Annelated Derivatives of 2-Phenylquinoline, 2-(2′-Pyridyl)quinoline and 2-Phenyl-1,8-naphthyridine

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Annelated derivatives of 2-phenylquinoline, 2-(2′-pyridyl)quinoline, and 2-phenyl-1,8-naphthyridine have been prepared where the bridging unit contains from one to four methylene units. The conformational properties of these molecules have been analyzed by ^{1}H nmr and uv spectroscopy as well as by pK_a determinations.

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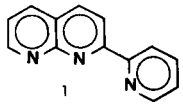
Introduction.

The introduction of sp^2 hybridized nitrogen atoms at non-bridgehead positions on the interior or "bay region" of cavity-shaped molecules provides systems which are of interest as coordinating ligands as well as substrates for cyclometallation processes. We have recently reported on the synthesis and properties of 3,3′-annelated derivatives of 2,2′-bipyridine [1], 2,2′-biquinoline [2], and 2,2′-bi-1,8-naphthyridine [3] as well as a number of bis-annelated derivatives of 2,2′; 6,2″-tripyridine [4]. The length of the annelating bridge was varied from one to four methylene units and was found to control the conformational properties of the system.

In our report on the binaphthyridines we also described three annelated derivatives of 2-(2′-pyridyl)-1,8-naphthyridine **12a-c** [3]. The parent unbridged molecule **1** has also been the subject of a detailed nmr study [5]. Our interest



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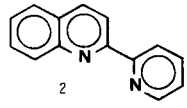

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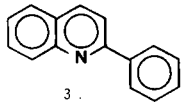

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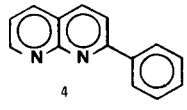

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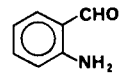
in these systems as well as the ready availability of necessary starting materials led us to prepare 3,3′-annelated derivatives of the closely related **2-4** as well as the tetramethylene bridged **12d** which we had not included in our earlier paper.

The parent, unbridged systems, **1-4** are all known compounds [6-9]. Harris and coworkers reported a high spin Fe(II) complex of **2** [7] while Klassen has prepared the corresponding ruthenium complex and examined its spectroscopy [10]. The tris-complex of ruthenium(II) with **1** has been characterized spectroscopically and electrochemically by Kaska and coworkers [11]. This same group has also prepared and studied a bis-complex of **1** with dirhodium(II) [12]. The reaction of 2-phenylquinoline with palladium chloride has led to a chlorine-bridged dimer of the cyclopalladated material [13]. We are interested in studying the effects which deviations in ligand planarity might have on the transition metal complex chemistry of systems such at **1-4**. Future reports will relate the properties of **9-12** in this regard.

Synthesis.

A straightforward approach to 2,3-cycloalkenopyridines and related systems involves the Friedlander condensation of a β-amino-α,β-unsaturated aldehyde with a cyclic ketone [14]. When 2-aminobenzaldehyde (**5**) or 2-aminonicotinaldehyde (**6**) are utilized in this reaction, 2,3-annelated quinolines or 1,8-naphthyridines [15] may be prepared.



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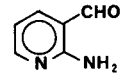

