Synthesis and Paratropicity of Heteroatom-bridged [17]Annulenones

By **Terry M. Cresp** and **Melvyn V. Sargent,** Department of Organic Chemistry, The University of Western Australia, Nedlands, Western Australia 6009, Australia

Syntheses of 2,5:8,11:14,17-triepoxy[17]annulenone (2) by three methods are described. The first method involved Perkin-type condensation between 2,2'-bis-5-formylfuryl ketone (6) and furan-2,5-diacetic acid (7) and subsequent transformations. The second method involved Wittig reaction between (6) and furan-2,5-diyldimethylenebis(triphenylphosphonium chloride) (9). The third method, that preferred, used the Wittig reaction between carbonyldi(furan-2,5-diyl)dimethylenebis(triphenylphosphonium chloride) (15) and furan-2,5-dicarbaldehyde (16). Similarly the Wittig reaction of (15) and pyrrole-2,5-dicarbaldehyde (19) gave 8,11-epimino-2,5:14,17-diepoxy[17]annulenone (1), and between (6) and thiophen-2,5-dimethylenebis(triphenylphosphonium chloride) (24) † gave 2,5:14,17-diepoxy-8,11-epithio[17]annulenone (3). Lithium aluminium hydride–aluminium chloride reduction of annulenones (1)—(3) gave 7,10-epimino-1,4:13,16-diepoxycycloheptadeca-1,3,5,7,9,11,-13,15-octaene (30), 1,4:7,10:13,16-triepoxycycloheptadeca-1,3,5,7,9,11,13,15-octaene (31), and 1,4:13,16-diepoxy-7,10-epithiocycloheptadeca-1,3,5,7,9,11,13,15-octaene (32). The paratropicity of (1)—(3) is discussed in terms of (30)—(32), as model systems. Reduction of (2) and (3) followed by methylation of the resultant alcohols gave 17-methoxy-1,4:7,10:13,16-triepoxycycloheptadeca-1,3,5,7,9,11,13,15-octaene (39) and the 7,10-epithioanalogue (40). The methyl ether (39) appeared to be paratropic.

COMPLETELY conjugated monocyclic ketones (annulenones) with $(4n + 1)$ carbon atoms may be expected to behave like paratropic $4n$ π-electron cyclic polyenes if the carbon–oxygen bond is polarized in the usual manner.[1] Also those annulenones with $(4n + 3)$ carbon atoms should behave like $(4n + 2)$ π-electron annulenes and be diatropic, providing the carbon skeleton can approach planarity.

When we commenced our work in this area the only known higher $(n > 1)$ annulenones were [13]-,[2] [15]-,[3] and [17]-dehydroannulenones,[4] and they supported the above predictions. Attempts to reduce these systems to the derived annulenones, in an analogous manner to the reduction of dehydroannulenes to annulenes,[5] have not yet been successful.[1] In addition a methylene-bridged [11]annulenone had been prepared which gave on protonation a species which sustained a diamagnetic ring current.[6] Since that date other examples of [13]-, [15]-, and [17]-dehydroannulenones [7] have been synthesized. A 10 π-electron, methylene-bridged analogue of tropolone has been reported.[8] Oxygen-bridged [11]- [9] and [15]-annulenones [10] have also been reported which exhibited ring currents on protonation.

Both alkane- [11] and heteroatom-bridged [12-14] annulenes have been studied and providing that the bridging

groups do not impose steric interference to planarity on these systems they behave like their parent annulenes.

We now report the synthesis and properties of the heteroatom-bridged analogues (1)—(3), of the as yet unknown [17]annulenone (4). This work has already appeared in preliminary form.[15] Two general routes for the syntheses of these compounds have been explored. The first method, used for the synthesis of annulenone (2), was a Perkin-type reaction in which 2,2'-bis-5-
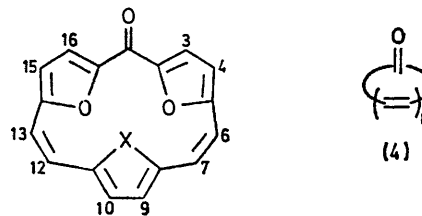
(1) X = NH
(2) X = O
(3) X = S

formylfuryl ketone (6) and furan-2,5-diacetic acid (7) [16] were condensed in a mixture of triethylamine and acetic anhydride at room temperature.[12,17] The other route, used for all three annulenones, was a Wittig condensation

† This name is preferred to that previously used [thiophen-2,5-diylbis(methylenetriphenylphosphonium chloride)] in a paper in this series (T. M. Cresp and M. V. Sargent, *J.C.S. Perkin I*, 1973, 1786).

[1] F. Sondheimer, (a) *Pure Appl. Chem.*, 1971, **28**, 331; (b) *Accounts Chem. Res.*, 1972, **5**, 81.
[2] G. M. Pilling and F. Sondheimer, *J. Amer. Chem. Soc.*, 1968, **90**, 5610; 1971, **93**, 1977.
[3] G. P. Cotterrell, G. H. Mitchell, F. Sondheimer, and G. M. Pilling, *J. Amer. Chem. Soc.*, 1971, **93**, 259.
[4] (a) G. W. Brown and F. Sondheimer, *J. Amer. Chem. Soc.*, 1969, **91**, 760; (b) J. Griffiths and F. Sondheimer, *ibid.*, p. 7518.
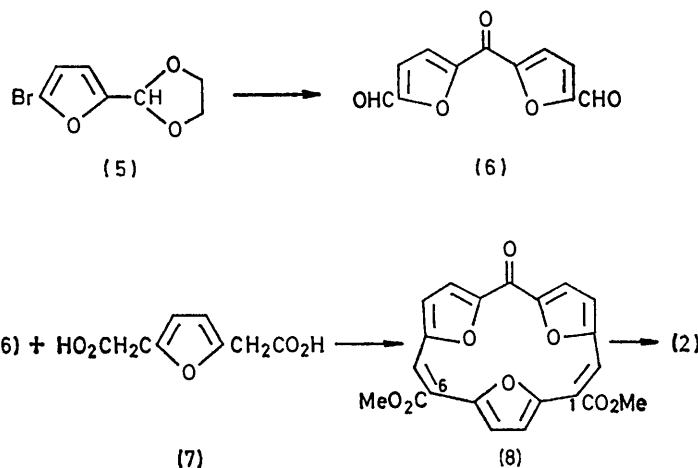[5] F. Sondheimer, *Pure Appl. Chem.*, 1963, **7**, 363.
[6] W. Grimme, J. Reisdorff, W. Jünemann, and E. Vogel, *J. Amer. Chem. Soc.*, 1970, **92**, 6335.
[7] P. D. Howes, E. L. Goff, and F. Sondheimer, *Tetrahedron Letters*, 1972, 3691, 3695.
[8] J. Reisdorff and E. Vogel, *Angew. Chem. Internat. Edn.*, 1972, **11**, 218.

[9] H. Ogawa, H. Kato, and M. Yoshida, *Tetrahedron Letters*, 1971, 1793.
[10] H. Ogawa, M. Yoshida, and H. Saikachi, *Tetrahedron Letters*, 1972, 153.
[11] E. Vogel, Proceedings Robert A. Welch Foundation Conference on Chemical Research, 1968, **12**, 215; *Pure Appl. Chem.*, 1971, **28**, 355.
[12] (a) G. M. Badger, J. A. Elix, and G. E. Lewis, *Austral. J. Chem.*, 1965, **18**, 70; (b) G. M. Badger, G. E. Lewis, and U. P. Singh, *ibid.*, 1965, **18**, 257; (c) G. M. Badger, J. A. Elix, and G. E. Lewis, *ibid.*, 1966, **19**, 1221; (d) G. M. Badger, G. E. Lewis, and U. P. Singh, *ibid.*, 1966, **19**, 1461; (e) 1967, **20**, 1635.
[13] J. A. Elix, *Austral. J. Chem.*, 1969, **22**, 1951.
[14] M. J. Broadhurst, R. Grigg, and A. W. Johnson, *J. Chem. Soc. (C)*, 1971, 3681; *J.C.S. Perkin I*, 1972, 1124, 2111.
[15] T. M. Cresp and M. V. Sargent, *Chem. Comm.*, 1971, 1457; *J.C.S. Chem. Comm.*, 1972, 807.
[16] K. Y. Novitskii, K. Y. Yur-ev, and V. N. Zhingareva, *Zhur. obshchei Khim.*, 1962, **32**, 3303.
[17] J. A. Elix, M. V. Sargent, and F. Sondheimer, *J. Amer. Chem. Soc.*, 1970, **92**, 973.

between the appropriate dicarbaldehyde and the appropriate bis(triphenylphosphonium salt). These latter reactions were performed by the dropwise addition of methanolic lithium methoxide, or ethanolic lithium ethoxide, to a stirred mixture of the reagents in NN-dimethylformamide (DMF) under dry nitrogen at 80—90°.

Reaction of 5-bromofuran-2-carbaldehyde [18] with ethylene glycol gave 2-(5-bromo-2-furyl)-1,3-dioxolan (5). The lithio-derivative of compound (5) on treatment

the monoylide (Scheme) in an analogous fashion to the elimination of triphenylphosphine from o-xylylenebis-(triphenylphosphonium bromide) [20] and $trans$-but-2-enylenebis(triphenylphosphonium bromide).[21]

To circumvent the problem of triphenylphosphine elimination we have reversed the order of the phosphonium salt and aldehyde substituents. Chloromethylation of 2,2'-difuryl ketone (10) [22] with chloromethyl methyl ether and tin(IV) chloride gave as the

(5)   (6)

(7)   (8)

with ethyl NN-dimethylcarbamate gave the dicarbaldehyde (6), after removal of the protecting groups. Condensation of compounds (6) and (7) followed by methylation of the crude product then afforded dimethyl 2,5:8,11:13,16-triepoxy-12-oxoheptadeca-2,4,6,8,10,13,-15,17-octaene-1,6-dicarboxylate (8) in 21% yield. Decarboxylation of the derived diacid with copper chromite in quinoline gave a low yield of 2,5:8,11:14,17-triepoxy-[17]annulenone (2). The overall yield (1·1%) of this sequence, the number of steps involved, and the necessity for two chromatographic separations prompted us to seek an alternative approach.

