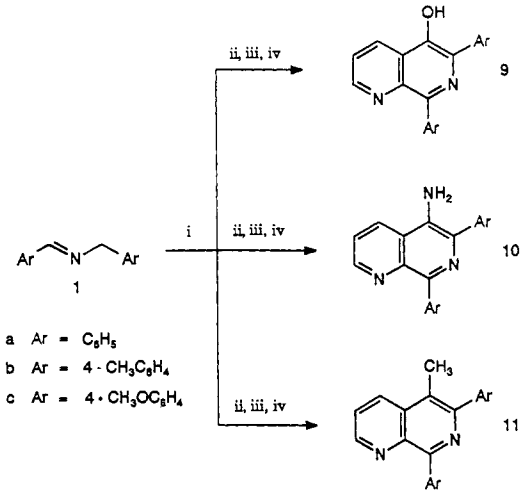


2-bromopyridine followed by addition of acetaldehyde and subsequent oxidation of the resulting alcohol with CrO_3 (Jones reagent). The *N*-arylmethylidene(arylmethyl)amines **1a–c** were quantitatively prepared in a conventional manner by refluxing the appropriate arylmethylamines and aromatic carbaldehydes in toluene with azeotropic elimination of water.

Deprotonation[2a,3] of the aldimines **1a–c** with lithium diisopropylamide yielded the corresponding 1,3-diaryl-2-azaallylic anions **2a–c**†[14] which are stable in THF at low temperature.[2a,b] The pyridine derivatives **6–8** dissolved in DMPU were added at 0 °C to the anions **2a–c** and the addition reaction occurred when the mixture was slowly warmed as evidenced by the disappearance of the characteristic deep-purple colour of the anions **2a–c**. The subsequent addition of a second equivalent of LDA was followed by warming the reaction mixture to 110 °C for 2 h (see Experimental section). This operation ensures the completion of the annulation reaction thus providing a ready access to a variety of diazanaphthalene derivatives **9–11** (Scheme 3). The results of a representative series of products obtained by this method are

Table 1 5-Methyl, 5-amino and 5-hydroxy-6,8-diaryl-1,7-naphthyridines prepared

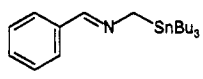
Aldimine	'Bis-anionophile'	Product (% yield)
1a	**6**	**9a** (52)
1b	**6**	**9b** (51)
1a	**7**	**10a** (72)
1b	**7**	**10b** (68)
1c	**7**	**10c** (59)
1a	**8**	**11a** (69)
1b	**8**	**11b** (63)
1c	**8**	**11c** (55)



Scheme 3 *Reagents and conditions:* i, LDA, THF, −78 to 0 °C; ii, **6**, **7** or **8**, DMPU, 0 °C to room temp.; iii, LDA, THF, 0 °C; iv, DMPU, 0 to 110 °C

presented in the Table 1 where it may be seen that this simple procedure affords very satisfying yields of the diversely 5-substituted 6,8-diaryl-1,7-naphthyridines **9a**, **b**, **10a–c** and **11a–c**.

Naphthyridines are a class of fused heterocycles which have received much attention in recent years and several reviews dealing with the different methodologies for their elaboration and emphasizing their pharmaceutical and medicinal activities have appeared in literature.[15] Among the various routes available for the synthesis of the 1,7-naphthyridine framework the most commonly adopted involves coupling 3-aminopyridine derivatives with enolizable ketones, esters and nitriles[15] (Skraup, Emme and Conrad–Limpach syntheses) but these cyclocondensation reactions suffer from competition with other cyclization pathways,[16] namely cyclization at the 2-position of the pyridine ring giving rise to the [1,5] member of the series. This difficulty may be overcome by the incorporation of a formyl[17] (Friedländer syntheses) or imidoyl group[18] at the 3-position of the parent pyridine compound. Several synthetic strategies starting from diversely substituted 2-cyanopyridines[19] have been also developed but few have demonstrated broad synthetic utility. The conceptually and experimentally simple new approach to the 1,7-naphthyridine skeleton reported here offers several advantages over previously reported procedures in terms of reaction conditions employed and exclusive formation of the [1,7] isomer. Furthermore this protocol delivers heterobicyclic compounds with diverse functionality and the presence of a hydroxy or amino group in the naphthyridine moiety will undoubtedly be of interest for further synthetic studies. The main limitation of this methodology concerns the necessity of having two aromatic units in the fused models **9–11** but attempts to perform the cyclocondensation reactions with the unstabilized 2-azaallyl anion obtained by transmetallation of the stannyl derivative **12** according to the elegant method recently developed by Pearson and co-workers[2c,20] were unrewarding.‡