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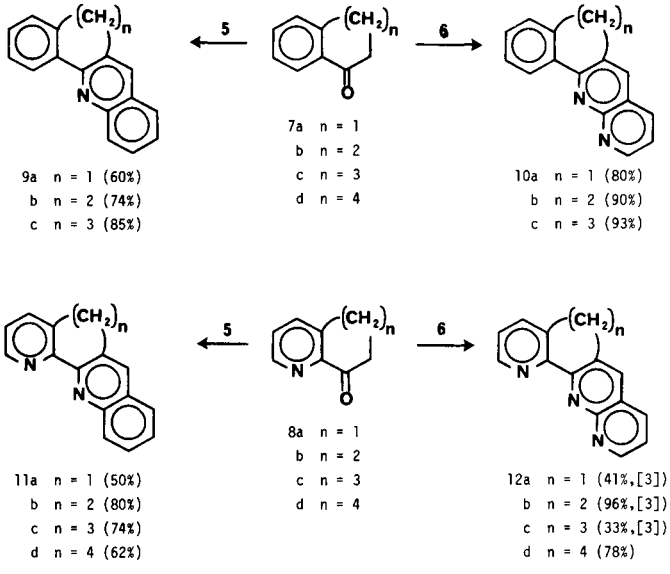
We have recently described a convenient two step method for introducing a carbonyl group at the α-position of 2,3-cycloalkenopyridines which made the series of annelated pyridyl ketones **8a-d** readily available. By employing these ketones as well as the commercially available **7a-c** in base catalyzed Friedlander condensations, the annelated systems **9**, **10**, and **11** were all prepared in good yields (Scheme I). Compounds **12a-c** have previously been reported [3] and we now add **12d** to complete this series. Unfortunately the synthesis of suitable amounts of 2,3-benzocyclooctanone (**7d**) has caused us some difficulty and thus we have postponed preparation of the tetramethylene bridged analogs of **9** and **10**.

It is interesting to note that the yields for the five-membered ring compounds are the lowest obtained in any given series. We have previously noted difficulties in condensation of 1,2-cyclopentanedione [2,3] and α,α'-dioxo-2,3,5,6-ditrimethylenepyridine [4]. It appears that carbonyl group reactivity in annelated ketones such as **7** and

Scheme 1

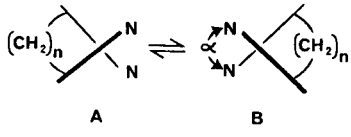


8 may be influenced by the relative coplanarity of the carbonyl group and the adjacent aromatic ring. We are currently giving this question more careful consideration.

Properties.

The title compounds were all characteized and identified by analysis of their 300 MHz nmr spectra in deuteriochloroform. The signal dispersion is sufficient to allow unambiguous assignment of most resonances. Relatively good first order behavior is observed for protons on the heteroaromatic rings and three and four bond H-H couplings can most often be assigned.

As the length of the 3,3′-annelating bridge is increased, the dihedral angle between the two covalently bonded aromatic rings also increases. Figure 1 lists the approximate dihedral angles for the molecules under consideration as estimated from analysis of Dreiding molecular



n	∝	Estimated Barrier
1	0°	0 Kcal/mole
2	20	≤4
3	55	≤13
4	80	

Figure 1

models. It should be noted that when the bridge contains more than one methylene unit a conformational inversion of the non-planar ring is possible, providing an interconvertible pair of enantiomers. Should the barrier to inversion become sufficiently high, the isolation of optical isomers might become possible.

The conformations of the annelated systems **9-12** can best be evaluated by a careful analysis of the methylene region of their proton nmr spectra. If conformational inversion is rapid at room temperature on the nmr time scale, then the two enantiomers A and B (Figure 1) will be rapidly equilibrating. In either conformation the two geminal protons of an α or β-methylene group are chemically distinct and hence magnetically nonequivalent. The chemical shift of the α-methylene protons will depend upon their orientation with respect to the shielding or deshielding region of the adjacent aromatic ring. Differences of up to 0.83 ppm can result. For the monomethylene bridged systems **9-12a**, a singlet is observ-

Table I

Ultraviolet Absorption Data, λmax (95% Ethanol) (ε)