Wittig condensation of dicarbaldehyde (6) with furan-2,5-diyldimethylenebis(triphenylphosphonium chloride)

major product 2,2'-bis-5-chloromethylfuryl ketone (11). This was obtained in 54% yield by direct crystallization of the crude reaction mixture. Also isolated were 5,5'-bismethoxymethyl analogue (12), and an inseparable mixture of 5-chloromethyl-2-furyl 5-methoxymethyl-2-furyl ketone (13) and 2-furyl 5-methoxymethyl-2-furyl ketone (14). Reaction of (11) with triphenylphosphine gave carbonyldi(furan-2,5-diyl)dimethylenebis-triphenyl-phosphonium chloride) (15). Wittig condensation of the salt (15) with furan-2,5-dicarbaldehyde (16) [23] afforded (2) in 10% yield. Although not representing a significant improvement in yield triphenylphosphine cannot be eliminated from the salt (15) thus facilitating the isolation of the cyclic product (2).
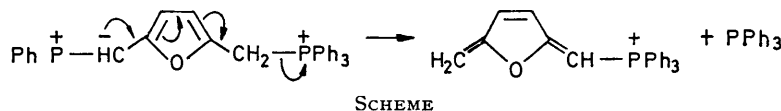
SCHEME

(9), obtained from 2,5-bis(chloromethyl)furan [16] by reaction with triphenylphosphine, gave annulenone (2) in 8% yield. In agreement with a previous report [19] triphenylphosphine was isolated as a by-product of this reaction. This presumably arose by 1,6-elimination from
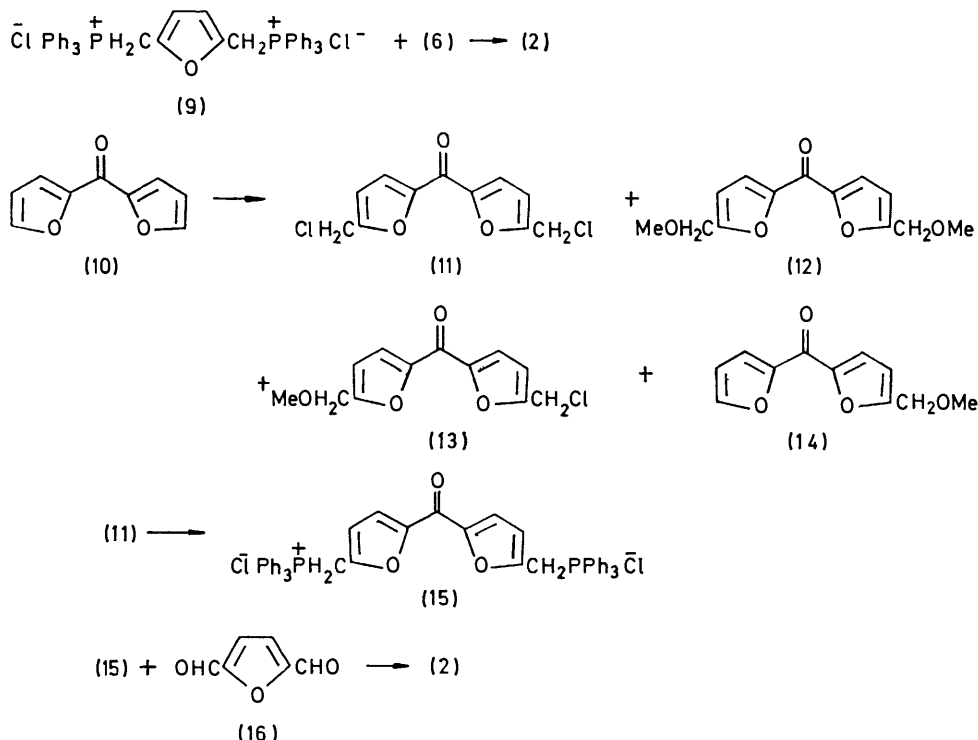
Pyrrole-2,5-dicarbaldehyde (19) was required for the synthesis of 8,11-epimino-2,5:14,17-diepoxy[17]annulen-one (1), and two routes towards its preparation were investigated.* Electrophilic substitution of pyrroles containing an electron-withdrawing group at the 2-position often gives appreciable proportions of the 5-substituted product. Thus Vilsmeier–Haack formylation of ethyl pyrrole-2-carboxylate [24] gave the 5- and

* Very recently another method for the preparation of the dicarbaldehyde (19) has been reported, see J. Bergman, *Tetrahedron Letters*, 1972, 4723.

[18] Z. N. Nazarova, *Zhur. obshchei Khim.*, 1954, **24**, 575.
[19] H. Saikachi, H. Ogawa, Y. Minami, and K. Sato, *Chem. and Pharm. Bull.* (*Japan*), 1970, **18**, 465.
[20] J. A. Elix and M. V. Sargent, *J. Amer. Chem. Soc.*, 1968, **90**, 1631.
[21] J. A. Ford and C. V. Wilson, *J. Org. Chem.*, 1961, **26**, 1433.

[22] U. Michael and A. Hörnfeldt, *Tetrahedron Letters*, 1970, 5219.
[23] G. Drechsler and K. Kopperschlaeger, East Ger. P. 26,542 (*Chem. Abs.*, 1964, **61**, 4315.)
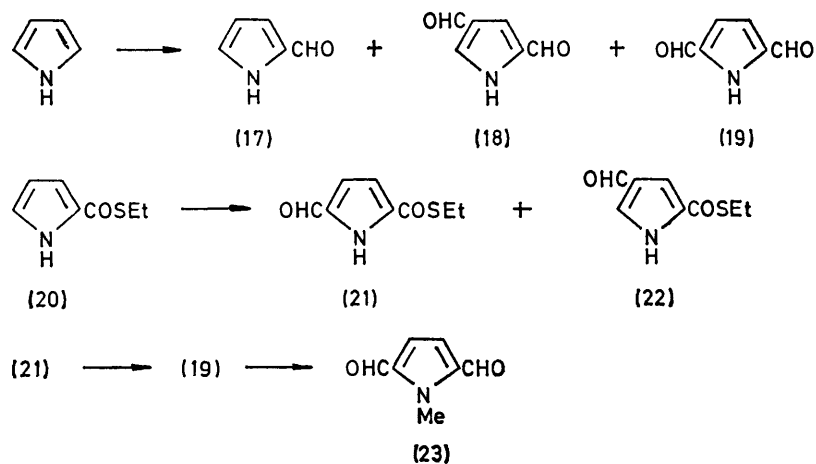[24] M. K. A. Khan, K. J. Morgan, and D. P. Morrey, *Tetrahedron*, 1966, **22**, 2095.

4-formyl isomers in a ratio of 3·5:1, and nitration [25] of pyrrole-2-carbaldehyde (17) gave a ratio of 5:4-isomer of *ca.* 1 : 1 6. We therefore formylated pyrrole with an excess of the phosphoryl chloride–DMF complex under forcing conditions. The products isolated were

phurization of thioester (21) with deactivated W-2 Raney nickel then yielded the desired dicarbaldehyde (19). Wittig reaction of the dicarbaldehyde (19) and the salt (15) then gave the [17]annulenone (1) in 14% yield.

$$\bar{C}l \ Ph_3 \overset{+}{P} H_2 C \langle \overset{O}{} \rangle CH_2 \overset{+}{P} Ph_3 Cl^- \ + \ (6) \longrightarrow (2)$$

(9)

(10) ⟶ (11) + (12)

+ MeOH₂C (13) + (14)

(11) ⟶ (15)

$$\bar{C}l \ Ph_3 \overset{+}{P} H_2 C \langle \overset{O}{} \rangle \overset{O}{} \langle \overset{O}{} \rangle CH_2 PPh_3 \bar{C}l$$

(15) + OHC⟨O⟩CHO ⟶ (2)

(16)

pyrrole-2-carbaldehyde (17) (39·0%), pyrrole-2,4-dicarbaldehyde (18) (4·0%), and the dicarbaldehyde (19) (0·5%). In contrast to this, formylation of *S*-ethyl pyrrole-2-thiocarboxylate (20) [26] gave *S*-ethyl 5-formyl-

In an attempt to replace the internal proton of annulenone (1) with a methyl group 1-methylpyrrole-2,5-dicarbaldehyde (23), obtained by *N*-methylation of dicarbaldehyde (19) with methyl iodide and potassium carbon-

(17) (18) (19)

(20) ⟶ (21) + (22)

(21) ⟶ (19) ⟶ (23)

pyrrole-2-thiocarboxylate (21) (59%) and *S*-ethyl 4-formylpyrrole-2-thiocarboxylate (22) (23%).[27] Desul-

ate in DMF, was treated with the salt (15), but none of the *N*-methyl analogue of annulenone (1) could be

[25] P. Fournari and J. Tirouflet, *Bull. Soc. chim. France*, 1963, 484.
[26] C. E. Loader and H. J. Anderson, *Tetrahedron*, 1969, **25**, 3879.

