The Stereochemistry and Reactions of Some 3,4-Disubstituted Thiochromans and Related Dihydronaphthothiopyrans

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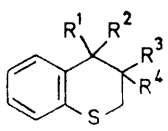
Hydrolysis of *trans*-3,4-dihalogenthiochromans, *trans*-1,2-dibromo-2,3-dihydro-1*H*-naphtho[2.1-*b*]thiopyran, and *trans*-3,4-dibromo-3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran yielded 2-hydroxymethylbenzo[*b*]thiophen, 2-hydroxymethylnaphtho[2,1-*b*]thiophen, and 2-hydroxymethylnaphtho[1,2-*b*]thiophen, respectively. Borohydride reduction of 3-halogenothiochroman-4-ones and related bromodihydronaphthothiopyranones gave *cis*-3-halogenothiochroman-4-ols and the corresponding *cis*-bromodihydronaphthopyranols. The ^{1}H n.m.r. spectra of these compounds show that the hetero-ring adopts the ' sofa ' conformation, with both substituents axial in the *trans*-isomers, and that the most stable conformation of the *cis*-isomer is that in which the substituent at the benzylic position is pseudo-axial.

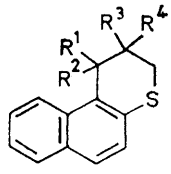
trans-3,4-DIBROMOTHIOCHROMAN (Ia), *trans*-1,2-dibromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran (IIa) and *trans*-3,4-dibromo-3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran (IIIa) were prepared by the addition of bromine to 2*H*-thiochromen (IV),[1] 3*H*-naphtho[2,1-*b*]thiopyran (V), and a mixture (4 : 1) of 2*H*-naphtho[1,2-*b*]- and 4*H*-naphtho[1,2-*b*]-thiopyran (VI) and (VII) in chloroform or carbon tetrachloride. The dibromo-compounds (Ia), (IIa), and (IIIa) were also obtained on treating the corresponding *cis*-bromohydrins (Ib), (IIb), and (IIIb) in benzene with phosphorus tribromide.

Attempts to prepare *trans*-3,4-dichlorothiochroman (Ic) by direct addition of chlorine to 2*H*-thiochromen (IV) in chloroform were unsuccessful, even when carried out at −60°, the dark coloured solid obtained could not be purified. The reactions between *cis*-3-chlorothiochroman-4-ol (Id) and either phosphorus pentachloride or thionyl chloride gave an intractable gum.



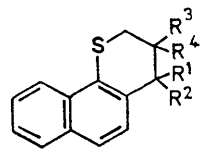
(I)

a; $R^1 = R^4 = Br$
b; $R^2 = OH$, $R^4 = Br$
c; $R^1 = R^4 = Cl$
d; $R^2 = OH$, $R^4 = Cl$
e; $R^1R^2 = O$, $R^4 = Cl$
f; $R^1R^2 = O$, $R^4 = Br$
g; $R^1R^2 = O$
h; $R^2 = OAc$, $R^4 = Br$
i; $R^2 = OAc$, $R^4 = Cl$



(II)

a; $R^1 = R^4 = Br$
b; $R^2 = OH$, $R^4 = Br$
c; $R^1R^2 = O$, $R^4 = Br$
d; $R^1R^2 = O$
e; $R^2 = OH$
f; $R^2 = Br$
g; $R^1 = R^2 = R^3 = R^4 = H$
h; $R^2 = OAc$, $R^4 = Br$

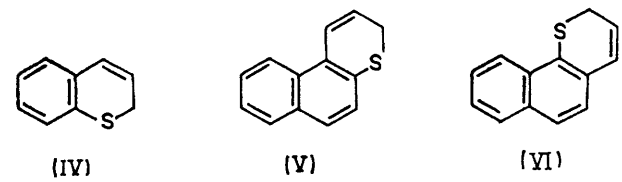


(III)

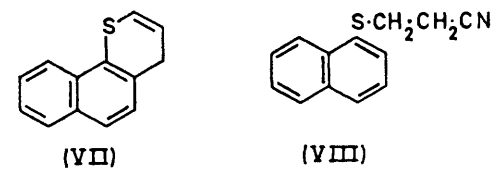
a; $R^1 = R^4 = Br$
b; $R^2 = OH$, $R^4 = Br$
c; $R^1R^2 = O$, $R^4 = Br$
d; $R^1R^2 = O$
e; $R^2 = OH$
f; $R^2 = OAc$, $R^4 = Br$

R^{1-4} = H unless otherwise stated.

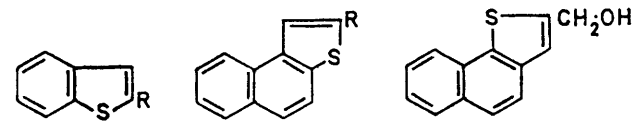
cis-3-Chlorothiochroman-4-ol (Id), *cis*-3-bromothiochroman-4-ol (Ib), 2-bromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran-1-ol (IIb), and 3-bromo-3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran-4-ol (IIIb) were prepared by sodium borohydride reduction of the corresponding



(IV) (V) (VI)



(VII) (VIII)



(IX) (X) (XI)

a; R = CH_2·OH
b; R = H
c; R = CO_2H
d; R = CO_2Me
e; R = CH_2·OMe
f; R = CH_2·ONa

a; R = CH_2·OH
b; R = CH_2·OMe
c; R = CH_2·ONa

halogeno-ketones (Ie), (If),[2] (IIc), and (IIIc). The chloro-ketone (Ie) was obtained by treating thiochroman-4-one (Ig) [3] with an equimolecular quantity of sulphuryl chloride in chloroform at <10°. The bromodihydronaphthothiopyrones (IIc) and (IIIc) were formed on treating the corresponding dihydronaphthothiopyrones (IId) and (IIId) with a molar proportion of bromine in chloroform.