9a	222 (14,320)	312 (9920)
	260 (15,360)	318 (10,620)
		326 (13,770)
		334 (12,620)
		341 (14,360)
9b	224 (13,900)	298 (7660)
	263 (14,670)	315 (8220)
		330 (10,900)
		345 (11,830)
9c	236 (14,600)	283 (6630)
	252 (14,550)	298 (6330)
		312 (7320)
		326 (8000)
10a	254 (27,070)	331 (27,480)
		345 (28,190)
10b	256 (17,400)	335 (14,600)
		349 (15,850)
10c	232 (15,000)	327 (11,300)
11a	220 (13,480)	312 (10,670)
	246 (14,030)	318 (11,570)
	270 (11,280)	326 (12,530)
		332 (13,230)
		341 (13,930)
11b	242 (13,820)	315 (6900)
	269 (7300)	329 (7250)
		343 (6760)
11c	240 (14,100)	310 (5450)
	269 (12,300)	324 (5270)
11d	267 (9520)	308 (4270)
		321 (4420)

Table II

Basicities of 3,3′-Annelated 2-Phenylquinolines

Compound	HNP	Pka
3	398 mV	4.34
9a	382	4.58
9b	393	4.41
9c	370	4.74

ed at about 4.0 ppm as expected for two equivalent protons flanked by two aromatic rings. For the dimethylene bridges of **9-12b**, the CH_2 groups are non-equivalent but the geminal protons are interconverting and two signals are observed which differ by 0.12 ppm. The trimethylene bridges of **9-12c** show two signals for the non-equivalent α-CH_2 groups at about 2.7 and 2.6 ppm as well as one β-CH_2 signal at about 2.25 ppm. The tetramethylene bridges of **11d** and **12d** are much more complex. Four distinct α-CH_2 resonances are observable with chemical shifts which are nearly identical for both molecules spanning the range from 2.13-2.96 ppm. These systems are thus undergoing slow conformational inversion relative to the nmr time scale. An examination of models indicates that two of the α-protons lie more in the plane of the adjacent aromatic ring, accounting for the low field signals at 2.96 and 2.75 ppm. The β-CH_2 protons are more remote from this deshielding region and hence show only two signals at 300 MHz. Similar behavior has been observed for the more symmetrical 3,3'-annelated biquinolines [2] and bi-1,8-naphthyridines [3].

Table I summarizes the principal absorptions to be found in the ultraviolet spectra of **9-11**. Two significant bands are observed, one in the region 220-270 mμ and the second at 310-350 mμ. These bands can be correlated with each of the two covalently bound aromatic nuclei. The phenyl or pyridyl ring accounting for the shorter wavelength band while the more delocalized quinoline or naphthyridine ring gives rise to the longer wavelength band. The quinoline absorption of **9a-c** and **11a-c** show distinct similarities. As conjugative interaction between the two rings increases due to increased coplarity, one would expect to see the absorption maxima shift to lower energy. Although there appears to be somewhat of a trend in this direction, the effect is clearly not uniform. In general, more vibrational fine structure and greater extinction coefficients are observed for systems with a monomethylene bridge. These data are consistent with a more allowed transition resulting from better Franck-Condon overlap between ground and excited states as would be expected for a molecule with less out-of-plane vibrational freedom.

The half-neutralization potentials of 2-phenylquinoline (**3**) and its annelated derivatives **9a-c** have been determined by non-aqueous titration (Table II) and these values have been converted to pK_a by means of a previously established relationship [16]. The basicity of the quinoline ring is dependent upon two factors. Coplanarity of the quinoline ring with 2-phenyl group should help to delocalize charge and increase proton affinity. However, in a coplanar conformation the 6'-hydrogen may sterically inhibit protonation. Examination of the basicity data in Table 2 indicates that steric effects are more important than electronic ones in that the least planar, trimethylene-bridged system, **9c** is the most basic. On these grounds the monomethylene-bridged compound **9a** appears to be more basic than expected. The anticipated pK_a for this rigid, planar system would be less than 4.34. Examination of a model indicates that the phenyl ring is pulled away from the quinoline nitrogen by the monomethylene bridge and in fact the $H_{6'}$-N distance is greater for **9a** than **9b**.

