264. A New Approach to 1,2,4-Trioxanes from Cyclic Allylic Hydroperoxides

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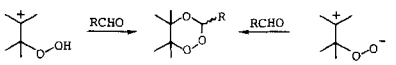
(27.VIII.84)

Summary

The reaction of 4,5-dimethyl-4-hydroperoxy-1(4*H*)-naphthalenone (**9**) with acetaldehyde, pivalaldehyde, benzaldehyde, and *p*-chlorobenzaldehyde in CH_2Cl_2 in the presence of *Amberlyst-15* as catalyst gave the corresponding *cis*-3-methyl, *t*-butyl, phenyl and *p*-chlorophenyl derivatives of 10,10b-dimethylnaphtho[2,1-*e*][1,2,4]trioxin-6(5*H*)-one in 80–95% yields. Acetone reacted similarly with **9** to give the 3,3'-dimethyl derivative. Configurations of all trioxinones were assigned by comparison of their spectral properties with that of the *p*-chloro derivative whose structure was determined by X-ray. 2,5-Diphenyl-2-hydroperoxypyrrole was less efficient than **9**, but it condensed with acetaldehyde and pivalaldehyde under the same conditions giving the *cis*-3-methyl and *cis*-3-(*t*-butyl) derivatives of 6,7a-diphenyl-4a,7a-dihydro-3*H*,5*H*-[1,2,4]trioxino[3,2-*e*]pyrrole in 24 and 20% yield, respectively.

Introduction. – We have recently demonstrated that transient *β*-hydroperoxy cations **1** [1] [2], zwitterionic peroxides **2** [3] or their formal equivalents [4] can be captured by aldehydes to form 1,2,4-trioxanes **3** *(Scheme 1)*. We now report that structurally related cyclic allylic hydroperoxides can also incorporate aldehydes to produce

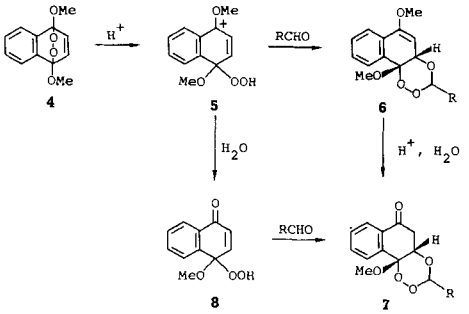
Scheme 1



1 **3** **2**

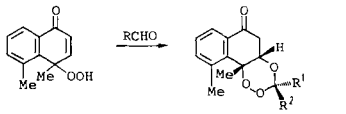
the corresponding 1,2,4-trioxanes in fair-to-excellent yields depending on the nature of the hydroperoxide. The first intimation of this mechanistic possibility was provided by the acid-catalyzed reaction of 1,4-dimethoxy-1,4-epidioxy-1,4-dihydronaphthalene (**4**) with acetaldehyde [1] *(Scheme 2)*. The product, the *cis*-fused trioxinone **7** may have arisen from the primary hydroperoxide cation **5** in two ways. Cyclization could have occurred directly to the trioxane enol ether **6** which then underwent hydrolysis to the product **7**. Alternatively, prior hydrolysis of **5** could have given the unsaturated hydroperoxy ketone **8** which by addition of acetaldehyde gave **7**.

Scheme 2



Results. – Support for the second possibility was obtained by allowing the hydroperoxydecalenone **9** to react with excess acetaldehyde in CH_2Cl_2 in the presence of *Amberlyst-15*. The trioxane **10** was immediately formed in quantitative yield *(Scheme 3)*. Cyclization worked just as well with the bulkier pivalaldehyde which formed the corresponding trioxane **11** in 81% yield. Benzaldehyde and its *p*-chloro derivative likewise afforded single trioxane products (**12** and **13**) in yields of 80–88%. In all cases only the *cis*-isomer[1]) was obtained. Acetone, although less electrophilic, underwent similar addition in good yield (64%) to give the dimethyltrioxane **14**.

