Addition Reactions of Heterocyclic Compounds. Part LXIII.[1] New Structures for Some 2:1 Molar Adducts from Dimethyl Acetylenedicarboxylate with Thiazoles and Benzo-imidazoles, -oxazoles, and -thiazoles formed by Novel Rearrangement. Crystal and Molecular Structure Determinations for Tetramethyl 3,8a-Dimethylpyrido[2,1-*b*]thiazole-5,6,7,8-tetracarboxylate and Tetramethyl 5-Methylpyrido[2,1-*b*]thiazole-6,7,8,8a-tetracarboxylate

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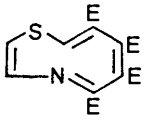
2,4-Dimethylthiazole with dimethyl acetylenedicarboxylate gives tetramethyl 3,8a-dimethylpyrido[2,1-*b*]thiazole-5,6,7,8-tetracarboxylate, whereas thiazole and other alkylthiazoles give tetramethyl pyrido[2,1-*b*]thiazole-6,7,8,8a-tetracarboxylates, rearrangements having taken place. Similar rearrangements can occur in the benzothiazole and benzimidazole series, and earlier formulations proposed for a number of adducts from several heterocycles with the acetylenic ester have now been revised on the basis of ^{13}C and ^{1}H n.m.r. spectra. The structures of the adducts from 2-methyl- and 2,4-dimethyl-thiazoles have been established by *X*-ray diffraction studies.

VARIOUS types of product have been obtained [2-4] by treating dimethyl acetylenedicarboxylate with thiazoles. The structure of the 2 : 1 molar adducts are the subject of the present investigation.

Reid, Skelton, and Bonthrone [3] assigned structures such as (1) and (2) to the products from the ester with thiazole and its 2- and 4-methyl derivatives, largely on



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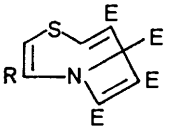


(2)

E = CO_2Me in all formulae

the basis of the presence of a low-field proton (τ *ca.* 1.8) or methyl resonance in their n.m.r. spectra, but were unable to distinguish between these possibilities. At the same time they allocated structure (4) to the corresponding adduct from 2,4-dimethylthiazole, as a high-field methyl signal was present. We considered [2] that all these adducts were best represented by structures based on (3), since their u.v. spectra were very similar, and because these spectra closely resembled those of tetramethyl 9a*H*-quinolizine-1,2,3,4-tetracarboxylates [*e.g.* (21) and (22)].[5] The n.m.r. spectra, however, were not explained convincingly. In view of the inconclusive position reached, it was decided to reinvestigate these thiazole derivatives, and some of our new conclusions have been published in preliminary form.[6]

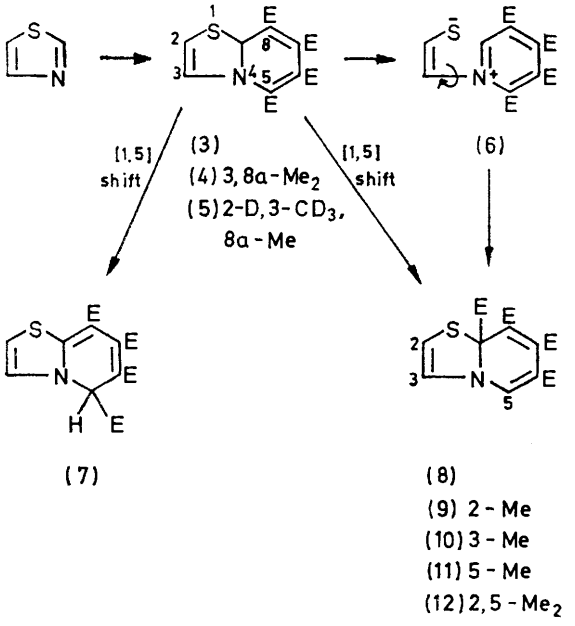
We have confirmed the findings of Reid *et al.*[3] that the proton n.m.r. spectrum of the 2,4-dimethylthiazole adduct shows high-field methyl resonances (τ 7.98 and 8.57) not shown by the analogous thiazole adducts. The ^{13}C n.m.r. spectrum of the 2,4-dimethylthiazole adduct was not sufficiently different from those of its analogues to be used as a basis for argument, and the structure of this adduct was finally confirmed as (4) by an *X*-ray crystallographic analysis.

The adducts from thiazole [2,3] and its 2-methyl,[2] 4-methyl,[2,3] 5-methyl, and 2,5-dimethyl derivatives have very closely related spectra and it may be assumed that they are structurally analogous. The ^{1}H signal due to the methyl group from the 2-position of the original thiazole appears at τ *ca.* 7.5, in contrast to that in the 2,4-dimethylthiazole adduct, but all the adducts show an sp^3 carbon resonance at δ *ca.* 75 in their ^{13}C spectra. Examination of the ^{13}C spectra leads to the conclusion, confirmed by an *X*-ray crystal analysis of the adduct from 2-methylthiazole, that this group of compounds possesses structures (8)—(12).

The above adducts are presumably formed by the rearrangement outlined in the Scheme. The initial formation of a compound such as (3) in the reaction is expected on the basis of many analogies,[7] and its rearrangement to the isomer (8) could take place *via* a concerted [1,5] suprafacial sigmatropic shift, which might be permitted for a thermal reaction since an atom with unbonded electrons is involved. An alternative non-concerted pathway could proceed *via* the zwitterion (6), for which stable analogues such as (13) are known,[8] and there are a number of reports of similar openings of thiazolium rings.[9] The proton resonances (τ 7.42) due

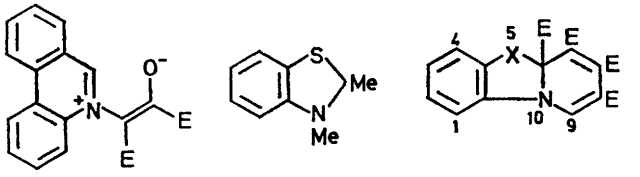
[1] Part LXII, P. J. Abbott, R. M. Acheson, M. Y. Kornilov, and J. K. Stubbs, *J.C.S. Perkin I*, 1975, 2322.
[2] R. M. Acheson, M. W. Foxton, and G. R. Miller, *J. Chem. Soc.*, 1965, 3200.
[3] D. H. Reid, F. S. Skelton, and W. Bonthrone, *Tetrahedron Letters*, 1964, 1797; W. Bonthrone, F. S. Skelton, and D. H. Reid, 'N.M.R. in Chemistry,' ed. B. Pesce, Academic Press, New York, 1965, p. 263.
[4] H. Ogura, H. Takayanagi, K. Furuhata, and Y. Iitaka, *J.C.S. Chem. Comm.*, 1974, 759.
[5] R. M. Acheson, A. R. Hands, and M. J. Woolven, *J. Chem. Soc.*, 1963, 2082; R. M. Acheson and G. A. Taylor, *ibid.*, 1960, 1691.
[6] P. J. Abbott, R. M. Acheson, U. Eisner, D. J. Watkin, and J. R. Carruthers, *J.C.S. Chem. Comm.*, 1975, 155.
[7] R. M. Acheson, *Adv. Heterocyclic Chem.*, 1963, **1**, 125.
[8] R. M. Acheson and I. A. Selby, *J. Chem. Soc.* (*C*), 1971, 691.
[9] J. M. Sprague and A. H. Land, in 'Heterocyclic Compounds' vol. 5, ed. R. C. Elderfield, Wiley, New York, 1957, p. 484; F. Kröhnke and W. Friedrich, *Chem. Ber.*, 1963, **96**, 1195; *cf.* G. Bartoli, M. Fiorentino, F. Ciminale, and P. E. Todesco, *J.C.S. Chem. Comm.*, 1974, 732; K. T. Potts, D. R. Choudhury, and T. R. Westby, *J. Org. Chem.*, 1976, **41**, 187.

to the *C*-methyl group of the 1 : 2 molar adduct from 2-methyl-4,5-dihydrothiazole and the acetylenic ester [10] shows that this adduct has the rearranged structure



SCHEME

(tetramethyl 2,3-dihydro-5-methyl-pyridol[2,1-*b*]thiazole 6,7,8,8a-tetracarboxylate) and not that proposed previously.[10]



This general type of structural change involving apparent ring opening and recyclization has been observed before in adducts from dimethyl acetylenedicarboxylate. The adduct from 4-ethoxyquinazoline undergoes acid-catalysed isomerisation,[1] phenanthridones are formed from indole,[11] and initially formed pyridazino[2,3-*a*]benzotriazoles from 1-alkylbenzotriazoles yield pyridazino[2,3-*a*]quinoxalinones.[12]

The 2,4-dimethylthiazole adduct (4) is the only unrearranged thiazole derivative isolated so far. It is stable in 1,2-dichlorobenzene at 150 °C, possibly owing to steric factors. Dreiding models show that our pyridothiazoles are all crowded, and that there is an additional interaction between methyl groups when these are present at *both* positions corresponding to the 2- and 4-positions of the original thiazoles, when rotation in the intermediate (6) is considered. One methyl group causes little additional hindrance over that already present in the isomerisation leading to (8), and a methyl group at position 5 of the original thiazole is well out of the way.