EXPERIMENTAL

Nuclear magnetic resonance spectra were obtained on a Varian Associates T-60 or FT-80 spectrometer or a Nicollet NT-300 WB Spectrometer and chemical shifts are reported in parts per million downfield from TMS. Infrared spectra were obtained on a Perkin Elmer 1330 or a Beckman IR-4250 Spectrophotometer. Ultraviolet spectra were obtained on a Perkin-Elmer 330 Spectrometer. Mass spectra were obtained by direct sample introduction into a Hewlett-Packard 6933A GC-Mass Spectrometer. *o*-Aminobenzaldehyde [17], and 2-aminonicotinaldehyde [18] were prepared according to literature procedures. All solvents were freshly distilled reagent grade and all melting points are uncorrected. Elemental analyses were performed by Canadian Microanalytical Service, Vancouver, B. C. Basicities were determined as half-neutralization potentials by titration with 0.10 *N* perchloric acid in acetic acid by a previously described method [16].

3,2'-Methylene-2-phenylquinoline (**9a**).

To a solution of 1.2 g (9.9 mmoles) of 2-aminobenzaldehyde and 1.32 g (10 mmoles) of 1-indanone in 40 ml of absolute ethanol was added 0.08 g of potassium hydroxide dissolved in 5 ml of absolute ethanol. The solution was refluxed under nitrogen for 19 hours. After evaporation of the solvent, the residue was chromatographed on 70 g of silica gel eluting with 1.5:8.5 ethyl acetate-hexane to give 1.25 g (60%) of **9a** which was recrystallized from ethanol to afford a white solid, mp 167-169°; ^{1}H nmr (deuteriochloroform): 300 MHz δ 8.31 (dd, $H_{6'}$, $J_{5'6'}$ = 7.1, $J_{4'6'}$ = 2.2 Hz), 8.2 (masked d, H_4 and H_8), 7.82 (d, H_5 or $H_{3'}$, J = 7.9 Hz), 7.70 (t, H_7, J = 7 Hz), 7.61 (d, H_5 or $H_{3'}$, J = 7 Hz), 7.52 (m, H_6, $H_{4'}$ and $H_{5'}$), and 4.04 (s, -CH_2-); ir (potassium bromide): 3060, 2900, 1630, 1565, 1505, 1400, 1320, 1100, 965, 900, 775, 740 cm^{-1}; ms: m/e (relative intensity) 218 (M + 1, 17.5), 217 (M, 100), 214 (9), and 189 (8).

Anal. Calcd. for $C_{16}H_{11}N$: C, 88.45; H, 5.10; N, 6.45. Found: C, 87.64; H, 5.18; N, 6.38 [20].

3,2'-Dimethylene-2-phenylquinoline (**9b**).

Following the same procedure as described above for **9a**, 1.1 g (9.1 mmoles) of 2-aminobenzaldehyde and 1.33 g (9.1 mmoles) of 1-tetralone were refluxed for 24 hours and stirred at 25° for 24 hours, to give, after chromatography, 1.54 g (74%) of **9b** which was recrystallized from ethanol to afford a white solid, mp 61-63°; ^{1}H nmr (deuteriochloroform): 300 MHz, δ 8.58 (d, $H_{6'}$, $J_{5'6'}$ = 7.2 Hz), 8.13 (d, H_8, $J_{7,8}$ = 8.4 Hz), 7.92 (s, H_4), 7.75 (d, H_5, $J_{5,6}$ = 8.2 Hz), 7.65 (t, H_7, $J_{6,7}$ = 7.8 Hz), 7.45 (m, H_6, $H_{4'}$ and $H_{5'}$), 7.27 (d, $H_{3'}$, $J_{3',4'}$ = 8.6 Hz), 3.13 (m, -CH_2-), 3.01 (m, -CH_2-); ir (potassium bromide): 3060, 2940, 1605, 1495, 1435, 1415, 1315, 1295, 1100, 955, 910, 860, 770 and 740 cm^{-1}; ms: m/e (relative intensity) 232 (M + 1, 14), 231 (M, 84), 230 (100), 228 (17), 202 (12), 88 (7), 87 (7), 75 (7), and 63 (8).