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The annulation reactions reported occur as the result of the nucleophilicity of azaallyllithium reagents and the sensitivity of the halogen atoms in α-halogenopyridines to nucleophilic attack. They enrich the repertoire of reactions involving 2-azaallyl species. Furthermore the scope of these cyclocondensation reactions can undoubtedly be broadened to include the elaboration of other [*x*,*y*]naphthyridine derivatives from suitably and contiguously substituted halogenopyridines.

Experimental

Melting point determinations were carried out on a Reichert-Thermopan apparatus and were recorded uncorrected. IR absorption spectra were run on a Perkin-Elmer 881. ^{1}H and ^{13}C NMR spectra were recorded at 300 MHz and 75 MHz, respectively on a Bruker AM 300 spectrometer as solutions in deuteriochloroform. Chemical shifts are referenced to tetramethylsilane and *J* values are given in Hz and rounded to the nearest 0.1 Hz. Mass spectral analyses were performed on a Ribermag 10–10 mass spectrometer. Elemental analyses were determined by the CNRS microanalysis centre. For flash chromatography, Merck silica gel 60 (230–400 mesh ASTM) was used. Tetrahydrofuran (THF) was freshly distilled over $LiAlH_4$ and diisopropylamine and 1,3-dimethyl-3,4,5,6-tetrahydropyrimidin-2(1*H*)-one (DMPU)[22] over CaH_2. Dry glassware for moisture-sensitive reactions was obtained by oven-drying and assembly under Ar. An inert atmosphere was obtained with a stream of Ar and glassware equipped with rubber septa; reagent transfer was performed by syringe or cannula techniques.

Compounds **6**,[23] **7**[24] and **8**[25] were prepared following reported experimental procedures. Alternatively,[26] ethyl 2-chloropyridine-3-carboxylate **6** was obtained in the following manner. A solution of 2-chloropyridine-3-carboxylic acid (9.7 g, 61 mmol), 4-dimethylaminopyridine (1.1 g, 8 mmol) and ethanol (10 cm^3) in *N*, *N*-dimethylformamide (DMF) (100 cm^3) at 0 °C was treated with a suspension of 1,3-dicyclohexylcarbodiimide (DCC) (30 g, 145 mmol) in DMF (50 cm^3) at 0 °C and the reaction mixture was stirred for 4 h. Filtration followed by evaporation *in vacuo* and distillation afforded **6** (11 g, 95%) as a colourless liquid, bp 78 °C 0.1 mmHg.

Imines **1a–c** were prepared from an equimolar mixture of aldehyde and amine in refluxing toluene (3 h). The reaction was catalysed by naphthalene-2-sulfonic acid and the water formed during the condensation was collected (Dean–Stark apparatus). After neutralization with saturated aqueous $NaHCO_3$ the organic phase was dried over $MgSO_4$. The solvent was removed under reduced pressure and the imines were finally purified by bulb-to-bulb distillation.

† Deprotonation of aldimines gives rise exclusively to 2-azaallyl anions whilst ketimines form preferentially 1-azaallyl anions.[14]

‡ This is probably due to the short lifetime of the unstabilized 2-azaallyl anion derived from **12** even at −78 °C which requires experimental conditions incompatible with base sensitive anionophiles.[21]

General procedure for the synthesis of 5-hydroxy-, 5-amino- and 5-methyl-1,7-naphthyridine derivatives 9–11

