The Synthesis and Fluorescent Characteristics of Some Heteroaromatic Derivatives of 2,2′-Bithienyl

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A series of novel, fluorescent derivatives of 2,2′-bithienyl has been prepared and the influence of structure on the absorption and emission spectra has been examined; the substituents introduced in this study were 2-quinolyl, 2-benzoxazolyl, 2-benzothiazolyl (all at the 5-position), 2-benzimidazolyl and 2-indolyl (3- or 5-position). The influence of solvent has also been investigated. For all but the indolyl derivatives, the spectral changes—bathochromic shifts with increasing solvent hydrogen-bonding character—were consistent with $\pi-\pi^*$ emission. In the exceptional cases, small hypsochromic shifts were observed on increasing solvent polarity.

PREVIOUS studies have dealt with the emission characteristics of a series of 5-acyl-2,2′-bithienyls [1] (1) and of a number of derivatives of 2-(2-quinolyl)thiophen,[2] including 5-(2-quinolyl)-2,2′-bithienyl (2; $R^1 = R^2 = H$). A wide range of such 5-heteroaryl derivatives of 2,2′-bithienyl has now been prepared and a study has been made of their absorption and emission spectra; the results are presented here.

RESULTS AND DISCUSSION

Synthetic Methods.—5-(2-Quinolyl)-2,2′-bithienyls (2) with inert substituents (alkyl, halogen, methoxy, dimethoxymethyl) were prepared from the appropriate lithium bithienyls, using the conditions previously described [2] for the parent compound (2; $R^1 = R^2 = H$), in 50—80% yield. Benzimidazolyl- (3), benzoxazolyl- (4), and benzothiazolyl- (5) bithienyls (R = H, Me) were best prepared by the condensation of a 5-cyano-2,2′-bithienyl (7) with an appropriate aniline derivative (8). Attempts to prepare these materials by the condensation of (8) with the corresponding aldehydes (9) or esters (10) using standard conditions [3,4] gave only very low yields (*ca.* 1%). In marked contrast, these approaches were used successfully for the preparation of 5,5′-dimethyl-3-(2-benzimidazolyl)-2,2′-bithienyl (11). The indolyl derivatives (6), (12) were prepared by means of the Fischer indole synthesis.[5]

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[1] R. E. Atkinson and F. E. Hardy, *J. Chem. Soc.* (*B*), 1971, 357.

[2] R. E. Atkinson and P. R. H. Speakman, *J. Chem. Soc.* (*B*), 1971, 2077.

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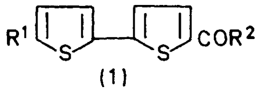
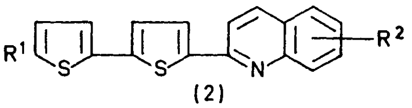
[3] A. Ladenburg, *Ber.*, 1878, **11**, 590.

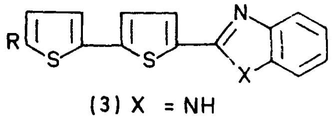
[4] A. Ladenburg, *Ber.*, 1875, **8**, 677.

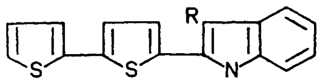
[5] E. Fischer, *Ber.*, 1886, **19**, 1564.

Electrophilic substitution of bithienyls (2; $R^1 = H$) and (3—5; R = H) occurred generally at the 5′-bithienyl position, structural assignments being made on the basis of i.r. spectral changes (*e.g.* disappearance of strong absorption at 840—850 cm^{-1} characteristic[6] of thiophen derivatives with an unsubstituted α-position). Hence, nitration of the parent quinolyl- and benzoxazolylbithienyls gave the corresponding 5′-nitro-derivatives (2; $R^1 = NO_2$, $R^2 = H$) and (4; $R = NO_2$). Similarly, Vilsmeier formylation of 5-(2-benzothiazolyl)-2,2′-bithienyl produced the 5′-formyl derivative (5; R = CHO).