Anal. Calcd. for $C_{17}H_{13}N$: C, 88.28; H, 5.67; N, 6.06. Found: C, 88.13; H, 5.67; N, 6.07.

3,2'-Trimethylene-2-phenylquinoline (**9c**).

Following the same procedure as described above for **9a**, 1.1 g (9.1 mmoles) of 2-aminobenzaldehyde and 1.39 g (8.7 mmoles) of benzosuberone were refluxed for 24 hours and stirred at 25° for 48 hours to give, after chromatography, 1.80 g (85%) of **9c** as a green oil which solidified upon cooling. Recrystallization from hexane afforded a white

solid, mp 69-71°; ^{1}H nmr (deuteriochloroform): 300 MHz, 8.18 (d, H_8, $J_{7,8}$ = 8.2 Hz), 7.97 (s, H_4), 7.83 (m, H_5 and $H_{6'}$), 7.69 (t, H_7, $J_{6,7}$ = 7.5 Hz), 7.51 (m, H_6), 7.42 (m, $H_{3'}$ and $H_{4'}$), 7.26 (d, $H_{3'}$, $J_{3'4'}$ = 5.4 Hz), 2.69 (m, 2H, α-CH_2-), 2.60 (m, 2H, α-CH_2-), 2.23 (quintet, 2H, β-CH_2-); ir (potassium bromide): 3040, 2920, 2850, 1600, 1490, 1445, 1405, 1310, 1000, 945, 900, 755, and 740 cm^{-1}; ms: m/e (relative intensity) 246 (M + 1, 18), 245 (M, 100), 244 (90), 242 (17), 241 (14), 231 (11), 230 (60), 228 (12), 216 (19), 121 (19), 120 (12), 115 (23) and 108 (27).

Anal. Calcd. for $C_{18}H_{15}N$: C, 88.16; H, 6.12; N, 5.72. Found: C, 88.12; H, 6.17; N, 5.71.

3,2′-Methylene-2-Phenyl-1,8-naphthyridine (**10a**).

Following the same procedure as described above for **9a**, 1.1 g (9 mmoles) of 2-aminonicotinaldehyde and 1.31 g (9.9 mmoles) of 1-indanone were refluxed for 12 hours and stirred at 25° overnight. Unreacted starting materials were recovered by chromatography on 60 g of silica gel, eluting with 1:1 ethyl acetate-hexane; further elution with ethyl acetate afforded 1.55 g (80%) of **10a**, mp 203-205°; ^{1}H nmr (deuteriochloroform): 300 MHz, 9.07 (dd, H_7, $J_{6,7}$ = 4.3, $J_{5,7}$ = 2.0 Hz), 8.41 (dd, $H_{6'}$, $J_{5'6'}$ = 6.4, $J_{4',6'}$ = 2.5 Hz), 8.16 (d, H_4, J = 0.8 Hz), 8.16 (dd, H_5, $J_{5,6}$ = 8 Hz), 7.6-7.5 (m, $H_{3'}$, $H_{4'}$, $H_{5'}$), 7.43 (dd, H_6); 4.03 (s, -CH_2-); ir (potassium bromide): 1630, 1600, 1490, 1400, 1235, 1090, 900, 790, 780 and 735 cm^{-1}; ms: m/e (relative intensity) 219 (17), 218 (100, M), 191 (9), 190 (16), 164 (6), 163 (6).

Anal. Calcd. for $C_{15}H_{10}N_2$: C, 82.54; H, 4.62; N, 12.84. Found: C, 82.33; H, 4.61; N, 12.68.

3,2′-Dimethylene-2-Phenyl-1,8-naphthyridine (**10b**).