3*H*-Naphtho[2,1-*b*]thiopyran (V) was obtained by the dehydrobromination of 1-bromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran (IIf) and also by the dehydration of 2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran-1-ol (IIe) [4] with anhydrous copper sulphate in boiling benzene. Attempts to prepare 3*H*-naphtho[2,1-*b*]thiopyran

[1] W. E. Parham and R. Koncos, *J. Amer. Chem. Soc.*, 1961, **83**, 4034.
[2] F. Arndt, W. Fleming, E. Scholz, W. Lowensohn, and G. Kallner, *Ber.*, 1925, **58**, 1612; F. Krollpfeiffer, H. Schultze, E. Schlumbohm, and E. Sommermeyer, *ibid.*, p. 1654.
[3] W. E. Truce and J. P. Milionis, *J. Amer. Chem. Soc.*, 1952, **74**, 974; F. Krollpfeiffer and H. Schultze, *Ber.*, 1923, **56**, 1819.
[4] T. E. Young and C. J. Ohnmacht, *J. Org. Chem.*, 1967, **32**, 444.

(V) by dehydrating 2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran-1-ol (IIe) with potassium hydrogen sulphate or polyphosphoric acid afforded 2,3-dihydro-1*H*-naphtho[2,1-*b*]pyran (IIg),[5] which presumably arises through an intermolecular hydride shift reaction.[6]

Dehydration of 3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran-4-ol (IIIe)[4] in boiling benzene containing anhydrous copper sulphate gave a mixture (4 : 1) of 2*H*-naphtho[1,2-*b*]thiopyran (VI) and 4*H*-naphtho[1,2-*b*]thiopyran (VII), which could not be separated by distillation. The presence of the isomeric benzothiochromens (VI) and (VII) was deduced from the ^{1}H n.m.r. spectrum of the mixture. 2,3-Dihydronaphtho[1,2-*b*]thiopyran-4-one (IIId) was obtained on treating 3-(1-naphthylthio)propiononitrile (VIII) with 85% sulphuric acid at room temperature. Treatment of the ketone (IIId) with sodium borohydride gave 3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran-4-ol (IIIe).

Hydrolysis of *trans*-3,4-dibromothiochroman (Ia) in aqueous acetone alone or containing an equimolecular acid qu:IIId)[7] of potassium hydroxide was accompanied by ring-contraction with the formation of 2-hydroxymethylbenzo[*b*]thiophen (IXa).[7] The structure of the hydrolysis product (IXa) was deduced from its u.v. spectrum {which closely resembles that[8] of benzo[*b*]thiophen (IXb)} and its i.r. and ^{1}H n.m.r. spectra, and from the fact that oxidation with potassium permanganate in acetone afforded the known benzo[*b*]thiophen-2-carboxylic acid (IXc).[9] Confirmation of the structure of the hydrolysis product (IXa) was provided by its synthesis from methyl benzo[*b*]thiophen-2-carboxylate (IXd)[9] by lithium aluminium hydride reduction. A mechanism for the ring contraction of *trans*-3,4-dibromothiochroman (Ia) to 2-hydroxymethylbenzo[*b*]thiophen (IXa) has been reported previously.[10]

trans-1,2-Dibromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran (IIa) and *trans*-3,4-dibromo-3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran (IIIa) were also found to undergo ring contraction on treatment with aqueous acetone, giving 2-hydroxymethylnaphtho[2,1-*b*]thiophen (Xa) and 2-hydroxymethylnaphtho[1,2-*b*]thiophen (XI), respectively. The structures of compounds (Xa) and (XI) were assigned by analogy with 2-hydroxymethylbenzo[*b*]thiophen (IXa) and were supported by i.r. and ^{1}H n.m.r. spectral data.

Ring contraction of *trans*-3,4-dibromothiochroman (Ia) and *trans*-1,2-dibromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran (IIa) also occurred in methanol with the formation of 2-methoxymethylbenzo[*b*]thiophen (IXe) and 2-methoxymethylnaphtho[2,1-*b*]thiophen (Xb), respectively. The methoxymethyl compounds (IXe) and (Xb) were also obtained on treating the corresponding sodium thienylmethoxides (IXf) and (Xc) with methyl iodide.

^{1}H N.m.r. spectroscopy was used to determine the configurations of the *trans*-dihalogeno-compounds (Ia), (IIa), and (IIIa), and the related *cis*-halogenohydroxy-derivatives (Ib), (Id), (IIb), and (IIIb), and the conformation of the dihydrothiopyran ring. In the case of *cis*-3-chloro- and 3-bromo-thiochroman-4-ols (Ib and d), support for the assignment of configuration was provided by the fact that dehydrohalogenation with potassium hydroxide gave thiochroman-4-one (Ig).[11] Analysis of the ^{1}H n.m.r. spectra of the *cis*-halogenothiochroman-4-ols (Ib and d), 2-bromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]-thiopyran-1-ol (IIb), and 3-bromo-3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran-4-ol (IIIb) proved to be difficult, and the configuration of these compounds was determined indirectly from the ^{1}H n.m.r. spectral data of their acetyl derivatives (Ih), (Ii), (IIh), and (IIIf).