The ^{13}C resonances for the adducts (4), (5), (8), (9), (11), and (12) (Table 1) fall into a clear pattern; compound (10) was not soluble enough for measurement. The sp^3 8a-carbon signals for compounds (8), (9), (11), and (12) appear between δ 73.7 and 75.3, and that for compound (4) (δ 77.0) shows that replacing the bridgehead ester substituent by a methyl group causes a small downfield shift. The position of these sp^3 carbon resonances is in good accord with that (δ 69.9) of the sp^3 carbon atom in the thiazoline (14). A comparison of the ^1H the ^{13}C resonances for the adduct (4) with those of the deuteriated derivative (5) enables unambiguous assignments to be made for the ^{13}C and ^1H resonances of the methyl groups and the atoms at position 2. From comparing the data in Table 1 for these compounds it is clear that replacing a hydrogen atom by a methyl substituent at positions 2-, 3-, and 5- deshields the adjacent sp^2 carbon atom by *ca.* 13, 8, and 10 p.p.m., respectively, whereas 2- [compounds (9) and (12)] and 3-methyl groups [compound (4)] shield the ring carbon atoms at positions 3 and 2 by smaller amounts. The resonances due to the 5-^{13}C atoms were at very low field (δ 144), and those from the 6-, 7-, and 8-carbon atoms, bearing an ester group, were in the δ 100—139 range but could not be individually assigned. The ^{13}C resonances for the 2- and 5-methyl groups of compounds (9), (11), and (12) correlate well with each other, and the bridgehead-methyl group of compound (4) is much more strongly deshielded. This last characteristic, however, should be used with caution if employed to locate methyl groups, for the chemical shift of the sp^3-attached 9a-methyl group of the quinolizine (21) and that of one of the sp^2-attached methyl groups of (23) are indistinguishable.

In view of the above findings it was necessary to reconsider the structures of similar adducts which have been reported to be formed from benzo-thiazole, -oxazole, -imidazole, *etc.* Benzothiazole with the ester in the absence of solvent,[2] or in acetonitrile, dimethylformamide or toluene, gives as major product a 1 : 2 molar adduct described earlier [2] as tetramethyl 5a*H*-dibenzo-

[10] J. Roggero and C. Divorne, *Compt. rend.*, 1969, **268***C*, 870.
[11] R. M. Acheson, J. N. Bridson, T. R. Cecil, and A. R. Hands, *J.C.S. Perkin I*, 1972, 1569.
[12] P. J. Abbott, R. M. Acheson, M. W. Foxton, N. R. Raulins, and G. E. Robinson, *J.C.S. Perkin I*, 1972, 2182.

TABLE 1

^{13}C N.m.r. spectra (22.63 MHz; internal Me_4Si or CD_3NO_2 as reference; shifts, δ_C, with respect to Me_4Si)

Compd.	Solvent	t/°C	No. of scans $\times 10^{-3}$	Carbon assignments	sp^2-C·CO_2Me and unidentified sp^2-C	C=O	OCH_3
(4) [a]	CD_3NO_2	45	4.00	2-C, 108.7; 3-C, 133.5;[c] 3-CH_3, 15.1; 5-C, 144.4; 8a-C, 77.0; 8a-CH_3, 25.4	132.8,[c] 113.3, 103.5	168.3, 165.8, 165.3, 165.0	54.1, 53.1, 52.7, 52.7
(5) [a]	CD_3NO_2	45	3.40	2-C, 108.9;[d] 3-C, 133.6;[c] 3-CD_3 not observed; 5-C, 144.4; 8a-C, 76.9; 8a-CH_3, 25.4	132.8,[c] 113.3, 103.5	168.3, 165.8, 165.3, 165.0	54.1, 53.1, 52.7. 52.7
(8) [a]	CD_3NO_2	33	1.08	2-C, 112.0; 3-C, 126.9; 5-C, 144.7; 8a-C, 74.5	138.0, 106.0, 101.8	169.9, 168.3, 165.2, 165.2	54.4, 53.2, 53.0, 52.3
(9) [a]	CD_3NO_2	27	3.00	2-C, 125.6; 2-CH_3, 12.7; 3-C, 122.7; 5-C, 144.3; 8a-C, 74.9	139.1, 104.6, 100.6	170.1, 168.4, 165.4, 165.2	54.7, 53.4, 53.2, 52.6
(11) [a]	CD_3NO_2–$(CD_3)_2SO$	40	4.00	2-C, 111.4; 3-C, 124.6; 5-C, 154.5; 5-CH_3, 18.7; 8a-C, 73.7	138.2, 106.5, 103.0	170.5, 168.8, 166.8, 165.3	54.2, 53.1, 52.8, 52.1
(12) [a]	CD_3NO_2	50	4.10	2-C, 125.0; 2-Me, 12.8; 3-C, 120.6; 5-C, 154.3; 5-CH_3, 18.4; 8a-C, 75.3	138.8, 105.9, 102.1	170.8, 168.9, 167.0, 165.4	54.2, 53.0, 52.7, 52.0
(14) [a]	CD_3NO_2	27	0.5	2-C, 69.9; 2-CH_3, 20.8; 3-CH_3, 33.2; Ar-CH, 126.2, 122.2, 119.4, 108.3; 3a, 7a-C_2, 124.8, 149.2			
(15) [a,b]	CD_3NO_2	80	10.00	Ar-CH, 127.7, 127.6, 123.9, 110.3; 4a, 10a-C_2, 140.3, 129.4; 5a-C, 75.6; 9-C, 141.7	138.8, 110.3, 103.9	170.2, 168.0, 165.3 [e]	54.4, 53.0,[e] 52.4
(16) [a]	CD_3NO_2	50	21.00	Ar-CH, 127.3, 121.3, 110.7, 108.2; 4a, 10a-C_2, 144.1, 131.7; 5-CH_3, 34.9; 5a-C, 86.5; 9-C, 136.4	136.4,[g] 110.6, 104.0	168.5,[e] 165.5, 165.0	53.5, 53.2, 52.8, 50.8
(17)	$CDCl_3$	27	55.2	Ar-CH, 125.0, 119.8, 113.6, 109.0; 4a, 10a-C_2, 143.9,[e] 131.4; 5-CH_3, 33.8; 5a-C, 84.9; 9-C, 143.9;[e] 9-CH_3, 17.7	150.5?, 104.8[f]	168.1,[e] 167.6, 165.8	52.9, 52.6, 52.2, 51.5
(18)	CD_3NO_2	80	14.84	Ar-CH, 128.5, 126.1, 123.6, 113.1; 9-C, 57.2	140.7, 129.6, 103.0[f]	169.9, 168.3, 165.6, 165.2	53.8, 53.0, 52.7, 52.2
(19)	CD_3NO_2	69	7.5	Ar-CH, 127.0, 126.2, 112.0, 112.0; 9-C, 56.8	161.9, 149.1, 145.8, 130.8, 126.1, 102.4	169.6, 168.5, 165.4, 164.6	53.8, 53.0, 52.7, 51.7
(20) [a]	$(CD_3)_2SO$–$CDCl_3$ (1 : 1)	25	81.0	Ar-CH, 123.6, 123.4, 110.0, 109.4; 5-CH_3, 34.9; 9-C, 53.5	149.0, 144.9, 133.9, 129.0, 123.6,[g] 97.1	167.9,[h] 167.2, 163.2,[i] 162.4	52.6, 51.8, 51.3, 50.3
(21) [a]	$CDCl_3$	25	1.00	6,7,8,9-C_4, 125.7, 123.0, 120.6, 106.8; 9a-C, 60.2; 9a-CH_3, 22.0	146.1, 130.4, 118.8, 100.5	167.3, 165.0, 163.9, 163.9	53.4, 52.4, 52.2, 52.0
(22) [a]	$CDCl_3$	25	2.00	6,8-C_2, 122.6, 119.5; 7-CH_3, 17.9;[e] 9-CH_3, 17.5;[e] 9a-C, 57.7	148.5, 134.9, 131.6, 127.4, 107.6, 97.1	167.6, 164.4, 163.8, 162.9	53.2, 52.3, 52.0, 51.8
(23) [a]	$CDCl_3$	25	2.00	4-C, 65.5; 6,8-C_2, 142.6, 134.8; 7-CH_3, 17.3;[e] 9-CH_3, 22.1 [e]	147.7, 145.2, 133.8, 126.4, 93.7, 92.9	169.6, 168.6, 165.0, 164.2	53.3, 52.5, 51.8, 50.8
(25) [a]	CD_3NO_2	40	7.21	1-CH_3, 35.4; 2-C, 132.9,[e] 3-C, 107.1;[e] 8a-C, 83.6; 8a-CH_3, 15.0	114.0[f]	169.3, 168.9, 166.6, 165.4	54.2, 52.8, 52.4, 52.0

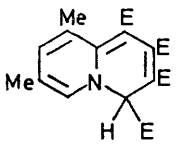
TABLE 1 (*Continued*)

Compd.	Solvent	*t*/°C	No. of scans $\times 10^{-3}$	Carbon assignments	sp^2-*C*·CO_2Me and unidentified sp^2-C	*C*=O	OCH_3
(26) [a]	CD_3NO_2	27	8.58	Ar-*C*H, 127.3, 120.7, 112.1, 111.0; 4a, 10a-C_2, 143.9, 129.8; 5-CH_3, 33.2; 5a-C, 85.7; 5a-CH_3, 17.2	139.8, 130.4, 119.0, 103.9	168.3, 165.9, 165.2, 165.0	54.4, 53.3, 53.1, 52.6

[a] All $^{13}C-^{1}H$ attachments confirmed by off-resonance experiments. [b] Trisacetylacetonatochromium added to reduce relaxation time. [c] These assignments may be interchanged. [d] Broad, confirming $^{13}C-^{2}H$ coupling. [e] Probably due to two coincident resonances. [f] All sp^2-C atoms not located. [g] Observed in off-resonance decoupling experiment. [h] 9-$^{13}CO_2$Me. [i] 8-$^{13}CO_2$Me.