Following the same procedure as described above for **9a**, 1.2 g (9.8 mmoles) of 2-aminonicotinaldehyde and 1.58 g (10.8 mmoles) of 1-tetralone were refluxed for 24 hours and stirred at 25° for 12 hours. Unreacted starting materials were recovered by chromatography on 60 g of silica gel eluting with 1.5:8.5 ethyl acetate-hexane. Further elution with 2:3 ethyl acetate-hexane afforded 2.06 g (90%) of **10b** which was sublimed (95°/0.05 mm) to give a pale yellow solid, mp 98-100°; ^{1}H nmr (deuteriochloroform): 300 MHz, 8.90 (dd, H_7, $J_{6,7}$ = 4.3, $J_{5,7}$ = 2 Hz), 8.61 (dd, $H_{6'}$, $J_{5'6'}$ = 6.5, $J_{4',6'}$ = 2.2 Hz), 7.95 (dd, H_5, $J_{5,6}$ = 8.1 Hz), 7.79 (d, H_4, J = 1.15 Hz), 7.31-7.22 (2 t of d and dd, $H_{4'}$, $H_{5'}$ and H_6), 7.12 (m, $H_{3'}$), 3.0 (t, -CH_2-, J = 6.6 Hz), 2.88 (t, -CH_2-); ir (potassium bromide): 3020, 2920, 1610, 1590, 1540, 1480, 1440, 1400, 1310, 905, 780 and 740 cm^{-1}; ms: m/e (relative intensity) 233 (M + 1, 17), 232 (M, 100), 231 (87), 204 (8), 203 (8), 176 (6).

Anal. Calcd. for $C_{16}H_{12}N_2$: C, 82.73; H, 5.21; N, 12.06. Found: C, 82.92; H, 5.26; N, 12.09.

3,2′-Trimethylene-2-Phenyl-1,8-naphthyridine (**10c**).

Following the same procedure as described above for **9a**, 1.24 g (10.2 mmoles) of 2-aminonicotinaldehyde and 1.79 g (11.2 mmoles) of benzosuberone were refluxed for 24 hours and stirred at 25° for 24 hours. Chromatography on 80 g of silica gel eluting with ethyl acetate afforded 2.31 g (93%) of **10c** which was recrystallized from ethyl acetate-hexane to afford a white solid, mp 141-143°; ^{1}H nmr (deuteriochloroform): 300 MHz, 9.05 (m, H_7), 8.18 (d of m, $H_{6'}$, J = 8.1 Hz), 8.01 (d of m, H_5), 7.99 (s, H_4), 7.42 (m, $H_{4'}$, $H_{5'}$, and H_6), 7.26 (m, $H_{3'}$), 2.72 (t, α-CH_2-), 2.60 (t, α-CH_2-), 2.25 (m, β-CH_2-); ir (potassium bromide): 3000, 2940, 1600, 1540, 1465, 1440, 1410, 1310, 1110, 1000, 940, 900, 790 and 740 cm^{-1}; ms: m/e (relative intensity) 247 (M + 1, 18), 246 (M, 100), 245 (80), 243 (18), 242 (12), 232 (12), 231 (58), 218 (63), 109 (12).

Anal. Calcd. for $C_{17}H_{14}N_2$: C, 82.90; H, 5.73; N, 11.37. Found: C, 82.96; H, 5.73; N, 11.36.

3,3′-Methylene-2-(2′-pyridyl)quinoline (**11a**).