In a three-necked flask equipped with a dry argon inlet and a rubber septum and connected to a micro-Claisen distillation apparatus, a solution of lithium diisopropylamide (LDA) in THF was prepared by the slow addition of butyllithium (1.6 mol dm^{-3} in hexane; 3.45 cm^3, 5.5 mmol) to a mixture of anhydrous THF (10 cm^3) and diisopropylamine (0.560 g, 0.78 cm^3, 5.5 mmol) at −78 °C. The mixture was allowed to warm to 0 °C over 0.5 h after which a solution of **1a**, **b**, **c** (5.4 mmol) was added dropwise to it at 0 °C. The deep purple–red solution of **2a–c** so obtained was stirred for 0.5 h at this temperature, after which a solution of **6–8** (5.4 mmol) in DMPU (5 cm^3) was slowly added. The mixture was stirred at 0 °C for 0.5 h and then allowed to warm to ambient temperature (0.5 h). A solution of LDA prepared as described above was then slowly transferred by way of a cannula into the reaction mixture recooled to 0 °C which was then stirred at this temperature for an additional 0.5 h. The cooling bath was then replaced by an oil bath and the temperature of the reaction mixture was raised to 110 °C over a period of 1 h. During this time the volatile solvents distilled off. DMPU (5 cm^3) was added to the mixture and the temperature was maintained at 110 °C for 1 h. DMPU was then eliminated by vacuum distillation (10^{-2} mmHg).

To obtain compounds **9** and **11**, water (50 cm^3) was added to the crude reaction mixture and the aqueous layer was extracted twice with diethyl ether (2 × 100 cm^3) and then with CH_2Cl_2 (50 cm^3). The combined organic extracts were washed with brine, dried ($MgSO_4$) and then evaporated under reduced pressure to give the annulated products **9** and **11** which were finally purified by flash chromatography using ethyl acetate–hexane (2:3) as eluent followed by recrystallization from ethanol (**9a**, **b**) or hexane–toluene (**11a–c**).

For the purification of compounds **10a–c**, the crude reaction mixture was extracted as described above and the combined organic layers were washed three times with dilute aqueous HCl (10%; 50 cm^3). The aqueous phase was then neutralized with $NaHCO_3$, extracted twice with diethyl ether (2 × 100 cm^3) and then with CH_2Cl_2 (50 cm^3). The combined organic extracts were dried with $MgSO_4$ and after removal of the solvents under reduced pressure, the products **10a–c** were purified by flash chromatography using ethyl acetate–hexane (1 : 1) as eluent and finally recrystallized from hexane–toluene.

5-Hydroxy-6,8-diphenyl-1,7-naphthyridine 9a. Pale yellow crystals, mp 188–189 °C (Found: C, 80.3; H, 4.8; N, 9.1. $C_{20}H_{14}N_2O$ requires C, 80.3; H, 4.75; N, 9.4%); $\delta_H(CDCl_3)$ 7.51 (7 H, m), 7.84 (2 H, d, *J* 7.3), 8.10 (2 H, d, *J* 7.3), 8.64 (1 H, dd, *J* 1.6 and 8.5) and 9.03 (1 H, dd, *J* 1.6 and 4.1); $\delta_C(CDCl_3)$ 160.1, 154.2, 151.7, 151.2, 140.8, 140.3, 133.6, 130.6, 130.2, 129.5, 129.1, 128.8, 128.3, 128.2, 124.5, 117.9 and 112.6; *m/z* 298 (M^+, 100%), 297 (54), 192 (14), 166 (28) and 91 (30); ν_{max}/cm^{-1} 3080 (OH) and 1585 (CN).

5-Hydroxy-6,8-di-*p*-tolyl-1,7-naphthyridine 9b. Pale yellow crystals, mp 158–159 °C (Found: C, 80.65; H, 5.6; N, 8.5. $C_{22}H_{18}N_2O$ requires C, 80.95; H, 5.55; N, 8.6%); $\delta_H(CDCl_3)$ 2.41 (3 H,s), 2.44 (3 H, s), 7.31 (2 H, d, *J* 6.8), 7.37 (2 H, d, *J* 6.4), 7.60 (1 H, dd, *J* 4.2 and 8.5), 7.72 (2 H, d, *J* 6.4), 8.00 (2 H, d, *J* 6.8), 8.62 (1 H, dd, *J* 1.8 and 8.5) and 9.02 (1 H, dd, *J* 1.8 and 4.2); $\delta_C(CDCl_3)$ 162.1, 155.3, 152.8, 152.0, 141.3, 140.7, 134.8, 134.2, 132.6, 129.6, 128.3, 128.0, 127.9, 125.7, 119.2, 113.7, 21.3 and 20.9; *m/z* 326 (M^+, 100%), 325 (27), 311 (56), 205 (11) and 180 (21); ν_{max}/cm^{-1} 3100 (OH) and 1591 (CN).