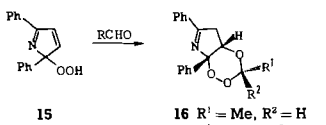
Scheme 3



9

10 R^1 = Me, R^2 = H
11 R^1 = *t*-Bu, R^2 = H
12 R^1 = Ph, R^2 = H
13 R^1 = *p*-ClPh, R^2 = H
14 R^1 = R^1 = Me

Scheme 4



15

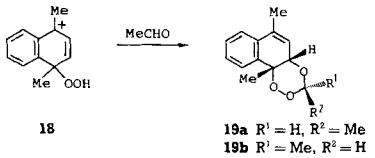
16 R^1 = Me, R^2 = H
17 R^1 = *t*-Bu, R^2 = H

Cyclization proceeded less efficiently with the conjugated allylic hydroperoxide, 2,5-diphenyl-2-hydroperoxypyrrole (**15**). Acetaldehyde and pivalaldehyde gave the corresponding trioxanes **16** and **17** in yields of 24 and 20%, respectively *(Scheme 4)*. Once again, of the two possible diastereomers, only the *cis*-isomer was observed.

Discussion. – The chief mechanistic feature of these reactions is that cyclization occurs by inclusion of the carbonyl function of the aldehyde or ketone in the expected electronic sense to unite the hydroperoxy group and the activated double bond. For reasons of geometry control [5], the newly created six-membered ring is fused in the *cis*-configuration. Since aldehydes may adopt two orientations with respect to the parent ring, the formation of a pair of *cis*- and *trans*-diastereomers is expected. For example, hydroperoxybenzocyclohexenyl cations such as **18**, which are unsubstituted on the aromatic ring, react with acetaldehyde to give the pair of diastereomeric methyltrioxanes **19a** and **19b** in varying ratios [1] *(Scheme 5)*. Usually, the *cis*-isomer **19b**

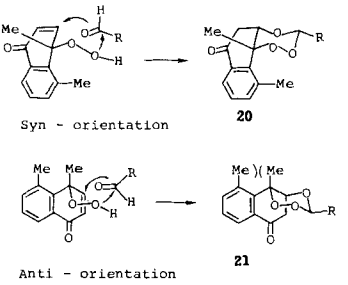
[1]) The prefix *cis* refers to the C(3) substituent on the trioxane ring and means that it is *cis* to the benzene moiety.

Scheme 5



18 **19a** $R^1 = H$, $R^2 = Me$ **19b** $R^1 = Me$, $R^2 = H$

Scheme 6



predominates. However, in a case where a CH_3 group is present at the C(8) position on the benzene ring, as in **9**, the formation of the minor diastereomer is completely suppressed. The reason for this suppression may lie in the potential steric conflict arising between the CH_3 substituents at C(1) and C(8), especially if they assume a peri-coplanar arrangement. It appears that adoption of the *syn*-orientation by the aldehyde will result in combination with **9** so that the aforementioned pair of CH_3 substituents are staggered; trioxanes having the chair conformation of configuration **20** will therefore be formed. Contrariwise, adoption of the *anti*-orientation by the aldehyde would place the two CH_3 groups in a sterically unfavorable peri-relation, thereby generating trioxanes of configuration **21**[2]).

The *cis*-configurations, *e.g.* **20**, of the trioxanes (**10**, **11** and **12**) were assigned by comparing their spectral properties with that of the key *p*-chlorophenyl derivative **13** whose structure was determined by X-ray analysis. The main structural characteristics of **13** are the chair conformation of the 1,2,4-trioxane ring, its *cis*-fusion to the benzocyclohexenone entity, and the placement of its *p*-chlorophenyl and CH_3 substituents in a 1,4-diequatorial arrangement *(Figure)*.