Following the same procedure as described above for **9a**, 0.36 g (3.3 mmoles) of 2-aminobenzaldehyde and 0.46 g (3 mmoles) of 5,6-dihydro-7*H*-[1]pyrinden-7-one [3] were refluxed for 24 hours. Chromatography on 25 g of silica gel eluting with ethyl acetate gave 0.33 g (50%) of **11a** which was recrystallized from ethyl acetate-hexane to give a white solid, mp 232-234°; ^{1}H nmr (deuteriochloroform): 300 MHz, δ 8.79 (d, $H_{6'}$, $J_{5',6'}$ = 4.7 Hz), 8.37 (dd, H_8, J $_{7,8}$ = 8.6, $J_{6,8}$ = 1.2 Hz), 8.21 (s, H_4), 7.88 (dd, $H_{4'}$, $J_{4'5'}$ = 7.8, $J_{4'6'}$ = 1.6 Hz), 7.82 (dd, H_5, $J_{5,6}$ = 8.5, $J_{5,7}$ = 2.0 Hz), 7.73 (t of d, H_7, J = 7.7 Hz), 7.54 (t of d, H_6, J = 7.5 Hz), 7.33 (dd, H_5), 3.97 (s, -CH_2-); ir (potassium bromide): 3040, 2920, 1620, 1560, 1400, 1320, 1170, 1120, 780, 750 and 740 cm^{-1}.

Anal. Calcd. for $C_{15}H_{10}N_2$: C, 82.54; H, 4.62; N, 12.84. Found: C, 82.31; H, 4.62; N, 12.78.

3,3′-Dimethylene-2-(2′-pyridyl)quinoline (**11b**).

Following the same procedure as described above for **9a**, 1.2 g (9.9 mmoles) of 2-aminobenzaldehyde and 1.32 g (9 mmoles) of 5,6,7,8-tetrahydro-8-quinolone [3] were refluxed for 24 hours. Chromatography on 70 g of silica gel eluting with ethyl acetate afforded 1.66 g (80%) of **11b** which was recrystallized from ethyl acetate-hexane to give yellow crystals, mp 78-83°; ^{1}H nmr (deuteriochloroform): 300 MHz, 8.84 (d, $H_{6'}$, $J_{5',6'}$ = 4.6 Hz), 8.38 (d, H_8, $J_{7,8}$ = 8.5 Hz), 8.16 (d, $H_{4'}$, $J_{4',5'}$ = 7.7 Hz), 7.98 (s, H_4), 7.76 (d, H_5, $J_{5,6}$ = 8.1 Hz), 7.65 (m, H_7), 7.51 (m, H_6), 7.29 (dd, poorly resolved, $H_{5'}$); 3.16 (t, -CH_2-), 3.04 (t, -CH_2-); ir (potassium bromide): 3040, 2920, 1680, 1600, 1480, 1400, 1300, 1120, 900, 770, 740 and 710 cm^{-1}. The molecule rapidly discolored due to apparent oxidation; it would not analyze correctly.

3,3′-Trimethylene-2-(2′-pyridyl)quinoline (**11c**).

Following the same procedure as described above for **9a**, 1.2 g (9.9 mmoles) of 2-aminobenzaldehyde and 1.75 g (10.9 mmoles) of cyclohepta[*b*]pyridin-9-one [3] were refluxed for 48 hours. Chromatography on 70 g of silica gel eluting with ethyl acetate afforded 1.8 g (74%) of **11c** which was recrystallized from ethyl acetate-hexane to give a white solid, mp 135-136°; ^{1}H nmr (deuteriochloroform): 300 MHz, 8.80 (d, $H_{6'}$, $J_{5',6'}$ = 4.6 Hz), 8.34 (d, H_8, $J_{7,8}$ = 8.5 Hz), 8.03 (s, H_4), 7.83 (d, H_5 or $H_{4'}$, J = 8.1 Hz), 7.71 (t of d, H_7, J = 7.5, J = 1.2 Hz) 7.61 (d, H_5 or $H_{4'}$, J = 7.5 Hz), 7.55 (t, H_6, J = 7.6 Hz), 7.33 (m, $H_{5'}$), 2.73 (t, α-CH_2-, J = 7 Hz), 2.59 (t, α-CH_2-, J = 7 Hz), 2.25 (d, β-CH_2-, J = 7 Hz); ir (potassium bromide): 3040, 2900, 2840, 1560, 1480, 1400, 1110, 1000, 905, 800 and 750 cm^{-1}.