[27] After our work was completed this reaction was reported by other workers, see P. Fournari, M. Farnier, and C. Fournier, *Bull. Soc. chim. France*, 1972, 283.

isolated. Porphyrins are known to undergo N-methylation [28] but the attempted N-methylation of compound (1) under a variety of conditions led only to the isolation of starting material.

Wittig reaction of thiophen-2,5-diyldimethylenebis(triphenylphosphonium chloride) (24), obtained by the reaction of 2,5-bis(chloromethyl)thiophen [29] and triphenylphosphine, with the dicarbaldehyde (6) gave an 8% yield of 2,5:14,17-diepoxy-8,11-epithio[17]annulenone (3). Again triphenylphosphine was a by-product of the reaction.

We have also attempted to synthesize 8,11-epoxy-2,5:14,17-diepithio[17]annulenone (28) and 2,5:8,11:14,17-triepithio[17]annulenone (29). Chloromethylation of

(24)

(25)   (26)   (27)

(27) + (24) ─✗─   ─✗─ (27) + (9)

(28) X = O
(29) X = S
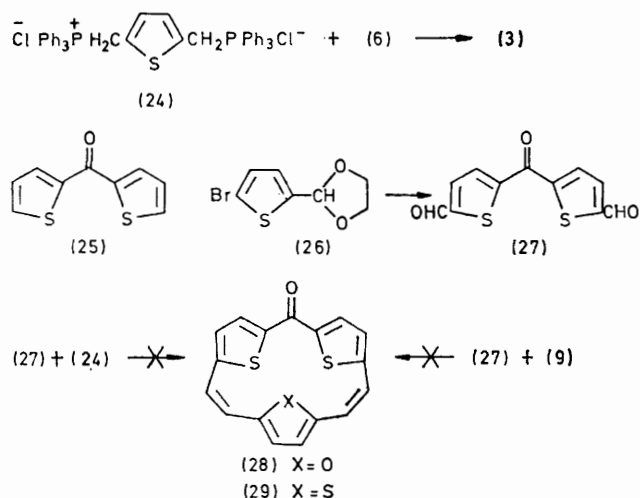
2-thienyl ketone (25) [22] using the same reagents as those used for the preparation of compound (11), gave tetrasubstitution or a mixture of isomers, depending on the reaction conditions. 2,2'-Bis-5-formylthienyl ketone (27) was therefore prepared from 2-(5-bromo-2-thienyl)-1,3-dioxolan (26) by a method similar to that used for the furan analogue (6). Attempted Wittig reactions between (27) and (9), or between (27) and (24) gave none of the annulenones (28) and (29), respectively. In both of these experiments triphenylphosphine was the sole product identified. This failure to obtain the cyclic products (28) and (29) presumably reflects the greater steric demands of sulphur as compared with oxygen.

The epiminodiepoxy[17]annulenone (1) was obtained as deep purple needles, m.p. 299—300° (decomp.), vivid blue in solution, the triepoxy[17]annulenone (2) was obtained as deep violet prisms, m.p. 236—237°, violet in solution, and the diepoxyepithio[17]annulenone (3) was obtained as silky reddish-brown plates, m.p. 148—150°, orange in solution. All three compounds appear to be reasonably stable and undergo only slow decomposition on storage at 0° in the solid state.

The mass spectra of the annulenones (1)—(3) are, as expected, very similar to those of the heteroatom-bridged [18]annulenes.[30] The base peaks in the spectra

[28] See R. Grigg, G. Shelton, A. Sweeney, and A. W. Johnson, J.C.S. Perkin I, 1972, 1789 and references therein.

of all three annulenones are the molecular ions and the initial fragmentation is the loss of carbon monoxide from the ketone function. Almost all the peaks due to singly-charged ions are accompanied by appropriate doubly-charged ions. In the triepoxy[17]annulenone (2) the initial loss of CO is followed by successive losses of CHO, CO, CO, and HC≡CH. After the loss of CO from the molecular ion the fragmentation pattern of the epiminodiepoxy[17]annulenone (1) involves the successive losses of ĊH=NH, CO, CO, and HC≡CH. The mass spectrum of the diepoxyepithioannulenone (3) is complicated by the loss of sulphur from the molecular ion as well as CO. The loss of sulphur is followed by successive losses of CHO, CO, CO, and HC≡CH, whilst the initial loss of CO is followed by successive losses of CHO, CO, CHṠ, and HC≡CH.

The behaviour of the carbonyl group of annulenone (2) with a number of reagents was investigated. Starting material was recovered from attempted reaction of (2) with hydroxylamine, methylenetriphenylphosphorane, and cyclopentadienyl anion. This lack of reactivity presumably reflects the steric hindrance of the carbonyl group by the flanking furan rings.
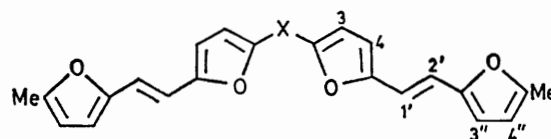
If the macrocycles (1)—(3) are to behave as planar $4n$ π-electron systems then the consequent existence of paramagnetic ring currents will be manifested in an upfield shift of the n.m.r. resonance positions of the
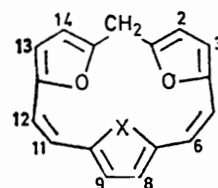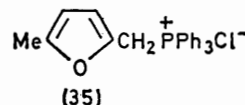

(30) X = NH
(31) X = O
(32) X = S

(33) X = CO
(34) X = CH₂

(35)

protons external to the carbon skeletons, and a deshielding of protons inside the rings relative to models in which no ring current can exist. We have chosen the homoannulenes (30)—(32) as suitable reference compounds. These were prepared by lithium aluminium hydride-

[29] J. M. Griffing and L. F. Salisbury, J. Amer. Chem. Soc., 1948, 70, 3416.
[30] G. M. Badger, J. H. Bowie, J. A. Elix, G. E. Lewis, and U. P. Singh, Austral. J. Chem., 1965, 20, 2669.

aluminium chloride reduction of the annulenones (1)—(3), respectively. If no ring current effect is present in annulenones (1)—(3) then one would expect the resonance positions of the peripheral protons to be lower in the annulenones than in the homoannulenes (30)—(32), as a result of deshielding by the carbonyl group.

To test this expectation we have prepared the linear compounds trans,trans-2,2'-bis-[5(5-methyl-2-furylvinyl)-furyl] ketone (33) and trans,trans-2,2'-bis-[5-(5-methyl-2-furylvinyl)furyl]methane (34). Wittig reaction between dicarbaldehyde (6) and 5-methyl-2-furylmethyltriphenyl-phosphonium chloride (35), prepared from 2-chloro-methyl-5-methylfuran,[31] gave the ketone (33). Reduction of (33) with lithium aluminium hydride–aluminium chloride then yielded the alkane (34). The chemical shifts for the protons of (33) and (34) are shown in Table 1. As expected there is a shift to higher field on going from ketone (33) to alkane (34) and the shift is greatest for those protons nearest the carbonyl group.

In Table 2 a similar comparison of resonance positions and their difference between annulenones (1)—(3) and

TABLE 1

Chemical shifts for protons of linear ketone (33) and alkane (34)

	Chemical shift (τ) [a]		Difference
Protons	(33)	(34)	(p.p.m.) [b]
2 × 3-H	2·49	3·90	+1·41
2 × 4-H	3·55	3·80	+0·25
2 × 1'-H	3·00 [c]	3·31	+0·31
2 × 2'-H	3·24 [c]	3·31	+0·07
2 × 3''-H	3·67	3·83	+0·16
2 × 4''-H	3·98	4·03	+0·05
2 × 5''-CH₃	7·67	7·66	−0·01

[a] Determined at 90 MHz for deuteriochloroform solutions. [b] Positive differences indicate a shift to higher field on going from (33) to (34). [c] We imply no definite assignment for the olefinic protons.

homoannulenes (30)—(32) is listed. In annulenone (1) all the external protons resonate at unusually high field. There is a shift to higher field for only the two external protons (3- and 16-H) nearest the carbonyl group, on going from annulenone (1) to homoannulene (30). For the remaining external protons there is a shift to lower field on going from (1) to (30) which is the opposite effect to that observed in the linear systems (33) and (34). The internal imino-proton of (1) is at very low field and has moved upfield by 5·9 p.p.m. to τ −2·4 in (30). The imino-proton of (1) is in the zone of shielding of the carbonyl group[32] but may well experience deshielding by the furan oxygen atoms. The close proximity of an oxygen atom to a proton has been noted in several cases to produce a down-field shift, but this effect is little understood.[33] Presumably any deshielding of the imino-proton in (1) due to the furan oxygen atoms would also be experienced by the imino-proton of (30). This

† The imino-proton of pyrrole resonates at τ ca. 2.