[*bd*]thiazole-5,6,7,8-tetracarboxylate. The low-field position of the 9-H n.m.r. signal and the correspondence of the ^{13}C n.m.r. spectrum with those of the thiazole adducts (Table 1) leave little doubt that rearrangement to the isomeric structure (15) has taken place. On this new premise, tetramethyl 1,2-dihydro-1-phenylpyridine-2,3,4,5-tetracarboxylate [2] is the expected product of Raney nickel desulphurisation, and the structure of (15) has now been fully established by *X*-ray crystallography.[13]

In methanol, benzothiazole with the ester yields a small amount of the pyridobenzothiazole (15) and 34% of an isomer with a different u.v. spectrum, a single proton (τ 3.60), and an sp^3 carbon atom bearing one hydrogen



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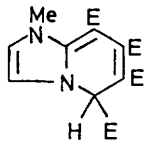

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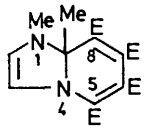

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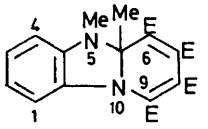

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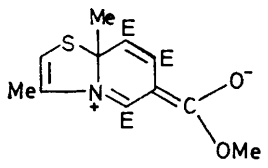

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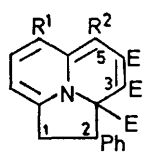

(28) R^1 = Me, R^2 = H
(29) R^1 = H, R^2 = E

atom (δ 57.2). These data correspond well to structure (18), which could be obtained from the benzo-analogue of (3) by a concerted [1,5] hydrogen shift similar to that established [14] in the quinolizine series, and *X*-ray studies have recently shown that this structure is correct.[13]

Benzoxazole gives a single adduct with dimethyl acetylenedicarboxylate,[2] originally formulated with a hydrogen atom at a bridgehead [*cf.* (3)]. However, the resonance position of the single proton (τ 3.82) and the chemical shift of the sp^3 carbon atom bearing a single hydrogen atom (δ 56.8) strongly suggest that a proton shift has occurred to give structure (19).

It is significant that the ^{13}C resonance positions for the 9-carbon atoms of compounds (18)—(20) are very similar, which would not be the case if the single hydrogen atom was at the bridgehead position [*cf.* (3)], for then the sp^3 carbon atom would be adjacent to different heteroatoms in the different compounds.

1-Methylbenzimidazole and the ester in acetonitrile gave mainly a 1 : 2 molar yellow adduct, the wide-band and off-resonance decoupled ^{13}C spectra for which confirm the structure (20) already proposed.[15] The undecoupled spectrum for the carbonyl carbon atoms shows quartets with $J(^{13}C,OCH_3)$ 3.5 Hz for two of these carbon atoms, which must be at positions 6 and 7 as a consequence of the subsequent argument, and more complex multiplets for the other two. Selective decoupling of the protons of all the ester-methyl groups caused the collapse of the multiplets due to the carbonyl carbon atoms at positions 6 and 7 to singlets, showing that these carbonyl ^{13}C atoms are coupled only to ester-methyl groups. The coupling constant is similar to that (3.7 Hz) observed [16] for the coupling between the ^{13}C of the carbonyl group and the OCH_3 of methyl benzoate. The other two ^{13}C signals of carbonyl groups now appeared as doublets, $J(^{13}C,H)$ 5.5 and 3.5 Hz. The whole picture is consistent with the coupled proton being present at position 9. It interacts most strongly with the 9-carbonyl ^{13}C atom, less so with the 8-carbonyl ^{13}C atom, and not with the others. Wasylischen and Schaefer have shown [17] that $^{13}C,H$-coupling over three bonds depends on the dihedral angle between the atoms, and our results are consistent with this but incompatible with the proton being present at either position 7 (when three ester groups would have coupled with it) or position 5a (when only one weak coupling would be anticipated). The same method has been used to establish [18] the structure of the pyridoimidazole (24).

[13] H. Ogura, K. Kikuchi, H. Takayanagi, K. Furuhata, Y. Iitaka, and R. M. Acheson, *J.C.S. Perkin I*, 1975, 2316.
[14] R. M. Acheson and B. J. Jones, *J. Chem. Soc.* (*C*), 1970, 1301.
[15] R. M. Acheson, M. W. Foxton, P. J. Abbott, and K. J. Mills, *J. Chem. Soc.* (*C*), 1967, 882.
[16] A. M. Ihrig and J. C. Marshall, *J. Amer. Chem. Soc.*, 1972, **94**, 3268.
[17] R. Wasylischen and T. Schaefer, *Canad. J. Chem.*, 1973, **51**, 961.
[18] F. Troxler, H. P. Weber, A. Jaunin, and H. R. Loosli, *Helv. Chim. Acta*, 1974, **57**, 750.

The ^{13}C spectrum for the red adduct from 1-methylbenzimidazole, for which an improved preparation is described, showed that it must possess structure (16) and not the earlier suggested [14] isomeric formulation with a bridgehead hydrogen atom [*cf.* (3)]. This new structure is consistent with the failure of the compound to isomerise thermally to (20), and with its reaction with bromine in perchloric acid, which causes substitution of one hydrogen atom.[15] Oxidation to a corresponding pyridobenzimidazolium salt, which is formed from (20) under these conditions,[15] is expected of a compound analogous to (3).

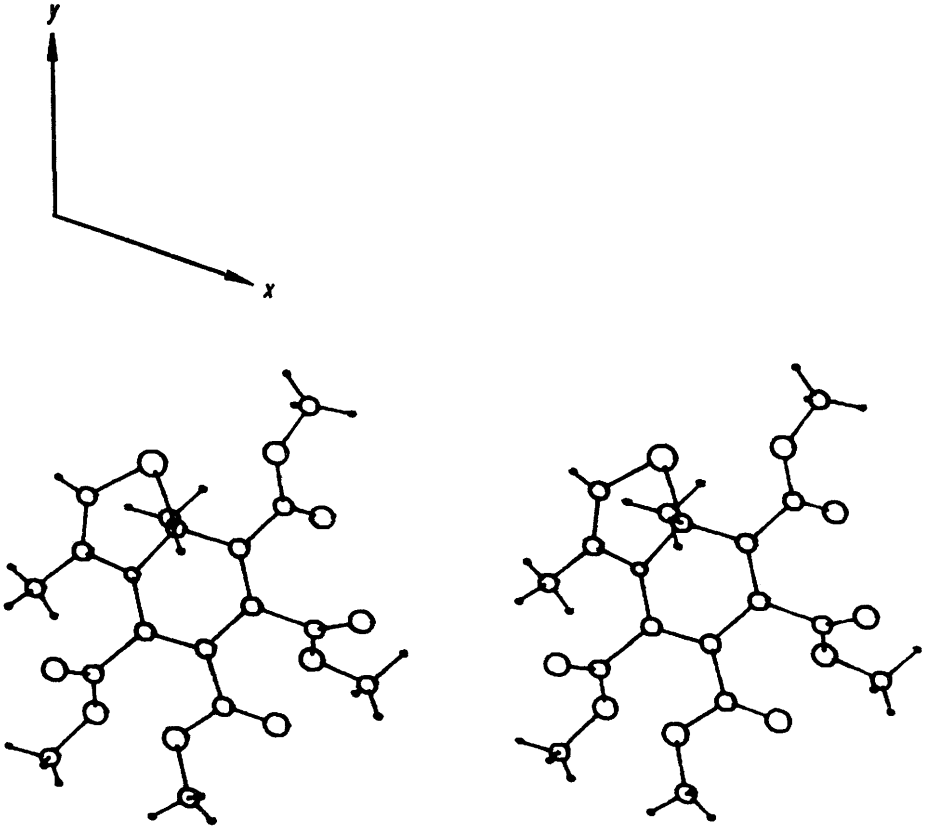

FIGURE 1 Stereoscopic projection for tetramethyl 3,8a-dimethylpyrido[2,1-*b*]thiazole-5,6,7,8-tetracarboxylate (4) down the *z* axis

1,2-Dimethylbenzimidazole with the ester in tetrahydrofuran gives [15] mainly tetramethyl 9,10-dihydro-5-methylazepino[1,2-*a*]benzimidazole-7,8,9,10-tetracarboxylate, along with 1 : 2 molar, isomeric, red and orange adducts, which we confirm are both formed and extremely difficult to separate. The red adduct, with a high-field *C*-methyl group (τ 8.56), is undoubtedly the direct cyclisation product (26), and the orange compound can now be identified from its much lower-field (τ 7.04) *C*-methyl signal and ^{13}C spectra as (17), formed by the rearrangement of (26). The aromatic proton resonance pattern for (26), which shows one low-field proton signal and three others of similar chemical shift, differs markedly from that for (17), where the signals are much more spread out.