5-Amino-6,8-diphenyl-1,7-naphthyridine 10a. Bright yellow crystals, mp 170–171 °C (Found: C, 81.05; H, 5.0; N, 14.4. $C_{20}H_{15}N_3$ requires C, 80.8; H, 5.1; N, 14.1%); $\delta_H(CDCl_3)$ 4.26 (2 H, br s), 7.46 (6 H, m), 7.58 (1 H, dd, *J* 4.1 and 8.6), 7.83 (2 H, m), 8.11 (2 H, m), 8.28 (1 H, dd, *J* 1.6 and 4.1) and 9.04 (1 H, dd, *J* 1.6 and 4.1); $\delta_C(CDCl_3)$ 162.9, 154.3, 152.6, 148.7, 141.2, 140.9, 133.8, 130.1, 129.5, 128.9, 128.6, 128.3, 128.1, 123.7, 121.3 and 118.8; *m/z* 297 (M^+, 5%), 296 (11), 147 (13), and 91 (100); ν_{max}/cm^{-1} 3363–3448 (NH_2) and 1613 (CN).

5-Amino-6,8-di-*p*-tolyl-1,7-naphthyridine 10b. Bright yellow crystals, mp 194–195 °C (Found: C, 81.2; H, 6.0; N, 12.7. $C_{22}H_{19}N_3$ requires C, 81.2; H, 5.9; N, 12.9%); $\delta_H(CDCl_3)$ 2.40 (3 H, s), 2.42 (3 H, s), 4.35 (2 H, br s), 7.28 (2 H, d, *J* 7.9), 7.32 (2 H, d, *J* 7.9), 7.54 (1 H, dd, *J* 4.1 and 8.6), 7.72 (2 H, d, *J* 7.9), 7.99 (2 H, d, *J* 7.9), 8.23 (1 H, dd, *J* 1.6 and 8.6) and 8.99 (1 H, dd, *J* 1.6 and 4.1); $\delta_C(CDCl_3)$ 163.2, 153.4, 150.8, 147.7, 141.2, 140.5, 134.8, 134.7, 134.3, 130.2, 129.9, 129.4, 128.7, 128.5, 128.3, 122.5, 122.2, 116.2, 22.6 and 21.8; *m/z* 325 (M^+, 100%), 324 (45), 310 (17), 154 (36) and 147 (43); ν_{max}/cm^{-1} 3372–3435 (NH_2) and 1610 (CN).

5-Amino-6,8-bis-(*p*-methoxyphenyl)-1,7-naphthyridine 10c. Bright yellow crystals, mp 177–178 °C (Found: C, 74.2; H, 5.45; N, 12.0. $C_{22}H_{19}N_3O_2$ requires C, 73.95; H, 5.35; N, 11.75%); $\delta_H(CDCl_3)$ 3.86 (3 H, s), 3.88 (3 H, s), 4.32 (2 H, br s), 7.02 (2 H, d, *J* 8.8), 7.06 (2 H, d, *J* 8.8), 7.56 (1 H, dd, *J* 4.1 and 8.6), 7.77 (2 H, d, *J* 8.8), 8.10 (2 H, d, *J* 8.8), 8.25 (1 H, dd, *J* 1.5 and 4.1) and 9.00 (1 H, dd, *J* 1.5 and 4.1); $\delta_C(CDCl_3)$ 162.5, 159.4, 157.3, 155.8, 149.7, 149.2, 140.8, 140.2, 134.7, 130.5, 130.2, 129.6, 129.3, 128.5, 128.2, 128.0, 125.4, 124.3, 118.8, 55.8 and 55.1; *m/z* 357 (M^+, 100%), 356 (18), 342 (21), 179 (26) and 135 (37); ν_{max}/cm^{-1} 3362–3446 (NH_2) and 1615 (CN).

5-Methyl-6,8-diphenyl-1,7-naphthyridine 11a. Fawn plate crystals, mp 171–172 °C (Found: C, 85.1; H, 5.4; N, 9.5. $C_{21}H_{16}N_2$ requires C, 85.1; H, 5.45; N, 9.45%); $\delta_H(CDCl_3)$ 2.69 (3 H, s), 7.53 (8 H, m), 8.17 (2 H, m), 8.46 (1 H, dd, *J* 1.8 and 8.8) and 9.06 (1 H, dd, *J* 1.8 and 4.0); $\delta_C(CDCl_3)$ 157.6, 151.7, 150.3, 140.9, 140.4, 138.8, 132.5, 132.3, 131.2, 130.1, 128.7, 128.1, 127.9, 124.3, 123.3 and 15.4; *m/z* 296 (M^+, 100%) and 147 (54); ν_{max}/cm^{-1} 3052 (CH) and 1543.