[31] T. Reichstein and H. Zschokke, Helv. Chim. Acta, 1932, 15, 249.
[32] L. M. Jackman and S. Sternhell, ' Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry,' Pergamon, Oxford, 1969, 2nd edn., p. 88.

effect could account for the relatively low-field resonance of the latter.† The 5·9 p.p.m. difference in the resonance position of the imino-protons in (1) and (30) is thus best explained by the presence of a paramagnetic ring current in (1). Further confirmation of this is given by the high-field resonance positions of the peripheral protons in (1). The low-field resonance for the internal imino-proton in this 16π-electron system contrasts markedly with that of the bridging imino-proton in the 10π-electron system 1,6-epimino[10]annulene (36)[34] at τ 11·1, and with the internal imino-proton of the 18π-electron porphyrin system (37) which resonate at τ ca. 14.[35]
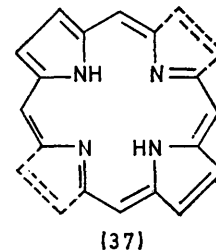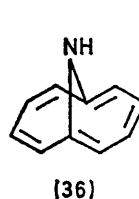

(36)

(37)

Comparison of the n.m.r. spectra of the triepoxy[17]-annulenone (2) and the derived homoannulene (31) (see Table 2) shows that the peripheral protons of (2) resonate

TABLE 2

Chemical shifts for protons of annulenones (1)—(3) and homoannulenes (30)—(32)

		Chemical shift (τ) [a]		
Compounds	Protons [*]	Annulen-one	Homo-annulene	Difference [b] (p.p.m.)
(1) ⟶ (30)	3,16	3·39	3·88	+0·49
	4,15	4·54	4·07	−0·47
	6,13	4·87 [c]	4·02 [c]	−0·85
	7,12	5·23 [c]	4·28 [c]	−0·95
	9,10	4·58	3·82	−0·76
	NH	−8·3 [d]	−2·4	+5·9
(2) ⟶ (31)	3,16	3·31	3·93	+0·62
	4,15	4·35	4·07	−0·28
	6,13	5·02 [c]	4·23	−0·79
	7,12	5·11 [c]	4·23	−0·88
	9,10	4·34	3·73	−0·61
(3) ⟶ (32)	3,16	2·90	3·94	+1·04
	4,15	3·88	4·00	+0·12
	6,13	3·67 [c]	3·62 [c]	−0·05
	7,12	4·15 [c]	3·97 [c]	−0·07
	9,10	3·25	3·20	−0·05

[*] For convenience, the numbering system of the annulenones (1)—(3) has been used for assigning the chemical shifts of the homoannulenes (30)—(32).

[a] Determined for deuteriochloroform solutions. [b] Positive differences indicate a shift to higher field on going from annulenone to appropriate homoannulene. [c] We imply no definite assignment for the olefinic protons. [d] This value was not concentration dependent.

at unusually high field and (2) is thus paratropic. In the diepoxyepithio[17]annulenone (3) the resonance positions of all the protons except those nearest the carbonyl group

[33] Ref. 32, p. 80.
[34] E. Vogel, W. Pretzer, and W. A. Böll, Tetrahedron Letters, 1965, 3613.
[35] R. J. Abraham, A. H. Jackson, and G. W. Kenner, J. Chem. Soc., 1961, 3468; R. B. Woodward and V. Skaric, J. Amer. Chem. Soc., 1961, 83, 4676.

(3- and 16-H) occur at nearly the same position as the analogous protons in homoannulene (33). This indicated that (3) fails to support any appreciable paramagnetic ring current. The presence of the bulky sulphur atom presumably forces the molecule to adopt a non-planar conformation. This is obvious on the examination of a Stuart–Briegleb model of (3).

The n.m.r. spectrum of dimethyl 2,5:8,11:13,16-triepoxy-12-oxoheptadeca-2,4,6,8,10,13,15,17-octaene-1,6-dicarboxylate (8) exhibited a 2H singlet at τ 2·28 (7- and 17-H), a 4H AB system (J 3·5 Hz) centred at τ 2·70 and 3·22 (9-, 10-, 15-, and 16-H), a 2H singlet at 3·65 (3- and 4-H), and a 6H singlet at 6·17 (2 × OMe). These data suggest that (8) is not paratropic. Examination of a Stuart–Briegleb model of (i) shows that in order for the carbonyl groups of the ester substituents to conjugate efficiently with the 1,17- and 6,7-double bonds

(38)

(39) X = O
(40) X = S

(41)
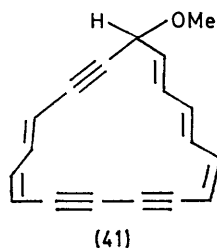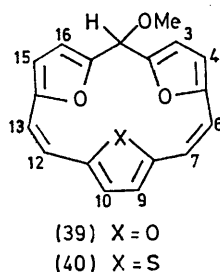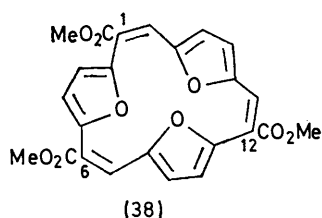
it is necessary for the furan ring remote from the ketone function to twist out of the plane of the rest of the molecule. A similar state of affairs exists for trimethyl 2,5:8,11:14,17-triepoxy[18]annulene-1,6,12-tricarboxylate (38).[12c]

Sodium borohydride or lithium aluminium hydride reduction of annulenones (2) and (3) followed by methylation of the unstable alcohols obtained gave the methyl

TABLE 3

Chemical shifts for protons of methyl ethers (39) and (40)

	Chemical shift (τ) [a]	
Protons	(39)	(40)
3,16	3·87	3·75
4,15	4·18	3·97
6,13}	4·53	3·53 [b]
7,12}	4·53	4·12 [b]
9,10	3·98	3·22

[a] Determined at 60 MHz for deuteriochloroform solutions.
[b] We imply no definite assignment for the olefinic protons.

ethers (39) and (40), respectively. The chemical shifts for the protons of (39) and (40) are listed in Table 3. The

protons of (39) resonate at higher field than might be expected in the absence of any ring current. The differences between the chemical shifts of analogous protons in methyl ethers (39) and (40) are greater than those between homoannulenes (31) and (32) by 0·13—0·29 p.p.m. This would indicate that (39) sustains a small paramagnetic ring current, an effect which results from the polarization of the carbon–oxygen bond of the methyl ether substituent. A similar case is that of the 16π-electron system (41),[1b,4a] in which the inner protons resonate at τ 1·93—2·77 and the outer protons at 3·15—4·67.

EXPERIMENTAL

M.p.s were measured on a Kofler hot-stage apparatus. Light petroleum refers to the fraction b.p. 58—65°. DMF was stored over 4 Å molecular sieves for a prolonged period, and then distilled at ca. 50—80 mmHg onto 4 Å molecular sieves. All phosphonium salts were dried at 56° at 0·05 mmHg for 24 h immediately before use. Silica gel for column chromatography was B.D.H. 60—120 mesh. The adsorbent for preparative layer chromatography (p.l.c.) (20 × 20 × 0·1 cm plates) was Merck Kieselgel GF$_{254}$. I.r. spectra were determined for potassium bromide discs using a Perkin-Elmer 337 grating spectrophotometer. U.v.-visible spectra were determined for ether solutions using a Perkin-Elmer 450 spectrophotometer. N.m.r. spectra were determined for deuteriochloroform solutions, unless stated otherwise, at 60 MHz on a Varian A-60-A spectrometer, or at 90 MHz on a Bruker Spectrospin instrument. Low resolution mass spectra were determined using a Varian-MAT CH7 spectrometer, and high resolution spectra on an A.E.I. MS-902 spectrometer, both operating at 70 eV.

2-(5-*Bromo-2-furyl*)-1,3-*dioxolan* (5).—2-Bromofuran-5-carbaldehyde (20·0 g), ethylene glycol (11·2 g), toluene-p-sulphonic acid (5 mg), and benzene (150 ml) were heated under reflux in a Dean–Stark apparatus for 14 h. The solution was cooled and diluted with ether and was washed successively with saturated sodium hydrogen carbonate, water, and with saturated sodium chloride solution. The solution was dried (Na$_2$SO$_4$) and evaporated. The residue was fractionated under reduced pressure and yielded 2-(5-(*bromo-2-furyl*)-1,3-*dioxolan* (5) (20·4 g, 81·5%), as an oil, b.p. 110—112° at 6 mmHg (Found: C, 38·45; H, 3·25; Br, 35·95. C$_7$H$_7$BrO$_3$ requires C, 38·4; H, 3·2; Br, 36·5%); τ (60 MHz; CCl$_4$) 3·67 and 3·77 (ABq, J 3·5 Hz, furan protons), 4·23 (1H, s, CH), and 6·05 (4H, m, CH$_2$), m/e 220 and 218 (M^+).

Ethyl NN-*Dimethylcarbamate*.—Ethyl chloroformate (108·5 g) was added dropwise over 0·5 h to a stirred, ice-cooled solution of dimethylamine (91 g) in water (305 ml). Stirring was continued for a further 1 h after the addition; the ice-bath was removed and stirring was continued for 5·5 h. The mixture was then extracted with ether and the extract was washed with saturated sodium chloride solution. The dried (Na$_2$SO$_4$) ether solution was fractionated using a 10 cm Vigreux column which afforded ethyl NN-dimethylcarbamate (103·2 g, 88·2%), b.p. 145° (lit.,[36] 147°), τ (60 MHz; CCl$_4$) 5·96 (2H, q, OCH_2CH$_3$), 7·16 (6H, s, NCH$_3$), and 8·88 (3H, t, OCH$_2$CH_3).

[36] A. P. N. Franchimont, *Rec. Trav. chim.*, 1884, **3**, 222.

2,2'-Bis-5-formylfuryl Ketone (6).—The dioxolan (5) (26·0 g) in dry ether (50 ml) was added dropwise over 15 min to a stirred solution of n-butyl-lithium (0·142 mol) in dry ether (170 ml) at −20° under an atmosphere of dry nitrogen. After a further 15 min at −20° a solution of ethyl *NN*-dimethylcarbamate (6·7 g) in dry ether (20 ml) was added over 5 min. The temperature was allowed to rise to −10° and stirring was continued at that temperature for 45 min. The mixture was then treated cautiously with an excess of saturated aqueous ammonium chloride solution and the precipitated material was separated by filtration, and washed well with water. A sample was crystallized from dichloromethane–light petroleum and formed glistening yellow leaflets of *2,2'-bis-5-(1,3-dioxolan-2-yl)furyl ketone*, m.p. 129—131° (Found: C, 58·95; H, 4·65. $C_{15}H_{14}O_7$ requires C, 58·8; H, 4·6%), τ (60 MHz) 2·52 and 3·38 (4H, ABq, *J* 3·5 Hz, furan protons), 3·97 (2H, s, CH), and 5·90 (8H, m, CH_2), *m/e* 306 (M^+).