1-Ethyl-2-methylbenzimidazole with the ester in tetrahydrofuran gave [15] mainly the corresponding azepine, along with an orange-red substance affording a good elemental analysis for a 1 : 2 molar adduct. The proton n.m.r. spectrum suggested that the substance was a mixture, and re-examination shows that without doubt it consists of the bridgehead methyl (τ 8.57) [*cf.* (26)] and rearranged (τ_{Me} 7.08) [*cf.* (17)] isomers in *ca.* 1 : 2 ratio. The corresponding product from 2-ethyl-1-methylbenzimidazole [15] is homogeneous, and the high-field position of the $CH_3{\cdot}CH_2$ resonance and the similarity of the aromatic proton resonance pattern to that of (26) but not that of (17) confirm that the assigned structure is correct.

The adduct of 1,2-dimethylimidazole and dimethyl acetylenedicarboxylate was assigned [19] structure (25) in spite of the fact that eight ester-methyl resonances were seen in the ^1H n.m.r. spectrum. Re-examination of this substance has shown that it indeed has a very complex ^1H n.m.r. spectrum, not appreciably changed by crystallisation from methanol or by chromatography. However, crystallisation from acetonitrile resulted in a material, the ^1H n.m.r. spectrum of which (see Experimental section) was entirely in accordance with structure (25). The compound is not very stable and decomposes in solution, particularly in solvents such as

[19] O. Diels, K. Alder, W. Winckler, and E. Peterson, *Annalen*, 1932, **498**, 1; R. M. Acheson and G. A. Taylor, *J. Chem. Soc.*, 1960, 4600.

chloroform. Its ^{13}C n.m.r. spectrum (solvent trideuterionitromethane) was complex owing to decomposition, but, although not all the signals could be assigned, the essential features were in accord with structure (25) and showed the expected differences from the spectrum [18] of (24).

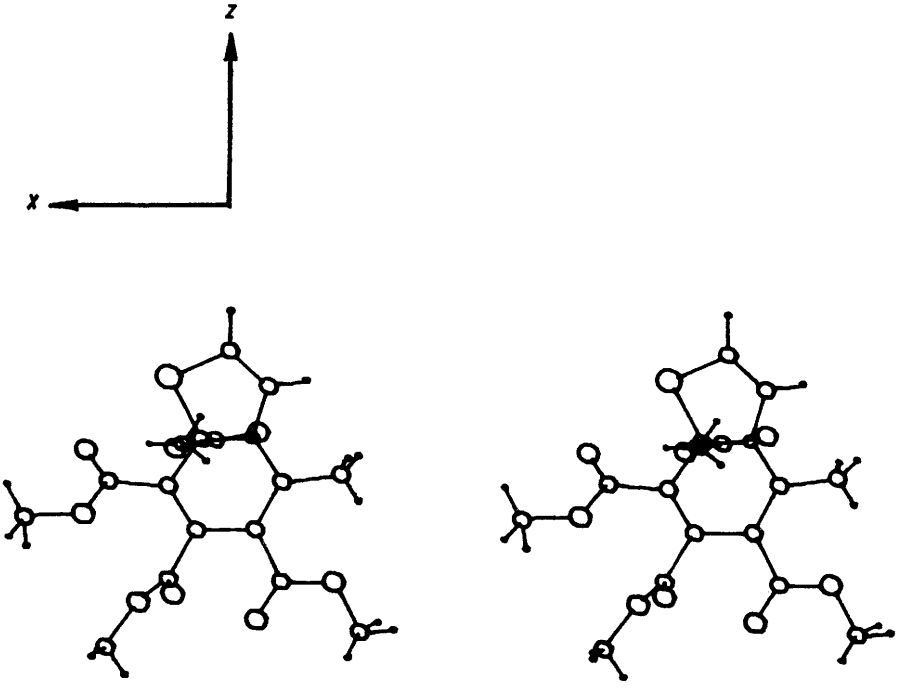

FIGURE 2 Stereoscopic projection for tetramethyl 5-methylpyrido[2,1-*b*]thiazole-6,7,8,8a-tetracarboxylate (11) down the *y* axis

The effect of adding the chiral shift reagent, tris-[3-(2,2,2-trifluoro-1-hydroxyethyl)-(+)-camphorato]-europium(III) [20] to solutions of the adducts (4), (11), (15), (16), (18), and (20) in deuteriochloroform was examined in the hope of detecting the resulting diastereoisomers. Although marked shifts of most of the proton resonances were observed in all cases, only for (18) and

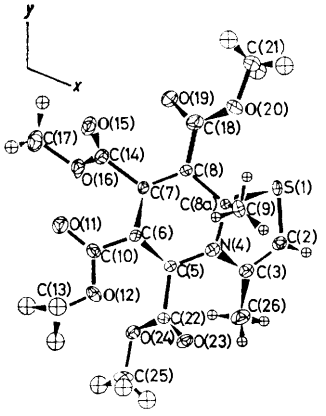

FIGURE 3 Atom numbering for compound (4)

(20) were diastereoisomers detected. The resonances due to all the methyl groups and the 9-proton were split into two lines of equal height, the biggest downfield shift being observed for the 9-proton, which must therefore be close to the europium atom.

Stereoscopic projections for the similarly shaped thiazole adducts (4) and (11) are shown in Figures 1 and 2, respectively. The nitrogen atoms and the carbon atoms to which they are attached are effectively coplanar in both compounds (Table 2; plane 1) which

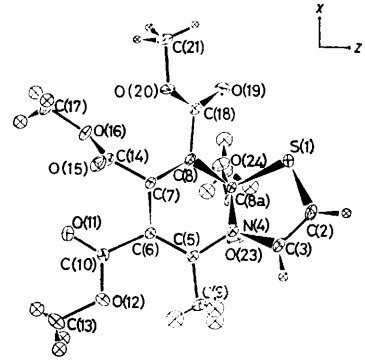

FIGURE 4 Atom numbering for compound (11)

means that the electronic hybridisations of the nitrogen atoms are essentially sp^2. For an sp^3 nitrogen this atom would be placed [21] *ca.* 0.5 Å away from the mean plane of the attached atoms. The bonds from the nitrogen atoms are unequal in length, the longest being to the bridgehead carbon atom and the shortest, which is even shorter than the N–C bond of pyrrole (1.383 Å),[22] leading

[20] V. Shurig, *Tetrahedron Letters*, 1972, 3297; *Inorg. Chem.*, 1972, **11**, 736.

[21] A. H.-J. Wang, I. C. Paul, E. R. Talaty, and A. E. Dupuy, *J.C.S. Chem. Comm.*, 1972, 43.

[22] B. Bak, D. Christensen, L. Hansen, and J. Rastrup-Andersen, *J. Chem. Phys.*, 1956, **24**, 720; *cf.* C. W. N. Cumper, *Trans. Faraday Soc.*, 1958, **54**, 1266.

to the 5-carbon atom. The deviations of individual atoms from the mean planes of the 4(N), 5-, 6-, 7-, and 8-carbon atoms are small (Table 2). The orientations of the mean planes (Table 2) for all the ester groups (*i.e.* the C–CO_2 atoms for each) to this last mean plane were also calculated. For the ester groups at position 6, for compounds (4) and (11), the divergences from coplanarity

TABLE 2

Deviations (Å) from calculated least-squares best planes

	Compound (4)		Compound (11)	
Plane	Atoms	Deviation	Atoms	Deviation
1	C(3)	0.001	C(3)	0.021
	N(4)	−0.004	N(4)	−0.062
	C(5)	0.001	C(5)	0.023
	C(8a)	0.001	C(8a)	0.018
2	N(4)	0.021	N(4)	−0.020
	C(5)	0.021	C(5)	−0.020
	C(6)	−0.085	C(6)	0.081
	C(7)	0.111	C(7)	−0.104
	C(8)	−0.068	C(8)	−0.064
3	C(6)	0.008	C(6)	−0.007
	C(10)	−0.026	C(10)	0.024
	O(11)	0.010	O(11)	−0.009
	O(12)	0.008	O(12)	−0.008
4	N(4)	0.115	N(4)	0.069
	C(5)	−0.160	C(5)	−0.028
	C(6)	−0.009	C(6)	−0.093
	C(10)	−0.015	C(10)	−0.029
	O(11)	0.013	O(11)	0.058
	O(12)	0.056	O(12)	0.022
5	C(8)	−0.003	C(8)	0.001
	C(18)	0.011	C(18)	−0.005
	O(19)	−0.004	O(19)	0.002
	O(20)	−0.003	O(20)	0.001
6	C(7)	−0.000	C(7)	−0.004
	C(14)	0.002	C(14)	0.013
	O(15)	−0.001	O(15)	−0.005
	O(16)	−0.001	O(16)	−0.004
7	C(5)	0.003		
	C(22)	−0.009		
	O(23)	0.004		
	O(24)	0.003		