5-Methyl-6,8-di-*p*-tolyl-1,7-naphthyridine 11b. Fawn plate crystals, mp 190–191 °C (Found: C, 85.3; H, 6.5; N, 8.65. $C_{23}H_{20}N_2$ requires C, 81.15; H, 6.2; N, 8.65%); $\delta_H(CDCl_3)$ 2.44 (6 H, s), 2.70 (3 H, s), 7.72 (9 H, m), 8.44 (1 H, dd, *J* 1.7 and 8.4) and 9.04 (1 H, dd, *J* 1.7 and 4.3); $\delta_C(CDCl_3)$ 158.9, 151.7, 149.3, 141.5, 140.9, 138.2, 134.8, 134.7, 133.1, 132.0, 130.9, 130.5, 129.6, 129.1, 128.5, 128.2, 124.8, 123.6, 19.6, 19.3 and 15.8; *m/z* 324 (M^+, 100%), 309 (22), 152 (26) and 147 (47); ν_{max}/cm^{-1} 3043 (CH) and 1565.

6,8-Bis(*p*-methoxyphenyl)-5-methyl-1,7-naphthyridine 11c. Fawn plate crystals, mp 184–185 °C (Found: C, 77.6; H, 5.7; N, 7.6. $C_{23}H_{20}N_2O_2$ requires C, 77.5; H, 5.65; N, 7.85%); $\delta_H(CDCl_3)$ 2.69 (3 H, s), 3.87 (3 H, s), 3.88 (3 H, s), 7.03 (2 H, d, *J* 8.8), 7.04 (2 H, d, *J* 9.6), 7.63 (3 H, m), 8.16 (2 H, d, *J* 8.8), 8.41 (1 H, dd, *J* 1.6 and 8.6) and 9.02 (1 H, dd, *J* 1.6 and 4.0); $\delta_C(CDCl_3)$ 166.3, 155.2, 155.0, 150.2, 149.9, 141.8, 141.2, 137.7, 131.8, 131.7, 129.6, 129.0, 128.7, 123.9, 123.6, 114.5, 113.7, 113.0, 55.9, 55.7 and 16.3; *m/z* 356 (M^+, 8%), 341 (5), 256 (100) and 134 (98); ν_{max}/cm^{-1} 3039 (CH) and 1595.

References

1 E. Buncel, *Comprehensive Carbanion Chemistry*, ed. T. Durst, Elsevier Science Publisher, Amsterdam, vols. A, B, C.

2 (*a*) T. Kauffmann, *Angew. Chem., Int. Ed. Engl.*, 1974, **13**, 627; (*b*) T. Kauffmann, K. Habersaat and E. Koppelmann, *Chem. Ber.*, 1977, **110**, 638; (*c*) W. H. Pearson, in *Studies in Natural Product Chemistry, Stereoselective Synthesis (Part A)*, ed. Atta-ur Rahman, Elsevier, Amsterdam, 1988, vol. 1, p. 323; (*d*) W. H. Pearson, M. A. Walters and K. D. Oswell, *J. Am. Chem. Soc.*, 1986, **108**, 2769.

3 (*a*) L. Vo-Quang and Y. Vo-Quang, *Tetrahedron Lett.*, 1977, 3963; (*b*) *J. Heterocycl. Chem.*, 1982, **19**, 145; (*c*) V. Dryanska, C. Ivarov and R. Krusteva, *Synthesis*, 1984, 1038; (*d*) R. A. Gracheva, V. M. Potapov, N. A. Sivov and L. I. Sivova, *J. Org. Chem. USSR*, 1982, **17**, 1963.