Hydrochloric acid (10%; 110 ml) was added to a warm solution of the remaining solid in acetone (300 ml). The solution was stirred for 1·5 h and the bulk of the acetone was then removed under reduced pressure. The precipitated material was collected by filtration and dried in vacuum, and then crystallized from dichloromethane–light petroleum to yield the *dicarbaldehyde* (6) (9·1 g, 70%), m.p. 189—191°. The analytical sample was prepared by sublimation at 145° at 2 mmHg followed by crystallization from dichloromethane–light petroleum and formed needles, m.p. 189—191° (Found: C, 60·1; H, 2·95. $C_{11}H_6O_5$ requires C, 60·55; H, 2·8%), τ (60 MHz) 0·05 (2H, s, CHO) and 2·13 and 2·26 (4H, ABq, *J* 3·5 Hz, furan protons), *m/e* 218 (M^+).

Dimethyl 2,5:8,11:13,16-Triepoxy-12-oxoheptadeca-2,4,6,8,-10,13,15,17-octaene-1,6-dicarboxylate (8).—The dicarbaldehyde (6) (2·2 g) was added to a solution of furan-2,5-diacetic acid (7) [10] (1·85 g) in acetic anhydride (12 ml) and triethylamine (12 ml) and the mixture was stirred at room temperature for 1 h, and the cooled in ice. Concentrated hydrochloric acid (25 ml) was added dropwise to the stirred solution, followed by water (25 ml). The precipitated material was separated by filtration, washed with water, and dried in vacuum to leave a brick-red solid (3·65 g). Dry methanol (150 ml) containing dry hydrogen chloride (4·8 g) was added to the solid and the suspension was heated under reflux for 1 h. Half the methanol was removed by distillation and the cooled residue was diluted with water and extracted exhaustively with ethyl acetate. The extract was washed in turn with water, saturated sodium hydrogen carbonate solution, and with saturated sodium chloride. The dried ($MgSO_4$) extract was evaporated and the orange, oily residue (174·8 mg) was applied to two p.l.c. plates which were developed with 5% ethyl acetate–benzene. The fastest moving orange band formed orange prisms of the *diester* (8) (82·3 mg, 20·7%), m.p. 206—208° (from dichloromethane–light petroleum) (Found: M^+, 394·0688. $^{12}C_{21}{}^{1}H_{14}{}^{16}O_8$ requires *M*, 394·0689), n.m.r. see Discussion section.

Hydrolysis and Decarboxylation of Diester (8).—The diester (8) (14·1 mg) in 50% aqueous methanol (3 ml) containing potassium hydroxide (0·3 g) was heated under reflux for 45 min. Most of the methanol was removed by distillation and the cooled solution was diluted with water and extracted with ether. The aqueous layer was acidified with ice-cold 50% hydrochloric acid and extracted exhaustively with dichloromethane. The organic layer was washed

with water and dried ($CaCl_2$). Removal of the solvent left 2,5:8,11:13,16-triepoxy-12-oxoheptadeca-2,4,6,8,10,13,-15,17-octaene-1,6-dicarboxylic acid as an orange solid (8·9 mg, 68%), decomp. at 295° without melting, *m/e* 366 (M^+). The foregoing dicarboxylic acid (31·5 mg) and copper chromite (20 mg) were suspended in quinoline (0·5 ml) and heated at 180° (bath) for 1·5 h and then cooled. The mixture was treated with an excess of ice-cold 10% hydrochloric acid, and then extraxted with ether, The extracts were washed in turn with 10% hydrochloric acid, water, and with saturated sodium chloride solution, and dried (Na_2SO_4). The dark solid (18·8 mg) left on removal of the ether was applied in dichloromethane to a p.l.c. plate which was developed with 10% ethyl acetate–light petrolepm. The fastest moving coloured band afforded 2,5:8,11:14,17-triepoxy[17]annulenone (2) (2·0 mg, 8%), identical (t.l.c., n.m.r., and mass spectra)with that described later.

Furan-2,5-diyldimethylenebis(triphenylphosphonium chloride) (9). A hot solution of triphenylphosphine (59·3 g) in dry DMF (100 ml) was added to a solution of 2,5-bis(chloromethyl)furan [16] (18·7 g) in dry DMF (60 ml) and the mixture was heated on the steam-bath for 1·5 h. The mixture was cooled and the precipitated material was separated by filtration and washed well with dry ether, and dried at 56° and 0·01 mmHg to afford the *phosphonium salt* (9) as an off-white solid (69·3 g, 88·8%). The analytical sample crystallized from ether–methanol as prisms, decomp. at 230° without melting (Found: C, 64·4; H, 6·15; Cl, 9·2. $C_{42}H_{36}Cl_2P_2O,5H_2O$ requires C, 64·7; H, 5·95; Cl, 9·1%).

Chloromethylation of Ketone (10).—Chloromethyl methyl ether (30 g) was added in one portion to an ice-cooled stirred solution of 2,2'-difuryl ketone [22] (10) (11·56 g) in dry dichloromethane (140 ml). The resulting green solution was treated by dropwise addition over 20 min with a solution of freshly distilled tin(IV) chloride (20 ml) in dry dichloromethane (10 ml). After a further 10 min with ice-cooling the solution was stirred at room temperature for 2 h. The mixture was poured onto ice–water and diluted with dichloromethane. The separated organic layer was washed with water and with saturated sodium chloride solution, and dried ($CaCl_2$). The residue, after removal of the solvent, was crystallized from dichloromethane–light petroleum (charcoal). Recrystallization of this material gave 2,2'-bis-5-chloromethylfuryl ketone (11) (9·9 g, 54%), as yellow prisms, m.p. 117—119·5°. The analytical sample was obtained by several crystallizations from the same solvent system (charcoal), and formed cream prisms, m.p. 119—120° (Found: C, 51·2; H, 3·05; Cl, 27·65. $C_{11}H_8Cl_2O_3$ requires C, 51·0; H, 3·1; Cl, 27·35%), τ (60 MHz) 2·52 and 3·40 (ABq, *J* 3·5 Hz, 3-,3',4- and 4'-H), and 5·33 (4H, s, CH_2), *m/e* 258, 260, and 262 (M^+).

The combined mother liquors from the crystallizations were evaporated and yielded a dark oil (9·15 g) which partially solidified. This was pre-adsorbed from dichloromethane onto silica gel and chromatographed over a column of silica gel (total 4·5 × 53 cm) using 5—30% ethyl acetate–light petroleum as eluant. The first material to be eluted was methyl 5-chloromethyl-2-furoate † (226 mg) which was identical (i.r., n.m.r., and mass spectra) with an authentic sample prepared by chloromethylation of methyl furoate.[37]

---

† We believe that this product arises from furoic acid present as a trace impurity in the ketone employed.

[37] A. L. Mndzhoyan and M. T. Grigoryan, *Doklady Akad. Nauk Armyan S.S.R.*, 1953, 17, 101.

The next material eluted was the chloride (11) (2·46 g, total yield 67%) identical with that obtained before. Further elution gave an oily mixture (2·36 g) of 5-chloromethyl-2-furyl 5-methoxymethyl-2-furyl ketone (13) (58 mol %) and 2-furyl 5-methoxymethyl-2-furyl ketone (14) (42 mol %) not further resolved on p.l.c., τ (60 MHz) 2·30 [m, 5-H of (14)], 2·48 (m, furan protons), 3·42 (m, furan protons), 5·33 [s, ClCH$_2$ of (13)], 5·48 [s, CH_2OMe of (13) and (14)], and 6·59 [s, CH$_2$OMe of (13) and (14)], the following peaks were assigned to (13) m/e 254 and 256 (M^+), 223 and 225 (M − OMe), 219 (M − Cl); the following peaks were assigned to (14) 206 (M^+) and 175 (M − OMe). This was followed by 2,2′-*bis*-5-*methoxymethylfuryl ketone* (12) (2·16 g) as an oil which darkened on standing, b.p. 180° (bath) at 0·04 mmHg (Found: M^+, 250·0839. $^{12}C_{13}{}^{1}H_{14}{}^{16}O_5$ requires M, 250·0841); τ (60 MHz) 2·55, 3·48 (4H, ABq, J 3·5 Hz, 3-, 3′-, 4-, and 4′-H), 5·52 (4H, s, CH$_2$), and 6·62 (6H, s CH$_3$).

Carbonyldi(furan-2,5-diyl)dimethylenebis(triphenylphosphonium chloride) (15).—A hot solution of triphenylphosphine (20 g) in dry DMF (15 ml) was added to a solution of the chloride (11) (9·9 g) in dry DMF (10 ml) and the solution was heated on the steam-bath for 11 h, and then allowed to cool. The precipitate was separated by filtration and washed well with dry ether, and then dried at 56° and 0·2 mmHg to give the *phosphonium salt* (15) as pale yellow prisms (28·1 g, 93·9%). A sample crystallized from dichloromethane-dry ether formed pale yellow prisms, decomp. at 280° without melting (Found: C, 70·7; H, 4·65; Cl, 9·0. C$_{47}$H$_{38}$Cl$_2$O$_3$P$_2$,H$_2$O requires C, 70·4; H, 5·05; Cl, 8·85%).