Angles between the planes

Planes	Compound (4)	Compound (11)
2 and 3	16.46°	10.23°
2 and 5	47.60°	43.53°
2 and 6	69.93°	69.35°
2 and 7	63.75°	

are only 16.5 and 10.2°, respectively, those for the 8-ester groups are much greater, and those for the other ester groups greater still. This suggests that of the charged resonance structures including a positively charged nitrogen atom which can be written, those involving the 6-ester group [*e.g.* (27)] are the most important. The lengths of the bonds joining the various ester groups to the ring system are in agreement with this concept, the shortest and next shortest being to the 6- and 8-ester groups, respectively. The carbon–oxygen bond lengths for the 6-ester group are also significantly greater than the others for compound (4), but not for (11). The bond length situation for compound (15) is similar.[13] A general implication of these results is that quinolizines such as (21) and (23) will be expected to possess similar sp^2-hybridised nitrogen atoms. The suggestion [23] that the large difference in u.v. spectra between the quinolizines (28) and (29) is due to the importance of charged resonance structures involving the 5-ester group is confirmed by our new results, which also fit in with the much smaller spectral change observed [23] when the 3-ester group is removed from compound (29). The low-field position of the 5-methyl proton resonance in the n.m.r. spectrum of the pyridobenzimidazole (20) has been attributed [15] to significant resonance contribution from charged structures, corresponding to (27) and involving the 6-ester group. Bond-length data are not available for this compound, but those [13] for the analogous pyridobenzothiazole (18) show a steady increase in the lengths of the bonds joining the 6-, 8-, 7-, and 9-ester groups, respectively, to the ring. This indicates the importance of such charged contributors in compound (18), and their importance in (20), sulphur having been replaced by nitrogen, should be greater.

[23] R. M. Acheson and R. S. Feinberg, *J. Chem. Soc.* (*C*), 1968, 350.

EXPERIMENTAL

Instruments and chromatographic procedures used have been described in earlier papers in the series.

2,3-Dihydro-2,3-dimethylbenzothiazole was prepared as described in ref. 24; τ (CD_3NO_2) 8.51 (6 H, d, *J* 6 Hz, 2-Me), 7.31 (3 H, s, 3-Me), 5.02 (2 H, q, *J* 6 Hz, 2-H), and 2.9—3.8 (4 H, m, ArH); very similar in $CDCl_3$.

Reaction of Dimethyl Acetylenedicarboxylate with Benzothiazole.—The ester (1.08 g) in methanol (2.5 ml) mixed with benzothiazole (0.50 g) in methanol (2.5 ml) was left overnight at room temperature. The methanol was removed *in vacuo*, toluene was added and evaporated off *in vacuo* with gentle warming (twice), and the residue was triturated with ether. The solid (0.54 g) yielded fluorescent yellow crystals (from acetonitrile) of *tetramethyl* 9H-*pyrido*[2,1-b]*benzothiazole*-6,7,8,9-*tetracarboxylate* (18), m.p. 249—249.5° (Found: C, 54.2; H, 4.3; N, 3.4; S, 7.4. $C_{19}H_{17}NO_8S$ requires C, 54.4; H, 4.1; N, 3.3; S, 7.6%); τ ($CDCl_3$) 2.3—2.9 (4 H, m, ArH), 3.60 (s, 9-H), and 6.10, 6.19, 6.20, and 6.37 (s, 4 × OMe), $\lambda_{max.}$ (MeOH) 229 (ε 22 800), 256 (13 300), 295infl (32 900), 309 (18 900), and 418 nm (19 400). The initial filtrate from (18) contained compound (15).

Tetramethyl 2,5-*Dimethylpyrido*[2,1-b]*thiazole*-6,7,8,8a-*tetracarboxylate* (12).—2,5-Dimethylthazole [25] (1.43 g) in dimethylformamide (5 ml) at 0 °C was added dropwise with stirring to dimethyl acetylenedicarboxylate (3.55 g) in dimethylformamide (5 ml). After 40 min at 0 °C and 10 days at room temperature, most of the solvent was removed *in vacuo*, water (450 ml) was added, and the methylene chloride-soluble material was collected. Chromatography on alumina and elution with methylene chloride gave the *thiazole* (12), orange crystals (2.85 g), m.p. 183—185° (from MeOH) (Found: C, 51.5; H, 4.9; N, 5.4. $C_{17}H_{19}NO_8$ requires C, 51.4; H, 4.8; N, 3.5%); τ ($CDCl_3$) 3.55 (q, *J ca.* 1 Hz, 3-H), 6.23, 6.30, 6.37, and 6.37 (s, 4 × OMe), 7.43 (s, 5-Me); and 8.03 (d, *J ca.* 1 Hz, 2-Me); $\lambda_{max.}$ (MeOH) 229 (ε 17 700), 287 (28 900), and 442 nm (6 400), unchanged by addition of a few drops of 72% $HClO_4$.

Tetramethyl 2-*Methylpyrido*[2,1-b]*thiazole*-6,7,8,8a-*tetracarboxylate* (9).—This was prepared similarly to (12)

[24] J. Metzger, H. Larive, E. J. Vincent, and R. Dennilauler, *J. Chim. phys.*, 1963, **60**, 944 (*Chem. Abs.*, 1963, **59**, 9,763b).

[25] M. Poite and J. Metzger, *Bull. Soc. chim. France*, 1962, 2078.

but from 5-methylthiazole [25] (0.56 g), and obtained as orange *crystals* (0.39 g), m.p. 185—186° (from MeOH) (Found: C, 50.2; H, 4.6; N, 3.6. $C_{16}H_{17}NO_8S$ requires C, 50.1; H, 4.5; N, 4.7%); τ ($CDCl_3$) 1.99 (s, 5-H), 3.77 (q, *J ca.* 1.5 Hz, 3-H), 6.17, 6.28, 6.35, and 6.35 (s, 4 × OCH_3), and 8.02 (d, *J ca.* 1.5 Hz, 2-Me); $\lambda_{max.}$ (MeOH) 228 (ε 21 300), 286 (30 900), and 443 nm (6 500); no change on acidification.

TABLE 3

Bond lengths (Å) for compounds (4) (Figure 3) and (11) (Figure 4); estimated standard deviations in parentheses. The atom numbers for (11) are only given when they differ from those for (4), but exactly comparable bond lengths are shown on the same line

Compound (4)		Compound (11)	
S(1)–C(2)	1.730(6)		1.744(6)
S(1)–C(8a)	1.832(5)		1.838(4)
C(2)–C(3)	1.320(8)		1.321(9)
C(3)–N(4)	1.411(6)		1.405(6)
C(3)–C(26)	1.483(8)		
N(4)–C(5)	1.359(6)		1.350(6)
N(4)–C(8a)	1.496(6)		1.468(6)
C(5)–C(6)	1.385(6)		1.392(6)
C(6)–C(7)	1.456(7)		1.461(6)
C(7)–C(8)	1.338(7)		1.350(6)
C(8)–C(8a)	1.521(6)		1.507(5)
C(6)–C(10)	1.439(7)		1.470(6)
C(10)–O(11)	1.207(6)		1.205(7)
C(10)–O(12)	1.342(7)		1.309(6)
O(12)–C(13)	1.429(8)		1.450(7)
C(7)–C(14)	1.504(6)		1.513(6)
C(14)–O(15)	1.193(7)		1.186(9)
C(14)–O(16)	1.326(7)		1.330(7)
O(16)–C(17)	1.435(7)		1.439(6)
C(8)–C(18)	1.464(7)		1.489(6)
C(18)–O(19)	1.187(7)		1.209(7)
C(18)–O(20)	1.335(6)		1.316(6)
O(20)–C(21)	1.466(8)		1.444(6)
C(8a)–C(9)	1.518(8)	C(8a)–C(22)	1.564(7)
		C(22)–O(23)	1.203(6)
		C(22)–O(24)	1.302(7)
		O(24)–C(25)	1.441(8)
C(5)–C(22)	1.503(7)	C(5)–C(9)	1.496(7)
C(22)–O(23)	1.191(7)		
C(22)–O(24)	1.322(7)		
O(24)–C(25)	1.446(9)		
C(2)–H(102)	0.95(9)		
		C(2)–H(102)	1.03(7)
		C(3)–H(103)	0.97(7)
		C(9)–H(109)	0.92(12)
		C(9)–H(209)	0.82(11)
		C(9)–H(309)	1.20(12)
C(9)–H(109)	1.03(6)		
C(9)–H(209)	0.93(6)		
C(9)–H(309)	0.96(6)		
C(13)–H(113)	0.95(10)		0.84(9)
C(13)–H(213)	1.05(11)		1.09(10)
C(13)–H(313)	0.92(10)		1.05(10)
C(17)–H(117)	1.09(8)		1.01(11)
C(17)–H(217)	0.79(8)		0.89(9)
C(17)–H(317)	1.02(9)		0.77(11)
C(21)–H(121)	0.97(9)		0.98(7)
C(21)–H(221)	0.93(9)		0.87(7)
C(21)–H(321)	0.82(11)		0.95(6)
		C(25)–H(125)	1.09(11)
		C(25)–H(225)	0.79(11)
		C(25)–H(325)	1.05(11)
C(25)–H(125)	0.93(9)		
C(25)–H(225)	0.97(8)		
C(25)–H(325)	0.92(9)		
C(26)–H(126)	1.07(6)		
C(26)–H(226)	0.99(6)		
C(26)–H(326)	0.98(6)		

Tetramethyl 5-*Methylpyrido*[2,1-b]*thiazole*-6,7,8,8a-*tetracarboxylate* (11).—This compound, prepared in the same way as (12), had m.p. 163—164° (lit.,[3] 159.5—161°).