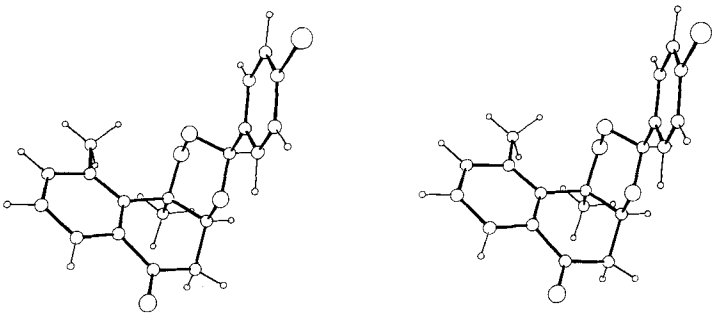


Fig. *Stereoscopic view of the structure of* **13**

Yields of **10–13** are presumably high due to the combined strengths of the nucleophilicity of the hydroperoxy group and the electrophilicity of the enone function.

The poorer yields obtained with **15** are probably a reflection of the diminished electrophilic nature of the conjugated enamine grouping. Nonetheless, the reaction of the structural equivalent of **15**, namely the cation obtained from the 1,4-endoperoxide

[2]) These arguments are predicated on the Hammond postulate that the transition state resembles the product and furthermore that the products themselves are the result of kinetic control.

of 1,4-diphenylcyclopentadiene by protonation, with acetaldehyde gave the corresponding trioxane in 81% yield [1].

Only the *cis*-isomers of **16** and **17** were formed from **15**. Again, it can be assumed that the presence of the bulky phenyl substituent at the ring junction disfavors one of the two orientations of the acetaldehyde component in the cyclization process.

Lastly, it is worth noting that the present reaction constitutes the higher homologous version of the formation of 1,3-dioxolanes from γ-hydroxycyclohexenones and aldehydes [6].

Conclusion. – The foregoing findings confirm the mechanistic principle that β-hydroperoxy cations and their analogues condense with aldehydes to give 1,2,4-trioxanes. Consequently, a variety of synthetic approaches to this little-known, but important [7] class of heterocycles is now available. Structural and conformational studies of *cis*-fused bicyclic trioxanes will be reported elsewhere.

We thank the *Swiss National Science Foundation* (grant No. 2.036-0.83) and *UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases* for support of this work.

Experimental Part

General. TLC: silica gel *60 F254 Merck*. Prep. layer chromatography: silica gel *60* F_{254} (thickness 2 mm). R_f values refer to silica gel and CH_2Cl_2 as eluant. Physical constants and spectra were determined as follows. Melting points (m.p.): *Reichert* hot-stage microscope (uncorrected). IR spectra: *Perkin-Elmer 681* spectrometer. ^{1}H- and ^{13}C-NMR spectra (chemical shifts in ppm relative to internal TMS (= 0 ppm), coupling constants J in Hz): *Bruker WH 360* spectrometer. Mass spectra: *CH-4 MAT* and *Finnigan GC/MS 4023* using the INCOS data system. Elemental analyses were performed by Drs. *H.* and *K. Eder,* Service de Microchimie, Institut de Chimie Pharmaceutique, University of Geneva.

*4,5-Dimethyl-4-hydroperoxy-1(4*H*)-naphthalenone* (**9**) was prepared by the perhydrolysis of 1,8-dimethyl-1,4-epidioxy-1,4-dihydronaphthalene [8].

cis-*3,10,10b-Trimethyl-4a,7a-dihydronaphtho[2,1-*e*][1,2,4]trioxin-6(5*H*)-one* (**10**). To a solution of **9** (6.6 mg, 0.0324 mmol) in CH_2Cl_2 (0.6 ml), acetaldehyde (0.1 ml) and *Amberlyst-15* (0.036 g) were successively added with stirring at 25°. After 21 h the mixture was filtered through *Celite* and evaporated to dryness *in vacuo*. A yellow oil (0.015 g) was obtained which according to its NMR spectrum consists of **10** (*ca.* 100% yield). Purification by prep. layer chromatography on silica gel F_{254} with CH_2Cl_2 afforded pure trioxane **10**, R_f 0.55, as a yellowish solid m.p. 109–111° (7.6 mg, 95% yield). IR (CH_2Cl_2): 1690*s* (> C=O). ^{1}H-NMR (360 MHz, $CDCl_3$): 1.12 (*d*, J = 5, 3H); 1.58 (*s*, 3H); 2.61 (*s*, 3H); 2.97 (*d*, J = 3, 2H); 4.26 (*t*, J = 3, 1H); 5.51 (*q*, J = 5, 1H); 7.32 (*t* J = 7, 1H); 7.44 (*d*, J = 7, 1H); 7.96 (*d*, J = 7, 1H). MS: 248 (8, M^+), 189 (13), 186 (16), 173 (22), 172 (26), 161 (100), 129 (18), 128 (16), 119 (16), 115 (27), 105 (14), 91 (17). Anal. calc. for $C_{14}H_{16}O_4$ (248.30): C 67.72, H 6.51; found: C 67.49, H 6.67.