2,5:8,11:14,17-*Triepoxy[17]annulenone* (2).—A *From phosphonium salt* (9) *and dicarbaldehyde* (6). Lithium ethoxide [from lithium (69·4 mg)] in absolute ethanol (19·8 ml) was added dropwise over 2 h to a stirred mixture of the salt (9) (3·49 g) and the dicarbaldehyde (6) (1·09 g) in dry DMF (120 ml) at 90° under dry nitrogen. After a further 45 min at 90°, and 10 h at 35° the cooled solution was poured into water and extracted with ether (3 × 300 ml). The combined extracts were washed with water (3×), and dried (Na$_2$SO$_4$). The residue left on removal of the solvent was pre-adsorbed from dichloromethane onto silica gel and chromatographed over a column of silica gel (total 3·5 × 40 cm). Elution with 10—15% ethyl acetate-light petroleum gave triphenylphosphine (232·8 mg) which was followed by the *annulenone* (2) (110·8 mg, 8·0%) which crystallized from dichloromethane-light petroleum as deep violet prisms, m.p. 236—237° (Found: C, 72·95; H, 3·8. C$_{17}$H$_{10}$O$_4$ requires C, 73·4; H, 3·6%), $\nu_{max.}$ 1601 cm^{-1} (CO), $\lambda_{max.}$ 254 nm (ε 26,800), 266sh (16,800), 295sh (68,000), 304 (81,000), 308 (82,000), 403 (1100), 520sh (780), 560 (940), and 610sh (660), τ (90 MHz) 3·31 and 4·35 (4H, ABq, $J_{3,4}$ = $J_{15,16}$ = 3·6 Hz, 3-, 4-, 15-, and 16-H), 4·34 (2H, s, 9- and 10-H), 5·02 and 5·11 (4H, ABq, $J_{6,7}$ = $J_{12,13}$ = 14·0 Hz, 6-, 7-, 12-, and 13-H), m/e 278 (M^+, 100%), 279 (19), 250 (5), 221 (5), 194 (5), 193 (5), 168 (5), 166 (9), 165 (34), 164 (5), 163 (5), 152 (5), and 139 (15), in addition there were doubly charged ions at m/e 139, 125, 96·5, 82·5, 81·5, and 69·5.

B *From salt* (15) *and furan-2,5-dicarbaldehyde* (16). The salt (15) (7·85 g) and the dicarbaldehyde (16) (1·24 g) were treated with lithium ethoxide [from lithium (138·8 mg)] in dry ethanol (29·5 ml) and the base was added over 4 h, followed by a further 2 h at 90° as described for the above preparation of (2). Chromatography as before (15% ethyl acetate-light petroleum as eluant) gave the annulenone (2) (268·2 mg, 9·6%).

Formylation of Pyrrole.—Phosphoryl chloride (73 ml) was added dropwise with stirring and ice-cooling to dry DMF (150 ml). The mixture was then stirred at room temperature for 15 min, and again cooled to 0° during the addition, over 20 min, of a solution of pyrrole (25·0 g) in DMF (10 ml). The mixture was stirred on the steam-bath for 2·5 h, and then poured into ice-water. Saturated aqueous sodium acetate, prepared from hydrated sodium acetate (700 g) was then added and the mixture kept at 5° for 12 h. It was then extracted exhaustively with ethyl acetate and the combined organic layers were washed with saturated sodium hydrogen carbonate solution and with brine, and dried (Na$_2$SO$_4$). The residue left on removal of the solvent was pre-adsorbed from ethyl acetate onto silica gel and chromatographed over a column of silica gel with 10—40% ethyl acetate-light petroleum as eluant. Early fractions gave pyrrole-2-carbaldehyde (17) (13·78 g, 39%). This was followed by *pyrrole-2,5-dicarbaldehyde* (19) (216 mg, 0·5%) which formed needles from dichloromethane-light petroleum, m.p. 121—122° (Found: C, 58·2; H, 3·85; N, 11·2. C$_6$H$_5$NO$_2$ requires C, 58·55; H, 4·1; N, 11·4%), τ (60 MHz) 0·18 (2H, s, CHO) and 2·99 (2H, d, J 2·5 Hz, pyrrole protons), m/e 123 (M^+).

Later fractions gave pyrrole-2,4-dicarbaldehyde (18) (1·81 g, 4·0%) which formed needles from dichloromethane-methanol (charcoal), m.p. 154—154·5° (lit.,[27] 151·5—152°) (Found: C, 58·5; H, 4·0; N, 11·4%), τ [60 MHz; CDCl$_3$-(CD$_3$)$_2$SO] 0·11 and 0·33br (each 1H, s, CHO), 2·19 (1H, m, 5-H), and 2·60 (1H, m, 3-H), m/e 123 (M^+). When this experiment was repeated in exactly the same way but with heating for 2·5 h at 130° (bath) the products obtained were pyrrole-2-carbaldehyde (17) (39%), pyrrole-2,5-dicarbaldehyde (19) (0·34%), and pyrrole-2,4-dicarbaldehyde (18) (8·7%).

Formylation of S-*Ethyl Pyrrole-2-thiocarboxylate.*[27]—Phosphoryl chloride (11·2 ml) was added with stirring and ice-cooling to dry DMF (10 ml). The mixture was then stirred at room temperature for 15 min, and then S-ethyl pyrrole-2-thiocarboxylate [26] (17·2 g) in dry 1,2-dichloroethane (30 ml) was added over 45 min with stirring and ice-cooling. The mixture was stirred at room temperature for 1·5 h, and then heated under gentle reflux for 15 min. The mixture was cooled and hydrated sodium acetate (85 g) in water was added with stirring. When the reaction had subsided the cooled mixture was extracted exhaustively with ethyl acetate. The extract was washed with saturated sodium hydrogen carbonate solution, and with saturated sodium chloride solution, and dried (Na$_2$SO$_4$). The black solid which remained on removal of the solvent was pre-adsorbed from chloroform onto silica gel and chromatographed over a column of silica gel (total 3·4 × 51 cm) with 10—20% ethyl acetate-light petroleum as eluant. Early fractions gave S-ethyl 5-formylpyrrole-2-thiocarboxylate (21) (12·0 g, 59%) which formed plates from light petroleum (charcoal), m.p. 65—65·5° (lit.,[27] 70°) (Found: C, 52·9; H, 5·3; N, 7·45. Calc. for C$_8$H$_9$NO$_2$S: C, 52·45; H, 4·9; N, 7·65%), τ† (90 MHz) −0·47br (1H, NH), 0·27 (1H, s, CHO), 3·04 and 3·07 (2H, AB part of ABX system, $J_{3,4}$ 4·0, $J_{1,3}$ = $J_{1,4}$ = 2·5 Hz, 3- and 4-H), 6·87 (2H, q, CH$_2$), and 8·64 (3H, t, CH$_3$), m/e 183 (M^+). Later fractions afforded S-ethyl 4-formylpyrrole-2-thiocarboxylate (22) as blades (4·58 g, 23%) from dichloromethane-light petroleum, m.p. 111—112° (lit.,[27] 111—112°), τ† (90 MHz) −0·78br (1H,

† A double irradiation experiment was carried out by irradiating at the frequency of the imino-proton.

NH), 0·15 (1H, s, CHO), 2·35 (1H, dd, $J_{3,5}$ 1·4, $J_{1,5}$ 3·4 Hz, 5-H), 2·59 (1H, dd, $J_{3,5}$ 1·4, $J_{1,3}$ 2·4 Hz, 3-H), 6·92 (2H, q, CH₂), and 8·65 (3H, t, CH₃), m/e 183 (M^+).

Desulphurization of S-Ethyl 5-Formylpyrrole-2-thiocarb-oxylate (21).—W-2 Raney nickel (10 teaspoons) was stirred and heated under reflux in acetone (100 ml) for 1 h, and then the thioester (21) (5·0 g) was added in acetone (20 ml), and water (20 ml) was added and heating continued for a further 2 h. The nickel was separated by filtration through Kieselguhr and washed well with acetone. Most of the acetone was removed under reduced pressure and the residue was taken up in ethyl acetate, washed with saturated sodium chloride solution, and dried (Na₂SO₄). The residue left on removal of the solvent was pre-adsorbed from chloroform onto silica gel and chromatographed over a column of silica gel (total 3·5 × 41 cm) with 15—20% ethyl acetate–light petroleum as eluant. Early fractions afforded the starting material (21) (493 mg) which was followed by pyrrole-2-carbaldehyde (863 mg, 37·0%). Later fractions afforded pyrrole-2,5-dicarbaldehyde (19) (1·07 g, 35·5%).

1-Methylpyrrole-2,5-dicarbaldehyde (23).—Pyrrole-2,5-dicarbaldehyde (110·9 mg), dry potassium carbonate (609 mg), dry DMF (3 ml), and methyl iodide (0·3 ml) were stirred together at room temperature for 45 min. The mixture was then diluted with water and extracted with ether. The extract was washed with saturated sodium chloride solution (2×) and dried (Na₂SO₄). Removal of the solvent left the N-*methyl compound* (23) (110·9 mg, 89·9%). It crystallized from pentane as feathery needles, m.p. 95—96° (Found: C, 61·4; H, 5·2; N, 10·15. C₇H₇NO₂ requires C, 61·3; H, 5·15; N, 10·2%): τ (60 MHz; CCl₄) 0·06 (2H, s, CHO), 3·13 (2H, s, pyrrole protons), and 5·72 (3H, s, CH₃), m/e 137 (M^+).