TABLE 4

Bond angles (°) for compounds (4) (Figure 3) and (11) (Figure 4); estimated standard deviations in parentheses. The atom numbers for (11) are only given when they differ from those for (4), but exactly comparable bond angles are shown on the same line

Compound (4)		Compound (11)	
C(2)–S(1)–C(8a)	90.9(7)		90.1(9)
S(1)–C(2)–C(3)	115.9(1.0)		114.1(1.1)
C(2)–C(3)–N(4)	112.9(9)		114.4(1.3)
C(2)–C(3)–C(26)	123.6(9)		
N(4)–C(3)–C(26)	123.1(1.0)		
C(3)–N(4)–C(5)	128.7(7)		127.5(7)
C(3)–N(4)–C(8a)	113.8(8)		112.2(9)
C(5)–N(4)–C(8a)	117.4(8)		119.2(8)
N(4)–C(5)–C(6)	119.6(8)		118.1(8)
		N(4)–C(5)–C(8)	116.2(8)
		C(6)–C(5)–C(9)	125.6(8)
N(4)–C(5)–C(22)	117.8(8)		
C(6)–C(5)–C(22)	122.4(8)		
C(5)–C(6)–C(7)	117.0(9)		117.5(8)
C(5)–C(6)–C(10)	123.3(8)		126.1(7)
C(7)–C(6)–C(10)	119.7(9)		116.3(8)
C(6)–C(7)–C(8)	121.0(8)		121.3(7)
C(6)–C(7)–C(14)	118.6(8)		116.6(7)
C(8)–C(7)–C(14)	120.4(8)		121.2(7)
C(7)–C(8)–C(8a)	117.0(9)		115.7(8)
C(7)–C(8)–C(18)	122.2(8)		125.6(6)
C(8a)–C(8)–C(18)	120.7(8)		118.6(7)
S(1)–C(8a)–N(4)	104.4(9)		105.0(8)
S(1)–C(8a)–C(8)	111.1(1.0)		112.9(7)
S(1)–C(8a)–C(9)	111.1(9)		
		S(1)–C(8a)–C(22)	107.0(9)
N(4)–C(8a)–C(8)	107.7(9)		109.4(8)
N(4)–C(8a)–C(9)	108.6(1.1)		
		N(4)–C(8a)–C(22)	107.1(1.0)
C(8)–C(8a)–C(9)	113.4(1.0)		
		C(8)–C(8a)–C(22)	114.7(9)
C(6)–C(10)–O(11)	124.7(9)		122.6(1.0)
C(6)–C(10)–O(12)	113.7(1.0)		115.6(9)
O(11)–C(10)–O(12)	121.4(9)		121.5(9)
C(10)–O(12)–C(13)	117.9(1.0)		116.5(1.0)
C(7)–C(14)–O(15)	124.9(1.0)		122.0(1.2)
C(7)–C(14)–O(16)	110.4(1.1)		112.4(1.1)
O(15)–C(14)–O(16)	124.7(9)		125.6(8)
C(14)–O(16)–C(17)	115.7(1.0)		115.0(9)
C(8)–C(18)–O(19)	125.4(9)		122.2(9)
C(8)–C(18)–O(20)	111.6(1)		113.5(9)
O(19)–C(18)–O(20)	123.0(9)		124.2(8)
C(18)–O(20)–C(21)	116.0(1)		116.4(8)
C(5)–C(22)–O(23)	122.7(1.0)		
C(5)–C(22)–O(24)	111.2(1.1)		
O(23)–C(22)–O(24)	126.2(9)		
C(22)–O(24)–C(25)	115.7(1.2)		
		C(8a)–C(22)–O(23)	122.8(9)
		C(8a)–C(22)–O(24)	111.8(9)
		O(23)–C(22)–O(24)	123.4(9)
		C(22)–O(24)–O(25)	116.3(1.0)

Tetramethyl 3,8a-*Dimethylpyrido*[2,1-b]*thiazole*-5,6,7,8-*tetracarboxylate* (4).—This was prepared as for compound (12); m.p. 149—149.5° (lit.,[3] 147.5—149°). The n.m.r. spectrum was essentially as described in ref. 3, and decoupling of the 2-H and 3-Me (τ 8.02) caused marked sharpening of the 3-Me and 2-H resonances, respectively.

The 2-deuterio-3-trideuteriomethyl analogue (5) was obtained similarly from bromopentadeuterioacetone (obtained by brominating perdeuterioacetone [26]) and was then converted into the deuteriated thiazole, τ ($CDCl_3$) 7.63 (2-Me), by Poite and Metzger's procedure.[25] The proton

[26] B. A. Levene, *Org. Synth.*, Coll. Vol. II, 1943, p. 88.

n.m.r. spectrum ($CDCl_3$) was as described in ref. 3 except that the resonances at τ 4.36 and 8.02 were missing.

Tetramethyl 5-Methylpyrido[1,2-a]*benzimidazole*-5a,6,7,8-*tetracarboxylate* (16).—*Improved preparation.* Dimethyl acetylenedicarboxylate (5.38 g) in toluene (25 ml) at 0 °C was added to 1-methylbenzimidazole (2.5 g) in toluene (25 ml) over 1 h at 0 °C with stirring. After 3 h at 0 °C and 5 days at room temperature the precipitate was collected and chromatographed on deactivated alumina. The first fraction, eluted with methylene chloride, on recrystallization from methanol, gave the adduct (0.9 g), m.p. 173—174° (lit.,[15] 173—174°), which showed one spot on t.l.c. [silica gel; ethyl acetate–petroleum (b.p. 60—80°) (1 : 1 v/v)].

Reaction of 1,2-*Dimethylbenzimidazole with Dimethyl Acetylenedicarboxylate.*—The reaction was carried out as described in ref. 15, the azepine was removed and the residue was chromatographed. Elution with methylene chloride gave first the red adduct (26). The mother liquor from the crystallization of this was combined with further methylene chloride eluates. Rechromatography and elution with toluene–light petroleum (b.p. 80—100°) (7 : 3 v/v) gave a series of fractions. A slow-moving orange material crystallized with methanol to give the orange adduct (17), m.p. 161—162° (lit.,[15] 158°); τ ($CDCl_3$) 2.80(d) and 3.35(d), (1- and 4-H), 2.97(t) and 3.23(t) (*J ca.* 8 Hz, 2- and 3-H), 6.92 (5-Me), 7.04 (5a-Me), and 6.20—6.28 (4 × OMe).

Tetramethyl 1,8a-*Dimethylpyrido*[1,2-a]*imidazole*-5,6,7,8-*tetracarboxylate* (25) (with G. Procter).—This was prepared as described in ref. 19 but the product was chromatographed over alumina with methylene chloride as solvent, and after crystallisation from acetonitrile had m.p. 163—164°; τ ($CDCl_3$) 7.00 (1-Me), 4.03(d) and 4.12(d) (*J* 4 Hz, 2- and 3-H), 8.72 (8a-Me), and 6.06, 6.15, 6.24, and 6.29 (4 × OMe).

X-*Ray Structure Determinations.*—Approximate cell dimensions were obtained from oscillation and Weissenberg photographs. The intensity data for compound (4) were collected on a Hilger and Watts linear diffractometer with Mo radiation and balanced filters.

The structure of the adduct (4) (Figures 1 and 3) was determined by Patterson and Fourier methods. All the atoms were located after two Fourier maps. One round of least-squares refinement with isotropic temperature factors, followed by three rounds with anisotropic temperature factors gave an *R* value of 0.078 6. A difference Fourier synthesis located 13 of the hydrogen atoms; the remainder were located by calculation.

The hydrogen atom positional parameters and isotropic temperature factors were refined individually and then refined together. Refinement of positional parameters and temperature factors (anisotropic except for H atoms) continued until convergence [root mean square (shift/e.s.d.) $\leqslant$0.13]. The root mean square (shift/e.s.d.) for all atoms except hydrogen was 0.07. The temperature factors for H atoms on the same carbon were equivalenced to the same least-squares parameter in the refinement.