Anal. Calcd. for $C_{17}H_{14}N_2$: C, 82.90; H, 5.73; N, 11.35. Found: C, 82.73; H, 5.76; N, 11.24.

3,3′-Tetramethylene-2-(2′-pyridyl)quinoline (**11d**).

Following the same procedure as described above for **9a**, 0.335 g (1.9 mmoles) of cycloocta[*b*]pyridin-10-one [19] and 0.242 g (2 mmoles) of 2-aminobenzaldehyde were refluxed for 2 hours. Chromatography on silica gel eluting with ethyl acetate afforded 0.31 g (62%) of **11d** which was recrystallized from ethyl acetate-hexane, mp 163°; ^{1}H nmr (deuteriochloroform): 300 MHz, 8.68 (d, $H_{6'}$, $J_{5',6'}$ = 4.7 Hz), 8.25 (d, H_8, $J_{7,8}$ = 8.5 Hz), 8.06 (s, H_4), 7.82 (d, H_5 or $H_{4'}$, J = 8.1 Hz), 7.69 (t, H_7), 7.62 (d, H_5 or $H_{4'}$, J = 7.7 Hz), 7.54 (t, H_6), 7.35 (dd, $H_{5'}$), 2.96 (dd, $1H_\alpha$, J_{gem} = 13.7, $J_{\alpha,\beta}$ = 8.0 Hz), 2.75 (dd, $1H_{\alpha'}$, J_{gem} = 13.7, $J_{\alpha',\beta'}$ = 8.0 Hz), 2,37 (t, 1H), 2.25 (m, 2H), 2.13 (t, 1H), 1.65 (m, 2H); ir (potassium bromide): 1570, 1480, 1440, 1115, 990, 900, 805, and 740 cm^{-1}.

Anal. Calcd. for $C_{18}H_{16}N_2$: C, 83.07; H, 6.15; N, 10.77. Found: C, 83.02; H, 6.19; N, 10.76.

3,3′-Tetramethylene-2-(2′-pyridyl)-1,8-naphthyridine (**12d**).

Following the same procedure as outlined above for **9a**, 0.244 g (2 mmoles) of 2-aminonicotinaldehyde and 0.335 g (1.9 mmoles) of cycloocta[*b*]pyridin-10-one [19] were refluxed for 2 hours. Chromatography on silica gel eluting with ethyl acetate-methanol (1:1) afforded 0.39 g (78%) of a yellow solid which was recrystallized from ethyl acetate-hexane, mp 248-252°; ^{1}H nmr (deuteriochloroform): 300 MHz, 9.11 (dd, H_7, $J_{6,7}$ = 4.2, $J_{5,7}$ = 1.8 Hz), 8.65 (dd, $H_{6'}$, $J_{5',6'}$ = 4.8, $J_{4',6'}$ = 1.6 Hz), 8.19 (dd, H_5, $J_{5,6}$ = 8.1 Hz), 8.08 (s, H_4), 7.61 (dd, $H_{4'}$, $J_{4',5'}$ = 7.7 Hz), 7.46 (dd, H_6), 7.35 (dd, $H_{5'}$), 2.96 (dd, $1H_\alpha$, J_{gem} = 13.8, $J_{\alpha,\beta}$ = 8.0 Hz), 2,75 (dd, $1H_{\alpha'}$, J_{gem} = 13.8, $J_{\alpha',\beta'}$ = 8.0 Hz), 2.42 (m, 1H), 2.24 (m, 2H), 2.13 (m, 1H), 1.62 (m, 2H); ir (potassium bromide): 1530, 1430, 1400, 1300, 1090, 900, 810, and 780 cm^{-1}.

Anal. Calcd. for $C_{17}H_{15}N_3$: C, 78.16; H, 5.75; N, 16.09. Found: C, 77.63; H, 5.78; N, 15.91 [20].

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