8,11-Epimino-2,5:14,17-diepoxy[17]annulenone (1).—The salt (15) (2·355 g) and the dicarbaldehyde (19) (369 mg) were treated with lithium methoxide [from lithium (41·6 mg)] in dry methanol (20·2 ml) at 80°, and the base was added over 3 h followed by a further 1 h at 80° as described for the above preparation of (2). Chromatography as before (25% ethyl acetate–light petroleum as eluant) gave the *annulenone* (1) (114·0 mg, 13·7%) which crystallized from dichloromethane–light petroleum as deep purple needles; m.p. 299—300° (decomp.) (Found: N, 4·7. C₁₇H₁₁NO₃ requires N, 5·05%) (Found: M^+, 277·0748. ^{12}C₁₇^{1}H₁₁^{14}N^{16}O₃ requires M, 277·0739), $ν_{max.}$ 3390 (NH) and 1601 cm⁻¹ (CO), $λ_{max.}$ 247sh (ε 15,500), 253 (16,400), 308 (68,000), 318 (66,000), 560sh (480), 600 (560), and 655sh nm (420), τ (90 MHz) −8·3br (1H, NH), 3·39 and 4·54 (4H, ABq, $J_{3,4} = J_{15,16}$ = 3·7 Hz, 3-, 4-, 15-, and 16-H), 4·58 (2H, d, $J_{9,NH} = J_{10,NH}$ = 2·4 Hz, 9- and 10-H), and 4·87 and 5·23 (4H, ABq, $J_{6,7} = J_{12,13}$ = 14·0 Hz, 6-, 7-, 12-, and 13-H), m/e 277 (M^+, 100%), 278 (18), 249 (2), 221 (7), 203 (13), 202 (15), 182 (4), 180 (5), 170 (5), 165 (6), 154 (6), 153 (2), 152 (2), 141 (6), 140 (3), and 139 (4), in addition there were doubly charged ions at m/e 138·5, 124·5, 95, 83·5, and 82·5.

Thiophen-2,5-diyldimethylenebis(triphenylphosphonium chloride) (24).—A hot solution of triphenylphosphine (12·8 g) in dry DMF (20 ml) was added to a solution of 2,5-bis(chloromethyl)thiophen [29] (4·4 g) in dry DMF (10 ml). The solution was heated on the steam-bath for 9 h. The precipitated material was separated by filtration from the cooled mixture, and the separated material washed well with dry ether and dried at 56° at 0·01 mmHg to give the salt (13·8 g, 80·5%), as an off-white solid. A sample crystallized from ether–methanol formed prisms, decomp. at 220°

without melting (Found: C, 67·75; H, 5·5; Cl, 9·3. C₄₂H₃₆Cl₂P₂S,2H₂O requires C, 68·0; H, 5·45; Cl, 9·55%).

2,5:14,17-Diepoxy-8,11-epithio[17]annulenone (3).—The salt (24) (3·53 g) and the dicarbaldehyde (6) (1·09 g) were treated with lithium methoxide [from lithium (69·4 mg)] in dry methanol (27·0 ml) and the base was added over 2 h, followed by a further 2 h at 90°, as described for the foregoing preparation of (2). Chromatography as before (10—15% ethyl acetate–light petroleum as eluant) yielded triphenylphosphine (155·9 mg) which was followed by the *annulenone* (3) (123·1 mg, 8·4%) which crystallized from dichloromethane–light petroleum as silky reddish-brown plates, m.p. 148—150° (Found: C, 69·6; H, 3·6. C₁₇H₁₀O₃S requires C, 69·4; H, 3·45%), $ν_{max.}$ 1600 cm⁻¹ (CO), $λ_{max.}$ 241 (ε 19,600), 297sh (39,000), 305 (43,000), and 405sh nm (1240), τ (60 MHz) 2·90 and 3·88 (4H, ABq, $J_{3,4} = J_{15,16}$ = 3·5 Hz, 3-, 4-, 15-, and 16-H), 3·25 (2H, s, 9- and 10-H), and 3·67 and 4·15 (4H, ABq, $J_{6,7} = J_{12,13}$ = 12·0 Hz, 6-, 7-, 12-, and 13-H), m/e 294 (M^+, 100%), 295 (20), 266 (2), 262 (2), 238 (4), 237 (4), 234 (2), 210 (8), 209 (22), 208 (12), 205 (2), 183 (8), 177 (3), 165 (16), 151 (2), 147 (4), and 139 (11), in addition there were doubly charged ions at m/e 147, 133, 118·5, 105, 104·5, 104, 97·5, 92, 91·5, 85·5, 82·5, 81·5, 80·5, 79·5, and 69·5.

2,2'-Bis-5-formylthienyl Ketone (27).—2-(5-Bromo-2-thienyl)-1,3-dioxolan [38] (26) (66·0 g) in dry ether (100 ml) was added dropwise over 30 min to a stirred solution of n-butyllithium (0·285 mol) in dry ether (300 ml) at −20° under an atmosphere of dry nitrogen. After a further 1 h at −20° a solution of ethyl NN-dimethylcarbamate (17·5 g) in dry ether (50 ml) was added over 15 min. The mixture was stirred at −20° for 2·5 h and then treated with an excess of saturated ammonium chloride solution. The mixture was allowed to warm to 0°, water was added, and the precipitate collected by filtration. The filtrate was extracted with ether and the extract was washed with saturated sodium chloride solution. The solvent was removed and the dark oily residue together with the above precipitate was dissolved in acetone (200 ml) and 10% hydrochloric acid (115 ml) was added, followed by just sufficient acetone to render the mixture homogeneous. The mixture was stirred for 5 h and the precipitated material separated by filtration and dried in vacuum. The crude *dicarbaldehyde* (27) was crystallized from acetone and formed cream needles (17·2 g, 49%), m.p. 202—203° (Found: C, 52·7; H, 2·7. C₁₁H₆O₃S₂ requires C, 52·8; H, 2·4%), τ [60 MHz, (CD₃)₂SO] −0·10 (2H, s, CHO) and 1·78 and 1·85 (4H, ABq, J 4·0 Hz, thiophen protons), m/e 250 (M^+).

Reduction of Annulenone (1) *to Homoannulene* (30).—The annulenone (1) (56·6 mg) was added to a stirred mixture of lithium aluminium hydride (322 mg) and aluminium chloride (20 mg) in dry ether (50 ml). The mixture was then stirred for 15 min, cooled in ice, and enough saturated ammonium chloride solution was added to promote coagulation. The coagulate was separated by filtration and washed well with ether. The ethereal filtrate was washed with water, and with saturated sodium chloride solution, and dried (Na₂SO₄). Removal of the solvent left a yellow solid (52·1 mg) which failed to crystallize from a variety of solvents. It was applied, in dichloromethane solution, to a p.l.c. plate which was developed once with 10% ethyl acetate–light petroleum. The fastest moving band yielded the *homoannulene* (30) (37·9 mg, 70·5%) which

³⁸ S. Gronowitz, A. Biezais, and B. Mathiasson, *Arkiv Kemi*, 1963, **21**, 265.

crystallized at $-78°$ from light petroleum as yellow prisms, m.p. 126—128° (Found: C, 77·15; H, 5·25; N, 4·7. $C_{17}H_{13}NO_2$ requires C, 77·55; H, 5·0; N, 5·3%), τ † (90 MHz) $-2·4br$ (1H, NH), 3·82 (2H, d, $J_{9,NH} = J_{10,NH} = 2·5$ Hz, 9- and 10-H), 3·88 (2H, dt, $J_{1,3} = J_{1,16} = 0·9$, $J_{3,4} = J_{15,16} = 3·5$ Hz, 3- and 16-H), 4·02 and 4·28 (4H, ABq, $J_{6,7} = J_{12,13} = 13·5$ Hz, 6-, 7-, 12-, and 13-H), 4·07 (2H, d, $J_{3,4} = J_{15,16} = 3·5$ Hz, 4- and 15-H), and 6·01 (2H, d, $J_{1,3} = J_{1,16} = 0·9$ Hz, CH_2), m/e 263 (M^+).

Reduction of Annulenone (2) *to Homoannulene* (31).—The annulenone (2) (64·7 mg) was reduced with lithium aluminium hydride (250 mg) and aluminium chloride (20 mg) as described for (1). The crude product (57·2 mg, 93·1%) was crystallized from pentane at $-78°$ and formed yellow prisms of the *homoannulene* (31), m.p. 90—92° (Found: M^+, 264·0784. $^{12}C_{17}{}^{1}H_{12}{}^{16}O_3$ requires M, 264·0786); τ (60 MHz) 3·73 (2H, s, 9- and 10-H), 3·93 and 4·07 (4H, ABq, $J_{3,4} = J_{15,16} = 3·5$ Hz, 3-, 4-, 15-, and 16-H), 4·23 (4H, s, 6-, 7-, 12-, and 13-H), and 6·00 (2H, s, CH_2).

Reduction of Annulenone (3) *to Homoannulene* (32).—The annulenone (3) (32·0 mg) was reduced with lithium aluminium hydride (60 mg) and aluminium chloride (10 mg) as described for (1). The crude product was dissolved in a light petroleum and filtered through a small column of silica gel with 10% ethyl acetate–light petroleum as eluant. This afforded the *homoannulene* (32) as a yellow oil (21·4 mg, 70·2%) (Found: M^+, 280·0577. $^{12}C_{17}{}^{1}H_{12}{}^{32}S^{16}O_2$ requires M, 280·0558); τ (60 MHz) 3·20 (2H, s, 9- and 10-H), 3·94 and 4·00 (4H, ABq, $J_{6,7} = J_{13,14} = 11·5$ Hz, 6-, 7-, 12-, and 13-H), 3·62 and 3·97 (4H, ABq, $J_{3,4} = J_{15,16} = 3·5$ Hz, 3-, 4-, 15-, and 16-H), and 6·19 (2H, s, CH_2).