Final cell dimensions and intensity data for compound

Table 5

Atomic co-ordinates for compound (4) (Figure 3); estimated standard deviations × 10^4

Atom	*x/a*	*y/b*	*z/c*
S(1)	0.213 24(7)	0.177 2(1)	0.152 3(2)
C(2)	0.134 7(3)	0.047 7(6)	0.092 5(6)
C(3)	0.126 4(3)	−0.087 6(6)	0.120 0(5)
N(4)	0.182 8(2)	−0.099 9(4)	0.200 6(4)
C(5)	0.195 6(2)	−0.221 0(5)	0.237 2(5)
C(6)	0.265 1(3)	−0.211 0(5)	0.276 0(5)
C(7)	0.324 2(2)	−0.076 4(5)	0.247 1(5)
C(8)	0.311 1(2)	0.046 3(5)	0.228 5(5)
C(8a)	0.233 5(2)	0.041 4(5)	0.251 9(5)
C(9)	0.216 2(3)	0.054 1(6)	0.396 2(6)
C(10)	0.280 7(3)	−0.326 3(6)	0.340 8(6)
O(11)	0.341 2(2)	−0.324 9(5)	0.366 7(5)
O(12)	0.220 9(2)	−0.434 3(4)	0.380 9(5)
C(13)	0.230 9(5)	−0.550 8(8)	0.452(1)
C(14)	0.400 4(3)	−0.078 6(6)	0.233 6(6)
O(15)	0.449 1(2)	−0.023 6(5)	0.308 9(5)
O(16)	0.405 8(2)	−0.151 1(4)	0.126 5(4)
C(17)	0.475 6(4)	−0.165(1)	0.105(1)
C(18)	0.368 6(3)	0.181 2(6)	0.190 4(6)
O(19)	0.421 4(2)	0.190 1(5)	0.128 0(6)
O(20)	0.356 2(2)	0.296 0(4)	0.238 5(5)
C(21)	0.402 1(4)	0.436 4(8)	0.186(1)
C(22)	0.131 6(3)	−0.360 3(5)	0.242 5(6)
O(23)	0.081 7(2)	−0.379 1(4)	0.316 1(5)
O(24)	0.138 0(2)	−0.453 1(4)	0.153 9(5)
C(25)	0.081 2(5)	−0.593 9(9)	0.155(1)
C(26)	0.069 4(4)	−0.213 7(8)	0.0597(8)
H(102)	0.102(4)	0.072(8)	0.035(9)
H(109)	0.254(3)	0.147(6)	0.435(6)
H(209)	0.168(3)	0.048(6)	0.401(6)
H(309)	0.226(3)	−0.012(7)	0.448(6)
H(113)	0.189(5)	−0.62(1)	0.42(1)
H(213)	0.237(5)	−0.53(1)	0.55(1)
H(313)	0.260(5)	−0.59(1)	0.40(1)
H(117)	0.519(4)	−0.061(8)	0.121(8)
H(217)	0.485(4)	−0.230(8)	0.133(8)
H(317)	0.471(4)	−0.196(8)	0.009(9)
H(121)	0.454(5)	0.452(9)	0.19(1)
H(221)	0.373(5)	0.49(1)	0.20(1)
H(321)	0.391(5)	0.43(1)	0.11(1)
H(125)	0.094(4)	−0.654(9)	0.097(9)
H(225)	0.032(5)	−0.603(8)	0.130(9)
H(325)	0.070(4)	−0.611(9)	0.24(1)
H(126)	0.034(3)	−0.277(6)	0.125(7)
H(226)	0.042(3)	−0.183(6)	−0.009(7)
H(326)	0.094(3)	−0.267(7)	0.009(7)

Table 6

Anisotropic temperature factors * and estimated standard deviations for compound (4) (Figure 3)

Atom	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
S(1)	0.036 4(7)	0.034 0(7)	0.048 2(9)	0.005 6(6)	−0.005 3(6)	0.016 7(6)
C(2)	0.035(3)	0.049(3)	0.043(3)	−0.002(3)	−0.011(2)	0.021(3)
C(3)	0.024(2)	0.044(3)	0.037(3)	−0.003(2)	−0.004(2)	0.012(2)
N(4)	0.021(2)	0.036(2)	0.030(2)	−0.001(2)	−0.000(2)	0.009(2)
C(5)	0.021(2)	0.034(3)	0.037(3)	0.000(2)	0.000(2)	0.008(2)
C(6)	0.025(2)	0.032(3)	0.037(3)	0.001(2)	0.001(2)	0.014(2)
C(7)	0.023(2)	0.036(3)	0.033(3)	−0.004(2)	0.002(2)	0.013(2)
C(8)	0.017(2)	0.028(2)	0.035(3)	−0.001(2)	0.001(2)	0.005(2)
C(8A)	0.020(2)	0.028(2)	0.038(3)	−0.003(2)	−0.002(2)	0.007(2)
C(9)	0.037(3)	0.031(3)	0.036(3)	0.000(2)	0.002(2)	0.016(2)
C(10)	0.042(3)	0.031(3)	0.041(3)	−0.005(2)	−0.001(2)	0.015(2)
O(11)	0.038(2)	0.059(3)	0.086(4)	0.021(3)	0.003(2)	0.027(2)
O(12)	0.044(2)	0.030(2)	0.077(3)	0.015(2)	−0.005(2)	0.010(2)
C(13)	0.092(6)	0.035(3)	0.081(6)	0.020(4)	0.004(4)	0.032(4)
C(14)	0.026(3)	0.039(3)	0.040(3)	0.005(2)	0.005(2)	0.013(2)
O(15)	0.033(2)	0.081(3)	0.070(3)	−0.022(3)	−0.011(2)	0.026(2)
O(16)	0.037(2)	0.051(2)	0.048(3)	−0.004(2)	0.007(2)	0.024(2)
C(17)	0.052(4)	0.075(5)	0.089(6)	0.005(4)	0.026(4)	0.043(4)
C(18)	0.032(3)	0.037(3)	0.043(3)	−0.000(2)	0.005(2)	0.010(2)
O(19)	0.044(3)	0.056(3)	0.104(4)	0.007(3)	0.037(3)	0.014(2)
O(20)	0.034(2)	0.026(2)	0.070(3)	−0.001(2)	0.003(2)	0.007(2)
C(21)	0.049(4)	0.035(3)	0.110(7)	0.015(4)	0.008(4)	0.006(3)
C(22)	0.027(3)	0.028(3)	0.053(4)	−0.007(2)	−0.006(2)	0.008(2)
O(23)	0.034(2)	0.040(2)	0.074(3)	−0.001(2)	0.018(2)	0.006(2)
O(24)	0.038(2)	0.043(2)	0.069(3)	−0.023(2)	−0.000(2)	0.011(2)
C(25)	0.053(4)	0.059(5)	0.129(9)	−0.057(5)	−0.001(5)	−0.003(4)
C(26)	0.036(3)	0.055(4)	0.064(5)	0.001(3)	−0.020(3)	0.005(3)

Atom	U_{iso} †	Atom	U_{iso} †	Atom	U_{iso} †
H(102)	0.03(2)	H(117)	0.04(1)	H(125)	0.05(1)
H(109)	0.020(9)	H(217)	0.04(1)	H(225)	0.05(1)
H(209)	0.020(9)	H(317)	0.04(1)	H(325)	0.05(1)
H(309)	0.020(9)	H(121)	0.07(2)	H(126)	0.023(9)
H(113)	0.07(2)	H(221)	0.07(2)	H(226)	0.023(9)
H(213)	0.07(2)	H(321)	0.07(2)	H(326)	0.023(9)
H(313)	0.07(2)				

* Temperature factor $T = \exp\{-2\pi^2[U_{11}(ha^*)^2 + \ldots + 2U_{12}(ha^*kb^*)]\}$.
† Temperature factor $T = \exp[(-8\pi^2U_{iso}S^2]$ where $S = \sin\theta/\lambda$.

(11) were measured on a Hilger and Watts four-circle diffractometer with Mo radiation.

TABLE 7

Atomic co-ordinates for compound (11) (Figure 4); estimated standard deviations × 10^4