cis-*3-(*tert*-Butyl)4a-7a-dihydronaphto[2,1-e][1,2,4]trioxin-6(5*H*)-one* (**11**). The same conditions and procedure as above, but using **9** (14.5 mg, 0.0771 mmol) and pivalaldehyde (0.3 ml) gave after 21 h a brown oil (29 mg) which on chromatography furnished pure **11** as a yellow solid, m.p. 74–76°, R_f 0.36 (18.1 mg, 81% yield) IR (CH_2Cl_2): 1688*s* (> C=O). ^{1}H-NMR (360 MHz, $CDCl_3$): 0.69 (*s*, 9H); 1.57 (*s*, 3H); 2.62 (*s*, 3H); 2.97 (*d*, J = 3, 2H); 4.23 (*t*, J = 3, 1H); 4.98 (*s*, 1H); 7.29 (*t*, J = 7, 1H); 7.42 (*d*, J = 7, 1H); 7.94 (*d*, J = 7, 1H). MS: 290 (5, M^+), 189 (9), 188 (8), 173 (29), 172 (62), 162 (36), 161 (100), 129 (15), 128 (12), 115 (16), 105 (15), 91 (13). Anal. calc. for $C_{17}H_{22}O_4$ (290.39): C 70.31, H 7.65; found: C 70.40, H 7.48.

cis-*3-Phenyl-10,10b-dimethyl-4a,7a-dihydronaphtho[2,1-*e*][1,2,4]trioxin-6(5*H*)-one* (**12**). Using the above procedure, the condensation of **9** (20.4 mg, 0.1 mmol), and benzaldehyde (0.1 ml) in the presence of *Amberlyst-15* (0.120 g) gave a brown oil. Excess benzaldehyde was removed at 0.01 Torr. The residue (36 mg) was purified by layer chromatography to give **12** as a yellow solid (24.8 mg, 80% yield). R_f = 0.40. Recrystallization from CH_2Cl_2/petroleum ether b.p. 60–80° gave colorless crystals, m.p. 161–163°. IR (CH_2Cl_2): 1692*s* (> C=O). ^{1}H-NMR (360 MHz, $CDCl_3$): 1.68 (*s*, 3H); 2.63 (*s*, 3H); 3.08 (*dd*, J = 3.5 and 1, 2H); 4.50 (*t*, J = 3.5, 1H); 6.34 (*s*, 1H); 7.17–7.37 (*m*, 6H); 7.45 (*d*, J = 7, 1H); 8.03 (*d*, J = 8, 1H). MS: 310 (4, M^+), 292 (8), 172 (77), 161 (25), 119 (10), 105 (100), 77 (36), 51 (24). Anal. calc. for $C_{19}H_{18}O_4$ (310.37): C 73.52, H 5.86; found: C 74.07, H 5.48.