5-Methyl-2-furylmethyltriphenylphosphonium Chloride (35).—2-Chloromethyl-5-methylfuran was prepared by a modification of the method of Reichstein and Zschokke.[31] 2-Hydroxymethyl-5-methylfuran [39] (10·5 g) in dry dichloromethane (18 ml) and dry pyridine (8·72 g) was treated dropwise over 20 min with stirring with a solution of purified [40] thionyl chloride (7·35 ml) in dry dichloromethane (4·6 ml) such that the reaction temperature was -15 to $-5°$. The mixture was then poured into ice–water and extracted with dichloromethane. The extract was washed with ice-cold water and with ice-cold 5% sodium hydroxide solution, and dried (K_2CO_3) at $-10°$. The mixture was filtered and dry toluene (50 ml) was added to the filtrate. The dichloromethane was removed under reduced pressure and triphenylphosphine (23·7 g) was added to the residual toluene solution of the chloride. The solution was heated under reflux with stirring for 3 h, and the precipitate was separated by filtration from the cooled mixture. The separated precipitate was washed well with dry ether, and dried at 56° and 0·01 mmHg to leave the *salt* (35) (7·5 g, 20·3%) as a light brown solid. A sample was crystallized from dichloromethane–dry ether from which it formed pale yellow blades, m.p. 250—251° (Found: C, 73·1; H, 5·45; Cl, 9·05. $C_{24}H_{22}ClOP$ requires C, 73·35; H, 5·65; Cl, 9·0%).

trans,trans-2,2′-Bis-[5-(5-methyl-2-furylvinyl)furyl] Ketone (33).— Lithium methoxide [from lithium (69·4 mg)] in dry methanol (28·8 ml) was added over 45 min to a stirred solution of the salt (35) (3·94 g) and the dicarbaldehyde (6)

† Double irradiation experiments were carried out by irradiating at the frequencies of the methylene protons and the imino-proton.

‡ A double irradiation experiment was carried out by irradiating at the frequency of the methyl protons.

§ Double irradiation experiments were carried out by irradiating at the frequencies of the methylene and methyl protons.

(1·09 g) in dry DMF (120 ml) at 90° under dry nitrogen. After the addition the mixture was stirred for 30 min at 90°, and for 1 h at 20°. The solution was poured into water (600 ml) and extracted with ether (3 × 250 ml). The extracts were washed with water and saturated sodium chloride solution and dried (Na_2SO_4). The residue left on removal of the solvent was pre-adsorbed from dichloromethane onto silica gel and chromatographed over a column of silica gel with 20% ethyl acetate–light petroleum as eluant to yield the *ketone* (33) (1·38 g, 73·8%) which crystallized from pentane–carbon tetrachloride at $-20°$ as orange prisms, m.p. 120—122°; elemental analysis indicated that this crystalline material was a solvate containing 1 mole of carbon tetrachloride. Solvent-free amorphous material was obtained as an orange solid by precipitation from light petroleum, m.p. 92—94°, with resolidification to rosettes of needles, m.p. 110—111° (Found: C, 73·9; H, 5·05. $C_{23}H_{18}O_5$ requires C, 73·8; H, 4·85%); τ ‡ (90 MHz) 2·49 and 3·55 (4H, ABq, $J_{3,4}$ 3·7 Hz, 3- and 4-H), 3·00 and 3·24 (4H, ABq, $J_{1′,2′}$ 16·0 Hz, 1′- and 2′-H), 3·67 (2H, d, $J_{3″,4″}$ 3·5 Hz, 3″-H), 3·98 (2H, dq, $J_{3″,4″}$ 3·5, $J_{4″,Me}$ 1·0 Hz, 4″-H), and 7·67 (6H, d, $J_{4″,Me}$ 1·0 Hz, Me) (Found: M^+, 374·1154. $^{12}C_{23}{}^{1}H_{18}{}^{16}O_5$ requires M, 374·1154).

trans,trans-2,2′-Bis-[5-(5-methylfurylvinyl)furyl]methane (34).—The ketone (33) (110·0 mg) was added to lithium aluminium hydride (200 mg) and aluminium chloride (5 mg) in dry ether (30 ml) and the mixture stirred and heated under reflux for 4·5 h. Work-up as for the above preparation of (30) gave the crude product (99·8 mg, 94·3%) which crystallized at $-20°$ from ether–light petroleum as pale yellow needles of the *alkane* (34), m.p. 118—119·5° (Found: C, 76·4; H, 5·7. $C_{23}H_{20}O_4$ requires C, 76·65; H, 5·6%), τ § (90 MHz) 3·31 (4H, s, 1′- and 2′-H), 3·80 (2H, d, $J_{3,4}$ 3·3 Hz, 4-H), 3·83 (2H, d, $J_{3″,4″}$ 3·2 Hz, 3″-H), 3·90 (2H, dt, $J_{CH_2,3}$ 0·9, $J_{3,4}$ 3·3 Hz, 3-H), 4·03 (2H, dq, $J_{3″,4″}$ 3·2, $J_{4″,Me}$ 1·0 Hz, 4″-H), 5·97br (2H, s, CH_2), and 7·66 (6H, d, $J_{4″,Me}$ 1·0 Hz, CH_3), m/e 360 (M^+).

Preparation of Methyl Ether (39).—The annulenone (2) (57·5 mg) was added to a stirred slurry of lithium aluminium hydride (57·5 mg) in dry ether (10 ml). After 10 min the mixture was cooled in ice and treated with an excess of ethyl formate. The mixture was allowed to warm to room temperature and dry ether (20 ml), methyl iodide (1 ml), and silver oxide (303·4 mg) were added and the mixture stirred for 6 h. Further quantities of methyl iodide (0·5 ml) and silver oxide (300 mg) were added and the mixture was stirred for 12 h. The solids were separated by filtration and washed well with ether. The combined filtrate and washings were washed with water and saturated sodium chloride solution, and dried (Na_2SO_4). The solvent was removed and the residue applied in dichloromethane to a p.l.c. plate which was developed once with 15% ethyl acetate–light petroleum. The fastest moving band afforded the *methyl ether* (39) (20·9 mg, 34·4%) which crystallized from ether–light petroleum as deep orange prisms, m.p. 141—142° (Found: M^+, 294·0896. $^{12}C_{18}{}^{1}H_{14}{}^{16}O_4$ requires M, 294·0892), τ (60 MHz) 3·87 and 4·18 (4H, ABq, $J_{3,4} = J_{15,16} = 3·5$ Hz, 3-, 4-, 15-, and 16-H), 3·98 (2H, s, 9- and 10-H), 4·53 (4H, s, 6-, 7-, 12-, and 13-H), 5·33 (1H, s, CH), and 6·53 (3H, s, OMe).

Preparation of Methyl Ether (40). Sodium borohydride (8·4 mg) in dry methanol (5 ml) was added to a stirred

[39] V. M. Micovic, R. I. Mamuzic, D. Jeremic, and M. L. Mihailovic, *Tetrahedron*, 1964, 20, 2279.

[40] W. Rigby, *Chem. and Ind.*, 1969, 1508.

solution of the annulenone (3) (7·9 mg) in dry ether (5 ml) under dry nitrogen. The mixture was stirred at room temperature for 2 h and then cooled in ice and acidified with an excess of ice-cold 5% hydrochloric acid. The mixture was extracted exhaustively with ether and the extracts washed with water, and with saturated sodium chloride solution, and dried (Na_2SO_4), and the solution concentrated to a volume of *ca.* 15 ml. Silver oxide (200 mg) and methyl iodide (0·4 ml) were added and the mixture was stirred for 12 h under an atmosphere of dry nitrogen. The solids were separated by filtration and washed well with ether. The combined filtrate and washings were concentrated and applied to a p.l.c. plate (10 × 20 × 0·1 cm) which was developed once with 15% ethyl acetate–light petroleum. The fastest moving coloured band afforded the *methyl ether* (40) as an orange oil (5·8 mg, 69·6%) (Found: M^+, 310·0662. $^{12}C_{18}{}^{1}H_{14}{}^{16}O_3{}^{32}S$ requires M, 310·0664), τ (60 MHz) 3·22 (2H, s, 9- and 10-H), 3·53 and 4·12 (4H, ABq, $J_{6,7} = J_{12,13} = 11·5$ Hz, 6-, 7-, 12- and 13-H), 3·75 and 3·97 (4H, ABq, $J_{3,4} = J_{15,16} = 3·5$ Hz, 3-, 4-, 15-, and 16-H), 4·92 (1H, s, CH), and 6·64 (3H, s, OMe).

Added in proof:—Very recently we have prepared the methyl ether (39; X = NH for X = O) in 45·6% yield from the annulenone (1) in exactly the same way as the methyl ether (39; X = O) from the annulenone (2). It was obtained as a brown *gum* (Found: M^+, 293·1051. $^{12}C_{18}{}^{1}H_{13}{}^{14}N^{16}O_3$ requires M, 293·1052), τ (90 MHz) −4·29 br (1H, NH), 3·96 and 4·38 (4H, ABq, $J_{3,4} = J_{15,16} = 3·4$ Hz, 3-, 4-, 15-, and 16-H), 4·25 (2H, d, $J_{9,\mathrm{NH}} = J_{10,\mathrm{NH}} = 2·2$ Hz, 9- and 10-H), 4·47 and 4·78 (4H, ABq, $J_{6,7} = J_{12,13} = 13·0$ Hz, 6-, 7-, 12-, and 13-H), 5·52 (1H, s, CH), and 6·71 (3H, s, OMe). It therefore supports a paramagnetic ring current.