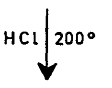

(1)


(2)

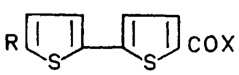

(3) X = NH
(4) X = O
(5) X = S

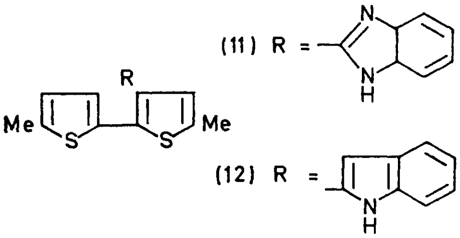

(6)


(7)
(8) X = NH, O, S



(3)-(5)


(9) X = H
(10) X = OEt



Direct bromination of the quinolylbithienyl (2; $R^1 = R^2 = H$) yielded a high-melting red solid which resisted attempts at purification. However, isolation of the 5′-cyano-derivative (2; $R^1 = CN$, $R^2 = H$) from the reaction of this material with cuprous cyanide in pyridine[7] suggests that it was substantially the hydrobromide of the corresponding 5′-bromo-derivative.

Effect of Structure on Fluorescence.—The absorption and emission spectral characteristics of the 5-(2-quinolyl)-2,2′-bithienyls are presented in Table 1. Inspection of these data shows that the introduction of electron-donating groups (alkyl, methoxy) into either the quinoline ring or the 5′-thiophen position had little effect on the fluorescence efficiency of 5-(2-quinolyl)-2,2′-bithienyl. Small bathochromic shifts (<1000 cm^{-1}) were observed for both absorption and emission spectra and are of the usual order for substituents of this type.[2,6] A 5′-dimethoxymethyl substituent also had little effect on fluorescence. For halogen substituents a decrease in fluorescence efficiency was observed on replacing chlorine by bromine; this is also in line with the general trends observed[8] for halogenated fluorescers. A particularly noteworthy feature of these results is the exceptionally low fluorescence efficiency of the 3-bromoquinolyl derivative (2; $R^1 = H$, $R^2 = 3\text{-Br}$); it seems reasonable to attribute this behaviour to a steric interaction with the neighbouring bithienyl moiety.

Of the strongly electron-withdrawing substituents introduced at the 5′-thiophen position, the nitro-group had by far the largest effect, greatly reducing the quantum efficiency of the emission process. Cyano- and formyl residues were responsible for only minor decreases in efficiency; this behaviour may be contrasted with their effect on the fluorescence of 5-acyl-2,2′-bithienyls, the former producing a ten-fold decrease in efficiency and the latter, total quenching.[1] Whilst the cyano-group was without influence on the positions of absorption and emission maxima, large bathochromic shifts were associated with the introduction of the other two substituents.

Fluorescence data for the other bithienyls examined in this study are presented in Table 2. Comparison of the fluorescence efficiencies of the parent 5-heteroaryl derivatives (3—6; R = H) with that of the corresponding quinolylbithienyl (2; $R^1 = H$, $R^2 = H$) shows that the benzimidazolyl, benzoxazolyl, and benzothiazolyl derivatives are all slightly more efficient whilst the indolyl compound is considerably less fluorescent. As expected,[9] the benzothiazole exhibited the longest fluorescent wavelength. A further feature of these data is revealed by comparison of the fluorescence efficiencies for the benzimidazolyl derivatives (3; R = H), and (11) and for the indolyl derivatives (6; R = H) and (12). Clearly, the efficiency of the emission process is not impaired by introducing heteroaryl substituents at position 3 of 2,2′-bithienyl rather than at position 5.

Effect of Solvent on Fluorescence.—For the substituted quinolyl- (2), benzimidazolyl- (3), benzoxazolyl- (4), and benzothiazolyl- (5) bithienyls small red shifts of the absorption maxima and larger red shifts of the associated emission maxima were found on moving from non-polar, aprotic solvents (*e.g.* dioxan, benzene) to polar, hydrogen-bonding solvents (*e.g.* methanol, acetic acid); typical

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[6] R. F. Curtis and G. T. Phillips, *Tetrahedron*, 1967, **23**, 4419.