N.m.r. spectral parameters of *cis*- and *trans*-disubstituted thiochromans and dihydronaphthothiopyrans

		δ (p.p.m.)					Coupling constants (Hz)					
Compound	Aromatic	H_X	H_M	H_A	H_B	OAc	$^2J_{AB}$	$^3J_{AM}$	$^3J_{BM}$	$^3J_{MX}$	$^4J_{BX}$	$^4J_{AX}$
(Ia)	6·88—7·40	5·55	4·95	4·28	3·06		14·4	2·6	4·0	3·5	1·5	0
(IIa)	7·03—8·05	6·14	5·1	4·41	3·21		14·0	2·5	3·9	3·6	1·5	0
(IIIa)	7·16—8·25	5·7	5·08	4·33	3·25		14·0	2·5	4·0	3·5	1·5	0
(Ih)	6·90—7·50	6·24	4·63	3·8	3·13	2·10	12·1	12·0	4·0	2·5	1·2	0
(Ii)	6·91—7·50	6·23	4·56	3·67	3·05	2·10	12·1	11·7	4·0	2·6	1·3	0
(IIh)	7·00—8·30		4·7	3·91	3·13	2·10	11·8	12·6	3·6	2·4	1·1	0
(IIIg)	7·20—8·10	6·38	4·37	3·87	3·30	2·11	12·0	12·0	3·9	2·8	1·3	0

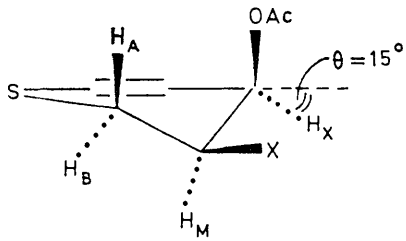
The protons in the hetero-ring of the *cis*-acetoxy-halogeno-compounds (Ih), (Ii), (IIh), and (IIIf) show similar coupling constants and chemical shifts (Table) and in the following discussion it has been assumed that the dihydrothiopyran ring adopts the same conformation in all the compounds. Application of the Karplus relationship[12] to the coupling constants $^3J_{AM}$ (*ca.* 12·0 Hz) and $^3J_{MX}$ (*ca.* 2·6 Hz) indicates that bonds C–H_A and C–H_M (XII) are in an antiperiplanar orientation and that bonds C–H_X and C–H_M are synclinal. This evidence supports a *cis*-configuration for the acetoxy- and halogeno-substituents and also shows that the most stable conformation is one in which the acetoxy-group is *pseudo*-axial and the halogeno-substituent is equatorial.

Dreiding models show that the introduction of the C–S

[5] P. Cagniant and P. Cagniant, *Bull. Soc. chim. France*, 1961, 1560.
[6] B. D. Tilak, H. S. Desai, C. V. Deshpande, S. K. Jain, and V. M. Vaidya, *Tetrahedron*, 1966, **22**, 7.
[7] F. F. Blicke and D. G. Sheets, *J. Amer. Chem. Soc.*, 1949, **71**, 2856.
[8] G. M. Badger and B. J. Christie, *J. Chem. Soc.*, 1956, 3438.
[9] R. Weissenberger and O. Kruber, *Ber.*, 1920, **53**, 1551.
[10] H. Hofmann and G. Salbeck, *Angew. Chem. Internat. Edn.*, 1969, **8**, 456.
[11] P. D. Bartlett, *J. Amer. Chem. Soc.*, 1935, **57**, 224.
[12] M. Karplus, *J. Amer. Chem. Soc.*, 1963, **85**, 2870.

bonds considerably modifies the conformation of the dihydrothiopyran ring relative to the analogous dihydropyran structure. The conformation (XII) adopted by the dihydrothiopyran ring must have bonds C–H_A and C–H_M near antiperiplanar, bonds C–H_B and C–H_X part of a ' planar W ' system [13] ($^4J_{BX}$ *ca.* 1·3 Hz) and the C–OAc bond antiperiplanar to C–H_M. [J_{MX} (*cis*) < J_{MX} (*trans*) owing to the electronegativity effect of substituents on vicinal coupling constants.[14]]

The models show that the ' sofa ' form (XII) accommodates these features best. The half-chair conformation (*cf.* the oxygen analogue [15]) is not a favourable

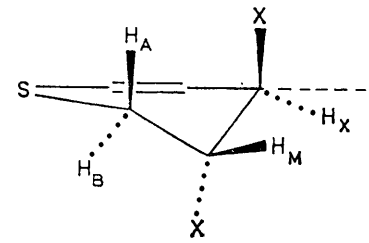


(XII)

alternative since it has considerable angle strain, and the relative proton orientations do not match the observed coupling constants ($\phi_{AM} < 180°$, $\phi_{BX} > 0°$). Further evidence for the sofa conformation may be obtained from chemical shifts of H_X in the benzo- and the naphtho-pyran and related thiopyran series. Although the present work supports the sofa conformation in the hetero-ring, conformational equilibrium between sofa and half-chair forms seems likely and in the equilibrium mixture the sofa form predominates.

The chemical shift difference (Δ_{a-b} 0·65 p.p.m.) between H_X in *cis*-1-acetoxy-2-bromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]pyran and in *cis*-4-acetoxy-3-bromochroman [16] may be explained in terms of an enhanced anisotropic effect [17] due to the additional benzene ring in the former compound. In the corresponding thiopyran compounds (Ih and IIh) the chemical shift difference is greater (Δ_{a-b} 0·78 p.p.m.). This increase may be explained by the oxygen and sulphur hetero-rings adopting different conformations. In compound (IIh), with the hetero-ring in a sofa conformation, steric interaction between H_X (H-1) and H-10 leads to van der Waal's deshielding [16–18] of H_X, but in the half-chair form of the oxygen analogue H_X and H-10 are separated by a distance greater than the sum of their van der Waal's radii, and deshielding due to steric interaction does not occur.