4 T. Kauffmann, A. Busch, K. Habersaat and E. Koppelmann, *Chem. Ber.*, 1983, **116**, 492.

5 T. Kauffmann and R. Eidenschink, *Chem. Ber.*, 1977, **110**, 651; *Angew. Chem., Int. Ed. Engl.*, 1973, **12**, 568.
6 (*a*) L. Vo-Quang and Y. Vo-Quang, *Tetrahedron Lett.*, 1980, **21**, 939; (*b*) L. Vo-Quang, Y. Vo-Quang, M. J. Pouet and M. P. Simonnin, *Tetrahedron*, 1981, **37**, 4343.
7 (*a*) T. Kauffmann and R. Eidenschink, *Chem. Ber.*, 1977, **110**, 645; (*b*) D. J. Bower and M. E. H. Howden, *J. Chem. Soc., Perkin Trans. 1*, 1980, 672.
8 L. Vo-Quang, H. Gaessler and Y. Vo-Quang, *Angew. Chem., Int. Ed. Engl.*, 1981, **20**, 880.
9 T. D. Barley, G. L. Goe and E. F. V. Scriven, in *Pyridine and its Derivatives*, ed. G. R. Newkome, Wiley, New York, part 5, ch. 1.
10 R. B. Bates, B. Gordon, P. C. Keller, J. V. Rund and N. S. Mills, *J. Org. Chem.*, 1980, **45**, 168.
11 T. W. Bell and L. Y. Hu, *Tetrahedron Lett.*, 1988, **29**, 4819.
12 H. Mayr, U. W. Heigl and J. Baran, *Chem. Ber.*, 1993, **126**, 1913.
13 J. E. Arrowsmith, M. J. Cook and D. J. Hardstone, *J. Chem. Soc., Perkin Trans. 1*, 1979, 2364.
14 J. K. Smith, D. E. Bergbreiter and M. Newcomb, *J. Org. Chem.*, 1985, **50**, 549.
15 (*a*) W. W. Paudler and T. J. Kress, *Adv. Heterocycl. Chem.*, 1970, **11**, 123; (*b*) W. W. Paudler and R. M. Sheets, *Adv. Heterocycl. Chem.*, 1983, **33**, 143; (*c*) N. J. Weiss and C. R. Hauser, *Heterocyclic Compounds*, Wiley, New York, 1961, vol. 7, p. 198; (*d*) M. Wozniak and H. C. van der Plas, *Heterocycles*, 1982, **19**, 623; (*e*) C. F. Allen, *Chem. Rev.*, 1950, **47**, 275.
16 (*a*) J. T. Adams, C. K. Bradsher, J. S. Breslow, S. T. Amore and C. R. Hauser, *J. Am. Chem. Soc.*, 1946, **68**, 1317; (*b*) H. J. Rapoport and A. D. Batcho, *J. Org. Chem.*, 1963, **28**, 1753.
17 A. Decormeille, F. Guignant, G. Queguiner and P. Pastour, *J. Heterocycl. Chem.*, 1976, **13**, 387.
18 (*a*) H. E. Baumgarten and K. C. Cook, *J. Org. Chem.*, 1957, **22**, 138; (*b*) H. E. Baumgarten and A. L. Krieger, *J. Am. Chem. Soc.*, 1955, **77**, 2438.
19 (*a*) F. Alhaique, F. M. Riccieri and E. Santucci, *Tetrahedron Lett.*, 1975, 173; (*b*) *Gazz. Chim. Ital.*, 1975, **105**, 1001; (*c*) J. Mayer and M. H. Sherlock, USP 4 017 500/1977 (*Chem. Abstr.*, 1977, **87**, 23252); (*d*) USP 3 928 367/1976 (*Chem. Abstr.*, 1976, **84**, 105562).
20 W. H. Pearson, D. P. Szura and W. G. Harter, *Tetrahedron Lett.*, 1988, **29**, 761.
21 W. H. Pearson, D. P. Szura and M. Postich, *J. Am. Chem. Soc.*, 1992, **114**, 1329.
22 T. Mukhopadhyay and D. Seebach, *Helv. Chim. Acta*, 1982, **65**, 385.
23 (*a*) J. Becker, M. C. Christensen and I. Winkelman, *Sulfur Lett.*, 1982, **1**, 43; (*b*) H. Sliwa, *Bull. Soc. Chim. Fr.*, 1970, 631.
24 E. C. Taylor and A. J. Crovetti, *Org. Synth., Coll. Vol. IV*, 1963, 163 and 704.
25 T. Güngor, F. Marsais and G. Queguiner, *J. Organomet. Chem.*, 1981, **215**, 139.
26 F. Guillier, F. Nivoliers, A. Godard, F. Marsais, G. Queguiner, M. A. Siddiqui and V. Snieckus, *J. Org. Chem.*, 1995, **60**, 292.

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