[7] R. E. Atkinson, R. F. Curtis, and G. T. Phillips, *J. Chem. Soc. (C)*, 1967, 2011.

[8] E. L. Wehry, ' Fluorescence Theory, Instrumentation and Practice,' ed. G. G. Guilbault, Edward Arnold, London, 1967, pp. 55—58.

[9] J. W. Bridges, ' Luminescence in Chemistry,' ed. E. J. Bowen, Van Nostrand, London, 1968, p. 89.

data for 5-(2-benzoxazolyl)-2,2′-bithienyl (4; R = H) are included in Table 3. The magnitude of the shifts involved generally followed solvent polarity as described by the empirical scale of *Z* values [10] although good linear relationships were not generally observed. These solvent effects, which are very similar to those reported previously [2] for 5-(2-quinolyl)-2,2′-bithienyl itself, point to an emission process which is mainly π–π^* in character.[2,11]

TABLE 1

Spectroscopic and analytical data for the 5-(2-quinolyl)-2,2′-bithienyls (2)

Compound R¹	Compound R²	$\bar{\nu}_{max.}$/cm^{-1} absorption	log ε	$\bar{\nu}_{max.}$ [a]/cm^{-1}	Relative fluorescence efficiency [b]	Elemental analysis (%) Found C	Found H	Found N	Theoretical C	Theoretical H	Theoretical N	M.p.
H	H	26,880	4·55	22,350	20·6							c
Me	H	26,320	4·52	21,740	32·6	70·45	4·5	4·6	70·35	4·25	4·55	128—130°
Et	H	26,740	4·00	21,740	28·8	70·9	5·0	4·6	71·0	4·7	4·35	69—70
CN	H	26,740	4·46	22,320	14·2	67·7	3·35	8·8	67·9	3·15	8·8	167
$CH(OMe)_2$	H	26,320	4·33	22,080	20·0							d
CHO	H	25,320	4·56	21,010	17·5							c
NO_2	H	24,270	4·05	21,280	2·9	60·25	2·8	8·6	60·35	3·0	8·3	219
Me	6-Me	26,250	4·50	21,880	24·4	71·2	4·8	4·6	71·0	4·7	4·35	161
H	3-Br	26,320	4·34	21,740	3·3	54·9	2·85	3·8	54·85	2·7	3·75	149—150
H	4-Me	30,580	4·45	22,420	29·3	70·35	4·4	4·35				145—148
H	6-Me	26,670	4·52	22,370	20·1	70·2	4·4	4·6				173
H	6-OMe	26,390	4·32	22,420	23·2	66·9	4·25	4·3	66·85	4·05	4·35	177
H	6-Cl	26,320	4·48	21,980	26·7	62·25	3·1	4·4	62·25	3·05	4·25	136
H	6-Br	26,250	4·43	21,930	11·4	54·8	2·55	4·0				140
H	7-Me	30,580	4·48	22,370	21·3	70·4	4·3	4·65				112—114
H	8-Me	26,740	4·44	22,470	20·0	70·7	4·3	4·65				115

[a] For dilute solutions (<10 mg/l) in ethanol. [b] On this scale, 9,10-diphenylanthracene has an efficiency of 100. [c] See ref. 2.
[d] Yellow oil characterised by hydrolysis to the formyl derivative.