The *trans*-dibromo-compounds (Ia), (IIa), and (IIIa) show similar n.m.r. spectral parameters and are considered together. The values of $^3J_{AM}$ (*ca.* 2·5 Hz) and $^3J_{BM}$ (*ca.* 4·0 Hz) indicate that the C–H_M bond bisects the angle formed by the methylene group; thus H_M is in an equatorial position and $^3J_{AM} < {}^3J_{BM}$ since the C–H_A and C–Br bonds are antiperiplanar.[14] The observation of the long-range coupling constant ($^4J_{BX}$ 1·5 Hz) signifies that the C–H_X and C–H_B bonds are locked in a ' planar W ' conformation [13] and that H_X is equatorial. The evidence that H_X is again more deshielded in the dihydronaphthothiopyran (Δ_{a-b} 0·59 p.p.m.) than in the corresponding oxygen series (Δ_{a-b} 0·49 p.p.m.), together with the fact that C–H_X and C–H_B must approach coplanarity suggests that the hetero-ring again adopts the sofa conformation. The compounds (Ia), (IIa), and (IIIa) exist predominantly in the sofa conformation (XIII), in which both halogeno-substituents are axial; the alternative conformation is destabilised by dipole–dipole repulsion between the equatorial halogen atoms. The sofa conformation which has been proposed for the sulphur hetero-ring in the previous discussion has five coplanar atoms with the



(XIII)

carbon atom β to the heteroatom lying out of the plane; this differs from a sofa conformation [19] proposed for the dihydropyran ring in chroman in which it is the carbon atom α to the heteroatom which lies out of the plane of the other five atoms.

EXPERIMENTAL

The n.m.r. spectra were obtained with a Varian A60A spectrometer for *ca.* 10% solutions in deuteriochloroform and were analysed as ABMX systems. The errors in coupling constants values are <0·3 Hz and in the chemical shifts are <0·02 p.p.m.

M.p.s were determined with a Kofler hot-stage apparatus. The acetates were prepared in the cold by use of acetic anhydride–pyridine.

3-(1-*Naphthylthio*)*propiononitrile* (VIII).—Naphthalene-1-thiol (50 g) [20] was added dropwise to stirred freshly distilled acrylonitrile (100 ml) containing Triton B (aqueous 40%; 1 ml) at <10°. The mixture was allowed to warm to room temperature and kept overnight. Excess of acrylonitrile was removed under reduced pressure; the residue was dissolved in ether, washed with 2N-hydrochloric acid, then water, and dried ($MgSO_4$). Removal of the solvent and distillation afforded 3-(1-*naphthylthio*)*propiononitrile* (50·4 g, 76%), as a liquid, b.p. 193—195° at 2·5 mmHg, n_D^{18} 1·643

[13] M. Barfield, *J. Chem. Phys.*, 1964, **41**, 3825.
[14] H. Booth, *Tetrahedron Letters*, 1965, 411.
[15] W. D. Cotterill, J. Cottam, and R. Livingstone, *J. Chem. Soc.* (C), 1970, 1006.
[16] W. D. Cotterill and R. Livingstone, unpublished work.
[17] C. E. Johnson, jun. and F. A. Bovey, *J. Chem. Phys.*, 1958, **29**, 1012; N. Jonathan, S. Gordon, and B. P. Dailey *ibid.*, 1962, **36**, 2443.
[18] M. J. Stephen, *Mol. Phys.*, 1958, **1**, 223; B. B. Haward, B. Linder, and M. T. Emerson, *J. Chem. Phys.*, 1962, **36**, 485.
[19] J. W. Clark-Lewis, *Rev. Pure Appl. Chem.*, 1962, **12**, 96; E. M. Philbin and T. S. Wheeler, *Proc. Chem. Soc.*, 1958, 167.
[20] E. Bourgeois, *Rec. Trav. chim.*, 1899, **18**, 144.

(Found: C, 73·25; H, 5·15; N, 6·6; S, 15·0. $C_{13}H_{11}NS$ requires C, 73·4; H, 5·35; N, 6·85; S, 15·0%).

2,3-*Dihydronaphtho*[1,2-b]*thiopyran-4-one* (IIId).—3-(1-Naphthylthio)propiononitrile (40 g) was added in one portion to stirred 85% sulphuric acid (400 g) at room temperature. After being stirred for 2 h the mixture was poured into water and set aside overnight. Filtration, washing with water, trituration with 5% sodium hydroxide solution, and washing with water again yielded a gummy solid. Recrystallisation from n-propanol afforded 2,3-dihydronaphtho[1,2-*b*]thiopyran-4-one (6·6 g, 16·5%), as bright yellow plates, m.p. 108—109° (lit.,[11] 107°).

2,3-*Dihydro*-1H-*naphtho*[2,1-b]*thiopyran*-1-*ol* (IIe).—Sodium borohydride (0·9 g) dissolved in water (5 ml) was added dropwise to a stirred suspension of 2,3-dihydronaphtho[2,1-*b*]thiopyran-1-one[21] (10 g) in methanol (100 ml) at room temperature. Stirring was continued for 1 h after the formation of a colourless solution. Dilution with water yielded a solid, which was separated by filtration and recrystallised from aqueous methanol (1 : 9) to give 2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran-1-ol (6·7 g, 67%), m.p. 134—135° (lit.,[4] 128—130°).

3,4-*Dihydro*-2H-*naphtho*[1,2-b]*thiopyran*-4-*ol* (IIIe).—(*a*) Finely powdered 2,3-dihydronaphtho[1,2-*b*]thiopyran-4-one (4·37 g), sodium borohydride (0·4 g), water (4·0 ml), and methanol (50 ml) were stirred at room temperature for 2 h. Dilution with water afforded a pink solid (4·2 g), m.p. 93—95°, which was separated by filtration and dried ($CaCl_2$ desiccator). Recrystallisation from ethyl acetate–light petroleum (b.p. 80—100°) gave 3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran-4-ol (3·8 g, 88%) as needles, m.p. 94—95° (lit.,[4] 94—95·5°).

(*b*) Powdered 2,3-dihydronaphtho[1,2-*b*]thiopyran-4-one (4·05 g) was added in small portions to a stirred slurry of lithium aluminium hydride (0·4 g) in tetrahydrofuran (20 ml; distilled from $LiAlH_4$ in N_2). The mixture was stirred at room temperature for 0·5 h, then boiled gently for 5 min, and cooled. Pouring on ice and acidification with 2N-hydrochloric acid afforded a solid, which when treated as before gave 3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran-4-ol (2·6 g, 63%), m.p. and mixed m.p. 94—95°.