Atom	x/a	y/b	z/c
S(1)	0.347 0(1)	−0.000 0	0.044 2(1)
C(2)	0.212 4(6)	0.072(1)	0.107 5(5)
C(3)	0.126 7(5)	0.093(1)	0.019 2(5)
N(4)	0.161 0(4)	0.056 7(8)	−0.109 0(4)
C(5)	0.094 9(4)	0.075 3(9)	−0.219 0(4)
C(6)	0.151 7(4)	0.060 4(8)	−0.337 8(4)
C(7)	0.281 5(4)	0.063 3(7)	−0.336 1(4)
C(8)	0.344 7(4)	0.022 7(7)	−0.227 4(4)
C(8a)	0.273 4(4)	−0.042 3(7)	−0.113 8(4)
C(9)	−0.033 4(5)	0.120(2)	−0.201 4(7)
C(10)	0.093 4(4)	0.053 9(9)	−0.466 9(5)
O(11)	0.146 7(4)	0.021(2)	−0.564 9(4)
O(12)	−0.022 2(3)	0.074(1)	−0.468 0(4)
C(13)	−0.081 5(7)	0.065(2)	−0.594 1(8)
C(14)	0.340 6(4)	0.143 2(9)	−0.4539(4)
O(15)	0.329 8(4)	0.296 1(7)	−0.481 5(5)
O(16)	0.407 3(3)	0.025 6(6)	−0.516 4(3)
C(17)	0.475 5(7)	0.098(1)	−0.621 4(7)
C(18)	0.476 6(4)	0.028 6(7)	−0.213 7(4)
O(19)	0.530 7(3)	−0.066 5(8)	−0.138 5(4)
O(20)	0.526 9(3)	0.144 2(7)	−0.291 9(4)
C(21)	0.655 1(5)	0.139(1)	−0.297 1(6)
C(22)	0.241 3(4)	−0.245 3(7)	−0.118 1(4)
O(23)	0.142 4(4)	−0.300 2(7)	−0.100 1(5)
O(24)	0.333 8(4)	−0.343 7(7)	−0.142 2(5)
C(25)	0.317 4(6)	−0.534(1)	−0.1325(7)
H(102)	0.213(6)	0.10(1)	0.205(7)
H(103)	0.046(6)	0.13(1)	0.032(6)
H(109)	−0.07(1)	0.03(2)	−0.16(1)
H(209)	−0.071(9)	0.14(2)	−0.27(1)
H(309)	−0.04(1)	0.27(2)	−0.15(1)
H(113)	−0.051(8)	0.18(1)	−0.649(9)
H(213)	−0.154(8)	0.09(1)	−0.586(9)
H(313)	−0.125(8)	−0.06(1)	−0.578(9)
H(117)	0.509(8)	−0.02(1)	−0.653(9)
H(217)	0.434(8)	0.07(1)	−0.694(9)
H(317)	0.490(9)	0.20(1)	−0.621(9)
H(121)	0.695(6)	0.13(1)	−0.215(6)
H(221)	0.653(6)	0.06(1)	−0.374(7)
H(321)	0.685(6)	0.23(1)	−0.342(6)
H(125)	0.277(9)	−0.62(2)	−0.06(1)
H(225)	0.26(1)	−0.54(2)	−0.18(1)
H(325)	0.397(9)	−0.61(2)	−0.13(1)

The same procedure [as used for (4)] was employed to determine the structure of (11). Refinement by using positional parameters and anisotropic temperature factors (isotropic for the hydrogen atoms) continued until convergence [root mean square (shift/e.s.d.) $\leqslant 0.17$]. The root mean square (shift/e.s.d.) for all atoms except hydrogen was 0.07. The temperature factors for hydrogen atoms on the same carbon atom were equivalenced to the same least-squares parameter in the refinement.

The carbon–hydrogen bond lengths were constrained to 1.0 ± 0.01 Å as there were large variations in bond lengths and angles. The constraints were removed near the end of the refinement.

The structures for compounds (4) and (11) were refined by use of weights calculated from expression (i) [27] where $x = F_o/F_{o(max.)}$

$$1/w = \{A[0]T[0]'x + A[1]T[1]'x \ldots + A[NP - 1]T[NP - 1]'x\} \quad \text{(i)}$$

* For details of Supplementary Publications see Notice to Authors No. 7 in *J.C.S. Perkin I*, 1975, Index issue.

Structure factor tables are available as Supplementary Publication No. SUP 21717 (35 pp., 1 microfiche).*

Crystal data. (i) Tetramethyl 3,8a-dimethylpyrido[2,1-*b*]thiazole-5,6,7,8-tetracarboxylate(4) $C_{17}H_{19}NO_8S$, $M = 397.45$, monoclinic, $a = 19.56(4)$, $b = 9.89(2)$, $c = 10.15(2)$ Å, $\alpha = 90.00$ $\beta = 90.00$ $\gamma = 110.50 \pm 0.08°$, $U = 1\,839.2$ Å^3, $D_c = 1.44$ g cm^{-3}, $Z = 4$, $F(000) = 832$. Space group $P2_1/a$. Mo-K_α radiation, $\lambda = 0.710\ 7$ Å, $\mu = 2.25$ cm^{-1}. 5 315 Reflections were observed up to $\theta = 34°$, yielding 4 203 independent reflections of which 2 220 were $\geqslant 3\sigma$ (I). Merging R was 6.7 over 2 220 reflections; terminal $R = 0.063$. In the weighting scheme above, A[0] = 8.5 and A[1] = 6.5. Orange crystals 0.07 × 0.02 × 0.02 cm.

(ii) Tetramethyl 5-methylpyrido[2,1-*b*]thiazole-6,7,8,8a-tetracarboxylate(11) $C_{16}H_{17}NO_8S$, $M = 383.40$, monoclinic, $a = 11.249(2)$, $b = 7.498(2)$, $c = 10.272(2)$ Å, $\alpha = 90.00$, $\beta = 90.91 \pm 0.02$, $\gamma = 90.00°$, $U = 866.2$ Å^3, $D_c = 1.47$ g cm^{-3}, $Z = 2$, $F(000) = 400$. Space group $P2_1$. Mo-K_α radiation, $\lambda = 0.710\ 7$ Å, $\mu = 2.35$ cm^{-1}. 3 091 reflections were observed up to $\theta = 28°$, yielding 2 246 independent reflections of which 2 056 were $\geqslant 3\sigma$ (I).

TABLE 8

Anistropic temperature factors * and estimated standard deviations for compound (11) (Figure 4)

Atom	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
S(1)	0.035 7(6)	0.0637(9)	0.0217(5)	−0.0046(5)	−0.0014(4)	0.0024(6)
C(2)	0.055(3)	0.063(3)	0.028(2)	−0.010(2)	0.011(2)	0.008(3)
C(3)	0.042(2)	0.067(4)	0.029(2)	−0.006(3)	0.015(2)	0.009(3)
N(4)	0.028(2)	0.054(2)	0.024(2)	−0.002(2)	0.007(1)	0.006(2)
C(5)	0.026(2)	0.058(3)	0.026(2)	−0.001(2)	0.007(2)	0.003(2)
C(6)	0.025(2)	0.045(2)	0.023(2)	0.001(2)	0.004(1)	0.001(2)
C(7)	0.028(2)	0.036(2)	0.022(2)	0.000(2)	0.008(1)	0.001(2)
C(8)	0.027(2)	0.032(2)	0.023(2)	−0.000(2)	0.008(1)	0.002(2)
C(8a)	0.025(2)	0.044(3)	0.019(2)	−0.002(2)	0.005(1)	0.004(2)
C(9)	0.029(2)	0.16(1)	0.042(3)	0.010(4)	0.008(2)	0.023(4)
C(10)	0.033(2)	0.054(3)	0.030(2)	0.004(2)	−0.001(2)	−0.002(2)
O(11)	0.048(2)	0.185(9)	0.029(2)	−0.011(4)	0.002(2)	0.007(4)
O(12)	0.032(2)	0.121(5)	0.039(2)	−0.008(3)	−0.009(1)	0.005(3)
C(13)	0.051(3)	0.104(7)	0.053(4)	−0.003(4)	−0.022(3)	−0.004(4)
C(14)	0.033(2)	0.047(3)	0.024(2)	0.005(2)	0.007(2)	−0.004(2)
O(15)	0.058(2)	0.053(3)	0.048(2)	0.016(2)	0.020(2)	0.007(2)
O(16)	0.046(2)	0.047(2)	0.032(2)	0.003(2)	0.019(1)	−0.001(2)
C(17)	0.069(4)	0.058(4)	0.039(3)	0.005(3)	0.030(3)	−0.007(3)
C(18)	0.028(2)	0.041(3)	0.027(2)	−0.003(2)	0.006(1)	0.003(2)
O(19)	0.031(2)	0.072(3)	0.045(2)	0.015(2)	−0.003(1)	0.000(2)
O(20)	0.020(1)	0.058(2)	0.044(2)	0.006(2)	0.005(1)	−0.005(2)
C(21)	0.026(2)	0.072(4)	0.050(3)	−0.002(3)	0.011(2)	−0.008(3)
C(22)	0.032(2)	0.040(3)	0.022(2)	−0.000(2)	0.008(1)	−0.005(2)
O(23)	0.037(2)	0.059(3)	0.069(3)	−0.001(2)	0.018(2)	−0.011(2)
O(24)	0.038(2)	0.038(2)	0.063(3)	0.000(2)	0.016(2)	−0.003(2)
C(25)	0.050(3)	0.048(3)	0.056(3)	0.001(3)	0.006(3)	−0.002(3)

Atom	U_{iso} †	Atom	U_{iso} †	Atom	U_{iso} †
H(102)	0.02(1)	H(213)	0.04(1)	H(221)	0.011(8)
H(103)	0.02(1)	H(313)	0.04(1)	H(321)	0.011(8)
H(109)	0.06(2)	H(117)	0.04(1)	H(125)	0.05(1)
H(209)	0.06(2)	H(217)	0.04(1)	H(225)	0.05(1)
H(309)	0.06(2)	H(317)	0.04(1)	H(325)	0.05(1)
H(113)	0.04(1)	H(121)	0.011(8)		

* † See Table 6

Merging R was 3.8 over 2 056 reflections; terminal $R = 0.081$. In the weighting scheme above, A[0] = 765, A[1] = 1 021, and A[2] = 260. Golden-yellow crystals 0.06 × 0.03 × 0.02 cm.

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[27] ' Crystals ' User Manual, J. R. Carruthers, Oxford University Computing Laboratory, 1975.