TABLE 2

Spectroscopic and analytical data for the benzimidazolyl- (3) and (11), benzoxazolyl- (4), benzothiazolyl- (5), and indolyl- (6) and (12) -2,2′-bithienyls

Compound	$\bar{\nu}_{max.}$/cm^{-1} absorption	log ε	$\bar{\nu}_{max.}$/cm^{-1} [b] emission	Relative [b] fluorescence efficiency	Elemental analysis (%) Found C	Found H	Found N	Theoretical C	Theoretical H	Theoretical N	M.p. (b.p.)
(3; R = H)	26,740	4·38	23,200	26·2	63·5	3·8	10·0	63·85	3·55	9·9	245—246°
(4; R = H	27,620	4·52	22,730	33·7	63·75	3·4	4·95	63·6	3·2	4·95	125—126
(4; R = Me)	27,030	4·64	22,120	23·7	64·45	3·75	4·7	64·6	3·75	4·7	136
(5; R = H)	27,780	4·47	22,030	30·8	60·05	3·0	4·7	60·2	3·05	4·7	167—170
(5; R = Me)	26,180	4·51	21,010	28·8	61·1	3·6	4·55	61·3	3·55	4·45	136—137
(5; R = CHO)	25,190	4·49	20,920	9·4	58·5	2·8	4·5	58·7	2·75	4·3	180
(6; R = H)	27,250	4·43	22,220	8·6	68·3	3·9	4·9	68·25	3·95	5·0	207—209
(6; R = Me)	27,030	4·46	22,120	8·2	69·5	4·25	4·5	69·1	4·45	4·75	145
(11)	29,850	4·29	22,320	54·2	66·0	4·6	9·05	65·8	4·5	9·0	220—222
(12)	30,030 [a]	4·18	26,040 24,940	9·5	69·75	5·0	4·8	69·9	4·85	4·5	(180/0·1 mm)

[a] Centre of complex multiplet. [b] See Table 1.

TABLE 3

Spectral characteristics of 5-(2-benzoxazolyl)-2,2′-bithienyl (4; R = H) and 5-(2-indolyl)-2,2′-bithienyl (6; R = H) in a range of solvents

Solvent	$\bar{\nu}_{max.}$/cm^{-1} absorption (4; R = H)	(6; R = H)	$\bar{\nu}_{max.}$/cm^{-1} emission (4; R = H)	(6; R = H)	Relative fluorescence efficiency [a] (4; R = H)	(6; R = H)
Dioxan	27,930	26,250	22,990	22,140	18·1	7·1
PhH	27,860	26,880	22,880	22,140	19·8	6·8
$CHCl_3$	27,780	26,880	22,730	22,160	27·1	6·3
Me_2CO	27,780	26,880	22,930	22,270	22·1	8·2
EtOH	27,700	26,880	22,730	22,350	33·7	8·2
MeOH	27,780	26,880	22,730	22,370	33·5	8·5
AcOH	27,740	27,030	22,075	22,350	31·4	8·2
MeOH–H_2O (1 :1)	27,550	26,880	22,220	22,350	44·8	8·2

[a] See Table 1.

The intensity of fluorescence was also influenced by solvent properties, with the highest efficiencies being noted in polar, hydrogen bonding solvents (see Table 3). The variations in efficiency were generally more noticeable for the benzazolylbithienyls than for the quinolyl

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[10] E. M. Kosower, *J. Amer. Chem. Soc.*, 1958, **80**, 3253, 3261.

[11] E. L. Wehry and L. B. Rogers, 'Fluorescence and Phosphorescence Analysis,' ed. D. M. Hercules, Interscience, New York, 1966, pp. 25—135.

derivatives. The effect has been rationalised [2] in terms of a reduction in the extent of vibronic interaction between the lowest π–π^* singlet state and a higher n–π^* state in the polar, hydrogen-bonding medium.

The fluorescence of the 5-(2-indolyl)-2,2′-bithienyls (**6**) showed an unusual solvent effect. Thus, while the absorption spectra were almost unaffected by solvent changes (apart from dioxan and acetic acid, see Table **3**), small hypsochromic shifts in emission maxima were observed on increasing solvent hydrogen-bonding character. It is noteworthy that this behaviour is in marked contrast to the unusually large bathochromic shifts reported [12] for indole itself. A further difference is that, whilst chloroform efficiently quenches the fluorescence of indole it has little effect on that of the indolylbithienyl (**6**; R = H) (Table **3**). Indeed, the fluorescence of the latter is insensitive to solvent variation.