3-*Chlorothiochroman*-4-*one* (Ie).—Sulphuryl chloride (9·9 ml) in chloroform (50 ml) was added dropwise to a stirred solution of thiochroman-4-one (20 g) in chloroform (50 ml) at $<10°$. The mixture was then allowed to warm to room temperature, and the solvent was removed at $<20°$ to give a yellow gummy solid, which was extracted with ether and chromatographed on alumina. Removal of the solvent yielded a yellow solid (2·1 g, 9%) which on recrystallisation gave 3-*chlorothiochroman*-4-*one*, as needles, m.p. 79—80° (Found: C, 54·8; H, 3·3; Cl, 17·6; S, 16·4. C_9H_7ClOS requires C, 54·5; H, 3·5; Cl, 17·9; S, 16·1%).

Bromodihydronaphthothiopyranones.—Several drops of a solution of bromine [1·2 ml for (i); 0·6 ml for (ii)] in chloroform (10 ml) were added to a solution of dihydronaphthothiopyranone (5 g) in chloroform (20 ml). The mixture was warmed gently [in (i)] or set aside [in (ii)] until decolourised. The remainder of the bromine–chloroform solution was added dropwise with stirring at $<10°$. After 1 h the solvent was removed at room temperature and the residue treated as indicated.

(i) 2-*Bromo*-2,3-*dihydronaphtho*[2,1-b]*thiopyran*-1-*one* (IIc), prepared from 2,3-dihydronaphtho[2,1-*b*]thiopyran-1-one (57%), had m.p. 131—133° (residue recrystallised from chloroform–methanol gave bright yellow flakes) (Found: C, 53·3; H, 2·85; Br, 27·65; S, 10·95. $C_{13}H_9BrOS$ requires C, 53·2; H, 3·05; Br, 27·3; S, 10·9%).

(ii) 3-*Bromo*-2,3-*dihydronaphtho*[1,2-b]*thiopyran*-4-*one* (IIIc), prepared from 2,3-dihydronaphtho[1,2-*b*]thiopyran-4-one (20%), had m.p. 109—111° (the residual oil on trituration with ether yielded a yellow solid, which was recrystallised from ethanol to give yellow flakes) (Found: C, 53·45; H, 3·2; Br, 27·6; S, 10·8. $C_{13}H_9BrOS$ requires C, 53·2; H, 3·05; Br, 27·3; S, 10·9%).

cis-3-*Halogenothiochroman*-4-*ols*.—Sodium borohydride (1·5 g) was added to the 3-halogenothiochroman-4-one (5·0 g) in methanol (25—50 ml). After 2 h dilution with water yielded a solid, which was separated by filtration, dried, and recrystallised from light petroleum (b.p. 80—100°).

(i) cis-3-*Bromothiochroman*-4-*ol* (Ib), prepared from 3-bromothiochroman-4-one[2] (70%), had m.p. 83—84° (Found: C, 47·2; H, 4·2; Br, 34·6. C_9H_9BrOS requires C, 47·2; H, 3·9; Br, 34·9%); *acetate*, m.p. 120—121° (needles from methanol) (Found: C, 45·8; H, 3·9; Br, 28·1; S, 11·3. $C_{11}H_{11}BrO_2S$ requires C, 46·0; H, 3·8; Br, 27·9; S, 11·2%).

(ii) cis-3-*Chlorothiochroman*-4-*ol* (Id), prepared from 3-chlorothiochroman-4-one (52%), had m.p. 105—106° (Found: C, 53·85; H, 4·5; Cl, 17·7; S, 15·8. C_9H_9ClOS requires C, 54·05; H, 4·7; Cl, 17·5; S, 16·0%); *acetate*, m.p. 94—95° (needles from aqueous methanol) (Found: C, 54·0; H, 4·8; Cl, 14·8; S, 13·3. $C_{11}H_{11}ClO_2S$ requires C, 54·4; H, 4·5; Cl, 14·6; S, 13·2%).

cis-*Bromodihydronaphthothiopyranols*.—Sodium borohydride (0·5—1 g) in water (3—5 ml) was added dropwise to a stirred suspension of bromodihydronaphthothiopyranone (4 g) in methanol (50—100 ml) at room temperature, and the mixture was stirred for a further 2 h. Pouring into water followed by filtration and drying ($CaCl_2$ desiccator) gave the crude *cis*-bromodihydronaphthopyranol. Analytical samples were obtained by recrystallisation from ethyl acetate–light petroleum (b.p. 60—80°).

(i) cis-2-*Bromo*-2,3-*dihydro*-1H-*naphtho*[2,1-b]*thiopyran*-1-*ol* (IIb). This compound in crude form {prepared from 2-bromo-2,3-dihydronaphtho[2,1-*b*]thiopyran-1-one (87%)} had m.p. 110—114° (decomp.); analytical sample, m.p. 116—119° (decomp.) (Found: C, 53·05; H, 3·6; Br, 27·4; S, 10·7. $C_{13}H_{11}BrOS$ requires C, 52·9; H, 3·7; Br, 27·1; S, 10·85%); *acetate*, m.p. 132—134° (decomp.) (needles from methanol) (Found: C, 53·65; H, 4·0; Br, 23·5; S, 9·8. $C_{15}H_{13}BrO_2S$ requires C, 53·4; H, 3·85; Br, 23·7; S, 9·5%).

(ii) cis-3-*Bromo*-3,4-*dihydro*-2H-*naphtho*[1,2-b]*thiopyran*-4-*ol* (IIIb). This compound in crude form {prepared from 3-bromo-2,3-dihydronaphtho[1,2-*b*]thiopyran-4-one (79%)} had m.p. 90—95°; analytical sample, m.p. 101—103° (Found: C, 53·1; H, 3·8; Br, 27·4; S, 11·05. $C_{13}H_{11}BrOS$ requires C, 52·9; H, 3·7; Br, 27·1; S, 10·85%); *acetate*, m.p. 111·5—113·5° (needles from methanol) (Found: C, 53·2; H, 4·1; Br, 24·0; S, 9·7. $C_{15}H_{13}BrO_2S$ requires C, 53·4; H, 3·85; Br, 23·7; S, 9·5%).

3H-*Naphtho*[2,1-b]*thiopyran* (V).—(*a*) 2,3-Dihydro-1*H*-naphtho[2,1-*b*]thiopyran (2·7 g) and phosphorus tribromide (2·7 g) in dry benzene (50 ml) were stirred at room temperature for 2 days. The benzene solution was decanted from the gummy solid formed and treated with triethylamine (5 ml). After 0·5 h at room temperature the mixture was boiled for 10 min, cooled, washed with water, and dried ($MgSO_4$). Removal of the solvent and recrystallisation

[21] G. B. Bachmann and H. A. Levine, *J. Amer. Chem. Soc.*, 1947, **69**, 2341.

from light petroleum (b.p. 40—60°) (carbon) gave 3H-*naphtho*[2,1-b]*thiopyran* (0·99 g, 40%), as small flakes, m.p. 90—92° (C, 78·5; H, 5·0; S, 16·4. $C_{13}H_{10}S$ requires C, 78·8; H, 5·05; S, 16·1%).

(*b*) 2,3-Dihydro-1*H*-naphtho[2,1-*b*]thiopyran-1-ol (1·4 g), anhydrous copper sulphate (0·7 g), and dry benzene (50 ml) were boiled for 24 h with azeotropic removal of water (Dean–Stark apparatus). Filtration and removal of the solvent gave a red solid, which was dissolved in the minimum of benzene and chromatographed on alumina [light petroleum (b.p. 60—80°) as eluant]. Removal of the solvent and recrystallisation as in (*a*) yielded 3*H*-naphtho-[2,1-*b*]thiopyran (0·66 g, 51%), m.p. and mixed m.p. 89·5—91·5°.

(*c*) 2,3-Dihydro-1*H*-naphtho[2,1-*b*]thiopyran-1-ol (1·0 g) and acetic acid (10 ml) were boiled for 10 min. The product was poured into water and isolated with ether; the residue obtained was dissolved in the minimum of benzene and chromatographed on alumina [light petroleum (b.p. 60—80°) as eluant]. Removal of the solvent and recrystallisation as in (*a*) yielded 3*H*-naphtho[2,1-*b*]thiopyran (0·24 g, 38%), m.p. and mixed m.p. 88·5—90·5°.

Attempted Preparation of 2H-*Naphtho*[1,2-b]*thiopyran* (VI).—3,4-Dihydro-2*H*-naphtho[1,2-*b*]thiopyran (4·01 g), anhydrous copper sulphate (2·0 g), and dry benzene (100 ml) were boiled for 12 h under Dean–Stark head. Filtration and removal of the solvent afforded a gum, which was dissolved in the minimum of benzene and chromatographed on alumina [light petroleum (b.p. 60—80°) as eluant]. Removal of the solvent gave a gum, a mixture of 2*H*-naphtho[1,2-*b*]thiopyran (VI) and 4*H*-naphtho[1,2-*b*]thiopyran (VII); δ 7·26—8·33 (complex m, aromatic protons), 6·58 [dt, H-4 in (VI), $J_{3,4}$ 10, $J_{2,4}$ 1·4 Hz], 3·55 [dt, H-2 in (VII), $J_{2,3}$ 9·0, $J_{2,4}$ 1·0 Hz], 6·05 [distorted quintet, H-3 in (VII), $J_{2,3}$ 9·0, $J_{3,4}$ 4·4 Hz], 5·93 [distorted quintet, H-3 in (VI), $J_{3,4}$ 10, $J_{2,3}$ 5·0 Hz], and 3·46 p.p.m. (dd, 2-H_2 in (VI) and 4-H_2 in (VII)]. By integrating the areas under the 3-proton signals the ratio of 2*H*- and 4*H*-isomers was shown to be *ca.* 4 : 1.

trans-3,4-*Dibromothiochroman* (Ia), trans-1,2-*Dibromo*-2,3-*dihydro*-1H-*naphtho*[2,1-b]*thiopyran* (IIa), and trans-3,4-*Dibromo*-3,4-*dihydro*-2H-*naphtho*[1,2-b]*thiopyran* (IIIa).—The *cis*-bromohydrin (1—3 g) and phosphorus tribromide (1—3 g) were stirred in dry benzene (50—100 ml) for 2—3 days. After being washed with water the benzene layer was dried (Na_2SO_4) and the solvent removed. Recrystallisation from a suitable solvent gave the *trans*-dibromo-derivative.

(i) *Compound* (Ia), prepared from *cis*-3-bromothiochroman-4-ol (64%), had m.p. 80—81° [from light petroleum (b.p. 60—80°)] (Found: C, 35·1; H, 2·8; Br, 51·9; S, 10·4. $C_9H_8Br_2S$ requires C, 35·1; H, 2·6; Br, 51·95; S, 10·3%).

(ii) *Compound* (IIa), prepared from crude *cis*-2-bromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran-1-ol (m.p. 110—114°) (37%), had m.p. 100—102° (decomp.) (yellow-green chunky crystals from ethyl acetate) (Found: C, 43·75; H, 2·6; Br, 44·4; S, 9·15. $C_{13}H_{10}Br_2S$ requires C, 43·6; H, 2·8; Br, 44·7; S, 8·9%).