Hypsochromic shifts (especially in the absorption spectra) with increasing solvent hydrogen-bonding character may be expected for heterocyclics whose lowest excited energy level is n–π^* in character.[13,14] However, n–π^* levels usually give rise to only very weak fluorescence and thus it is difficult to rationalise the rather efficient emission from the indolylbithienyl (**6**; R = H) with such a mechanism.

EXPERIMENTAL

The instruments and techniques used and precautions observed in fluorescence measurement have been described previously.[1,2]

The following examples typify the synthetic procedures employed. Physical constants and elemental analytical data are included in Tables 1 and 2.

5-(2-*Quinolyl*)-5′-*nitro*-2-2′-*bithienyl*.—Fuming nitric acid (1·0 ml.) in glacial acetic acid (5·0 ml.) was added to 5-(2-quinolyl)-2,2′-bithienyl (1·0 g.) in acetic anhydride (5·0 ml.). The mixture was stirred (1 hr.) at 20°, poured onto ice, extracted with chloroform, and purified by chromatography over silica to give 5-(2-*quinolyl*)-5′-*nitro*-2,2′-*bithienyl* (88%).

5′-*Cyano*-5-(2-*quinolyl*)-2,2′-*bithienyl*.—Cuprous cyanide (2·0 g.) in pyridine (2·0 ml.) was added to 5′-bromo-5-(2-quinolyl)-2,2′-bithienyl hydrobromide (2·0 g.) [from the bromination of 5-(2-quinolyl)-2,2′-bithienyl in carbon tetrachloride]. The mixture was heated under reflux (4 hr.) and chromatographed on silica to give the required 5′-*cyano-compound* in 20% yield.

5-(2-*Benzimidazolyl*)-2,2′-*bithienyl*.— 5-Cyano-2,2′-bithienyl [5,6] (4·0 g.) *o*-phenylenediamine (2·27 g.), and conc. hydrochloric acid (2·0 ml.) were heated in a sealed tube at 200° for 2 hr. Purification on chromatographic silica gave 5-(2-*benzimidazolyl*)-2,2′-*bithienyl* in 62% yield.

5,5′-*Dimethyl*-3-(2-*benzimidazolyl*)-2,2′-*bithienyl*.—A solution of 5,5′-dimethyl-3-formyl-2,2′-bithienyl [15] (4·0 g.) and *o*-phenylenediamine (2·0 g.) in xylene (20 ml.) and nitrobenzene (2·0 ml.) was heated under reflux (3 hr.). The required *benzimidazolylbithienyl* (22% yield) was purified by sublimation (160°/0·1 mm.).

5′-*Formyl*-5-(2-*benzothiazolyl*)-2,2′-*bithienyl*.—This compound was prepared in 32% yield by the reaction of 5-(2-benzothiazolyl)-2,2′-bithienyl with the Vilsmeier reagent, using the conditions described by Lescot *et al.*[15] for 5-formyl-2,2′-bithienyl.

5-(2-*Indolyl*)-2,2′-*bithienyl*.—5-Acetyl-2,2′-bithienyl [1] (8·6 g.) phenylhydrazine (4·7 g.), and zinc chloride (9·4 g.) were heated to 180° for 30 min. The *indolylbithienyl* was purified by chromatography over silica (yield 28%).

[1/1349 *Received, August 2nd*, 1971]

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[12] B. L. Van Duuren, *J. Org. Chem.*, 1961, **25**, 2954.

[13] Ref. 8, pp. 105—106.

[14] H. Baba, L. Goodman, and P. C. Valenti, *J. Amer. Chem. Soc.*, 1966, **88**, 5410.

[15] E. Lescot, N. P. Buu-Hoï, and N. D. Xuong, *J. Chem. Soc.*, 1959, 3234.