(iii) *Compound* (IIIa), prepared from crude *cis*-3-bromo-3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran-4-ol (m.p. 90—95°) (33%), had m.p. 100—103° (decomp.) (yellow chunky crystals from ethyl acetate) (Found: C, 43·7; H, 2·6; Br, 44·7; S, 9·15. $C_{13}H_{10}Br_2S$ requires C, 43·6; H, 2·8; Br, 44·7; S, 8·9%).

trans-3,4-*Dibromothiochroman* (Ia).—Bromine (28·0 g) in carbon tetrachloride (100 ml) was added to 2*H*-thiochromen (26·0 g) in carbon tetrachloride (100 ml), with the temperature kept below −5°. Removal of the solvent left a black gum, which was extracted with hot light petroleum (b.p. 60—80°). Recrystallisation from light petroleum (b.p. 60—80°) gave *trans*-3,4-dibromothiochroman (23·0 g, 42%), m.p. and mixed m.p. 80—81°.

trans-1,2-*Dibromo*-2,3-*dihydro*-1H-*naphtho*[2,1-b]*thiopyran* (IIa).—Bromine (0·56 g) in chloroform (1 ml) was added dropwise to 3*H*-naphtho[2,1-*b*]thiopyran (0·705 g) in chloroform at 0°. Removal of the solvent at room temperature and recrystallisation from ethyl acetate gave *trans*-1,2-dibromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran (0·34 g, 27%), m.p. and mixed m.p. 97—100°.

2-*Hydroxymethylbenzo*[b]*thiophen* (IXa).—(*a*) *trans*-3,4-Dibromothiochroman (5·0 g), acetone (40 ml), and potassium hydroxide (0·91 g, 1 mol. equiv.) in water (20 ml) were boiled together for 5 h. Pouring into water and isolation with ether yielded a solid, which on recrystallisation from light petroleum (b.p. 80—100°) gave 2-hydroxymethylbenzo[*b*]thiophen (1·4 g, 52%), m.p. 97—98° (lit.,[4] 99—100°); $\lambda_{max.}$ (EtOH) 230, 265, 290, and 301 nm (log ε 4·43, 4·06, 3·68, and 3·56); $\nu_{max.}$ (Nujol) 3250 cm^{-1} (OH); δ 7·2—7·9 (4H, complex m, aromatic protons), 7·15 (1H, t, vinylic proton, *J* 0·9 Hz), 4·85 (2H, d, α-H_2, *J* 0·8 Hz), and 2·45 p.p.m. (1H, s, OH); *acetate* (from methanol), m.p. 79—80° (Found: C, 63·9; H, 5·1; S, 15·6. $C_{11}H_{10}O_2S$ requires C, 64·1; H, 4·85; S, 15·5%).

(*b*) *trans*-3,4-Dibromothiochroman (4·1 g), acetone (20 ml), and water (8 ml) were boiled for 8 h. Pouring into water and then proceeding as in (*a*) gave 2-hydroxymethylbenzo[*b*]thiophen (1·55 g, 79%), m.p. and mixed m.p. 97—98°.

2-*Hydroxymethylnaphtho*[2,1-b]*thiophen* (Xa).—*trans*-1,2-Dibromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran (1·57 g), acetone (50 ml), and water (10 ml) were set aside at room temperature for 2 days and then boiled for 3 h. Pouring into water afforded a solid (1·15 g), which was separated by filtration and dried ($CaCl_2$ desiccator). Recrystallisation from light petroleum (b.p. 60—80°) containing a few drops of ethyl acetate gave 2-*hydroxymethylnaphtho*[2,1-b]*thiophen* (0·41 g, 45%), as needles, m.p. 107—108°; $\lambda_{max.}$ (EtOH) 233, 246, 256, 297, and 307 nm (log ε 4·515, 4·63, 4·46, 4·11, and 4·065); $\nu_{max.}$ (Nujol) 3200 cm^{-1} (OH); δ 7·4—8·26 (7H, complex m, 6 aromatic and one vinylic), 4·92br (2H, s, α-H_2), and 2·3 p.p.m. (1H, s, OH) (Found: C, 72·7; H, 4·6; S, 14·85. $C_{13}H_{10}OS$ requires C, 72·9; H, 4·7; S, 14·9%); *acetate*, needles (from methanol), m.p. 95·5—97° (Found: C, 70·3; H, 4·6; S, 12·2. $C_{15}H_{12}O_2S$ requires C, 70·3; H, 4·7; S, 12·5%).

2-*Hydroxymethylnaphtho*[1,2-b]*thiophen* (XI).—*trans*-3,4-Dibromo-3,4-dihydro-2*H*-naphtho[1,2-*b*]thiopyran (1·1 g), acetone (30 ml), and water (10 ml) were set aside at room temperature for 2 days and then boiled for 3 h. Pouring into water afforded a solid, which was separated by filtration, and dried ($CaCl_2$ desiccator). Recrystallisation from light petroleum (b.p. 80—100°) gave 2-*hydroxymethylnaphtho*-[1,2-b]*thiophen* (0·28 g, 42%), m.p. 89—91°; $\lambda_{max.}$ 263, 266, 284, and 291 nm (log ε 4·61, 4·64, 3·875, and 3·79); $\nu_{max.}$ (Nujol) 3200 cm^{-1} (OH); δ 7·2—8·1 (7H, complex m, 6 aromatic and one vinylic), 4·9br (2H, s, α-H_2), and 2·23 p.p.m. (1H, s, OH) (Found: C, 72·65; H, 4·6; S, 14·55. $C_{13}H_{10}OS$ requires C, 72·9; H, 4·7; S, 14·9%).

2-*Methoxymethylbenzo*[b]*thiophen* (IXe).—(*a*) *trans*-3,4-Dibromothiochroman (8·0 g) and methanol (100 ml) were boiled for 24 h and poured into water. Isolation with ether

and distillation under reduced pressure gave a clear liquid (1·6 g), which on trituration with light petroleum (b.p. <40°) and cooling afforded a solid. Crystallisation from light petroleum (b.p. <40°) gave 2-*methoxybenzo*[b]*thiophen* (2·1 g, 45%), as needles, m.p. 23—24°; δ 7·21—7·88 (4H, complex m, aromatic), 7·17 (1H, dd, vinylic, *ca.* equal *J* values 0·9 Hz), 4·67 (2H, d, α-H_2, *J* 0·9 Hz), and 3·38 p.p.m. (3H, s, OMe) (Found: C, 67·6; H, 5·4; S, 18·3. $C_{10}H_{10}OS$ requires C, 67·4; H, 5·6; S, 18·0%).

(*b*) 2-Hydroxymethylbenzo[*b*]thiophen (1·5 g) was added to powdered sodium (2·1 g) in ether (50 ml) and boiled for 0·5 h. Following the addition of methyl iodide (1·3 g) the mixture was boiled for 24 h. The ethereal solution was washed with water and dried ($MgSO_4$). Removal of the solvent, trituration with light petroleum (b.p. <40°), and cooling yielded a solid. Crystallisation from light petroleum (b.p. <40°) gave 2-*methoxymethylbenzo*[b]*thiophen* (0·35 g, 22%), m.p. and mixed m.p. 23—24°.

2-*Methoxymethylnaphtho*[2,1-b]*thiophen* (Xb).—(*a*) *trans*-1,2-Dibromo-2,3-dihydro-1*H*-naphtho[2,1-*b*]thiopyran (1·53 g) and methanol (150 ml) were set aside at room temperature for 2 days and then boiled for 6 h. The solution was concentrated and then diluted with water to precipitate a solid (0·91 g), which was filtered off and dried ($CaCl_2$ desiccator). Recrystallisation from light petroleum (b.p. <40°) gave 2-*methoxymethylnaphtho*[2,1-b]*thiophen* (0·57 g, 50%), as small plates, m.p. 85—87°; δ 7·41—8·4 (7H, complex m, 6 aromatic and one vinylic), 4·78 (2H, d, α-H_2, *J* 0·8 Hz), and 3·43 p.p.m. (3H, s, OMe) (Found: C, 73·9; H, 5·05; S, 14·3. $C_{14}H_{12}OS$ requires C, 73·7; H, 5·25; S, 14·4%).

(*b*) 2-Hydroxymethylnaphtho[2,1-*b*]thiophen (0·41 g) dissolved in t-butyl alcohol (10 ml) was added to sodium t-butoxide [from sodium (0·1 g) and t-butyl alcohol (10 ml)] and the mixture was boiled for 0·5 h. Following the addition of methyl iodide (1·0 ml) the mixture was boiled for 3 h and poured into water to yield a solid, which was separated by filtration and dried ($CaCl_2$ desiccator). The solid was dissolved in the minimum of benzene and chromatographed on alumina [benzene–light petroleum (b.p. 60—80°) (1 : 2) as eluant]. Removal of the solvent and recrystallisation from light petroleum (b.p. <40°) gave 2-*methoxymethylnaphtho*[2,1-b]*thiophen* (0·18 g, 41%), m.p. and mixed m.p. 85—86°.

Thiochroman-4-*one* (Xhc).—*cis*-3-Halogenothiochroman-4-ol (1·0 g), powdered potassium hydroxide (5·0 g), and ether (100 ml) were stirred intermittently for 7 days. Filtration and removal of the solvent afforded an oil, which on crystallisation from light petroleum (b.p. 40—60°) gave thiochroman-4-one: (i) yield 0·5 g (75%) (from *cis*-3-bromothiochroman-4-ol); (ii) yield 0·24 g (34%) (from *cis*-3-chlorothiochroman-4-ol), m.p. and mixed m.p. 29—30° (lit.,[1] 30—31°).

2,3-*Dihydro*-1H-*naphtho*[2,1-b]*thiopyran* (IIg).—2,3-Dihydro-1*H*-naphtho[2,1-*b*]thiopyran-1-ol (4·5 g) and polyphosphoric acid [from phosphorus pentoxide (18·0 g) and 85% orthophosphoric acid (*d* 1·75; 45 ml)] were stirred on a water-bath for 0·5 h to give a deep red solution. Pouring into ice–water afforded a solid, which was separated by filtration and dried ($CaCl_2$ desiccator). The crude product was dissolved in the minimum of benzene and chromatographed on alumina [light petroleum (b.p. 60—80°) as eluant]. Removal of the solvent and recrystallisation from light petroleum (b.p. <40°) gave 2,3-dihydro-1*H*-naphtho-[2,1-*b*]thiopyran (1·55 g, 37%), as platelets, m.p. and mixed m.p. with an authentic sample 92·5—93·5° (lit.,[4] 91°).

Benzo[b]*thiophen*-2-*carboxylic Acid* (IXc).—2-Hydroxymethylbenzo[*b*]thiophen (1·0 g), acetone (50 ml), and powdered potassium permanganate (5·0 g) were boiled for 3 h. After filtration the black residue was suspended in stirred 2N-sulphuric acid and sulphur dioxide bubbled through the mixture to give a cream-coloured solid, which was separated by filtration, dissolved in sodium hydrogen carbonate solution (carbon), and precipitated with 2N-hydrochloric acid. Filtration and recrystallisation from ethanol gave benzo[*b*]thiophen-2-carboxylic acid (0·31 g, 29%), m.p. and mixed m.p. 232—238° (lit.,[9] 236°); methyl ester, m.p. 70—71° (lit.,[9] 72—73°).

A grant from Imperial Chemical Industries Limited is gratefully acknowledged. J. C. and C. J. F. thank the Huddersfield Education Authority for financial assistance.

[1/1633 *Received, 8th September,* 1971]