cis-3-(p-Chlorophenyl)-10,10b-dimethyl-4a,7a-dihydronaphtho[2,1-e][1,2,4]trioxin-6(5H)-one (**13**). The *Amberlyst-15*-catalyzed condensation of **9** (20.4 mg, 0.1 mmol) with *p*-chlorobenzaldehyde (0.141 g, 1 mmol) gave an oil from which excess aldehyde was sublimed. A yellow semi-solid (0.044 g) was obtained which by chromatography gave **13** as colorless crystals, m.p. 168–169° (30.2 mg, 88% yield). Crystals suitable for X-ray analysis were secured by recrystallization from CH_2Cl_2/Et_2O/pentane at r.t. R_f 0.46. IR (CH_2Cl_2): 1692*s* (> C=O). ^{1}H-NMR (360 MHz, $CDCl_3$): 1.67 (*s*, 3H); 2.59 (*s*, 3H); 3.07 (*d*, *J* = 3, 2H); 4.47 (*t*, *J* = 3, 1H); 6.28 (*s*, 1H); 7.11 (*d*, *J* = 9, 2H); 7.23 (*d*, *J* = 9, 2H); 7.33 (*t*, *J* = 7, 1H); 7.43 (*d*, *J* = 7, 1H); 8.00 (*d*, *J* = 7, 1H). MS: 345 (trace, M^+), 326 (5), 172 (100), 139 (38), 111 (12), 75 (5), 43 (9). Anal. calc. for $C_{19}H_{17}ClO_4$ (344.81): C 66.18, H 4.98, Cl 10.28; found: C 66.00, H 5.13, Cl 10.14.

Crystallographic Data. $C_{19}H_{17}O_4Cl$, monoclinic, space group $P2_1/c$, $a = 7.330(1)$, $b = 6.193$ (1), $c = 36.048(9)$ Å, $\beta = 91.33(2)°$, $Z = 4$, $F_{000} = 720$, $D_c = 1.400$ g·cm^{-3}, $\mu = 2.495$ cm^{-1}. The lattice parameters and diffracted intensities were measured at r.t. on an automatic four-circle *Philips PW 1100* diffractometer using graphite-monochromated MoK_α radiation. 1760 independent reflections were recorded ($\omega - 2\theta$ scan) of which 930 had $|F_o| > 3\,\sigma(F_o)$ and $|F_o| > 7$. The structure was solved by direct methods [9] and refined by full matrix least-squares analysis [10]. Anisotropic temperature factors were employed for the non-H-atoms, while the H-atoms were calculated. The final *R* factor, based on the 930 reflections observed, was 0.091 ($R_\omega = 0.075$ with $\omega = (|F_o|/48)^2$ for $|F_o| \leq 48$ and $\omega = (48/|F_o|)^2$ for $|F_o| > 48$).

As the c axis is long, the limit of resolution for the diffractometer using MoK_α radiation is nearly attained, consequently, the *R* factor is relatively high and the values of σ are bigger than usual. The positional and vibrational parameters, the bond lengths and principal torsion angles found for **13** are listed in *Tables 1* and *2*[3]).

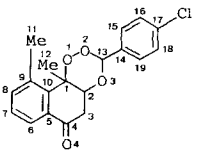


Table 1. *Fractional Co-ordinates and Equivalent Isotropic Temperature Factors, U_{eq} ($\times 10^3$ Å^2) with e.s.d.'s in Parentheses for* **13**

Atom	*X*	*Y*	*Z*	U_{eq}
Cl	0.8212(6)	0.1358(9)	0.47572(12)	73(2)
O(1)	−0.0152(13)	0.8129(19)	0.3912(3)	56(5)
O(2)	0.1291(12)	0.6581(18)	0.3990(3)	43(4)
O(3)	0.3470(11)	0.9244(17)	0.3944(3)	41(4)
O(4)	0.5124(14)	1.1131(22)	0.3029(3)	76(5)
C(1)	0.0520(20)	0.962(3)	0.3632(5)	53(7)
C(2)	0.2161(21)	1.072(3)	0.3798(4)	52(7)
C(3)	0.3161(20)	1.209(3)	0.3517(5)	56(7)
C(4)	0.3753(24)	1.065(3)	0.3191(4)	54(8)
C(5)	0.2580(21)	0.888(3)	0.3092(5)	49(7)
C(6)	0.3101(22)	0.767(3)	0.2783(5)	58(8)
C(7)	0.203(3)	0.606(4)	0.2654(4)	68(8)
C(8)	0.0367(25)	0.563(3)	0.2812(5)	66(8)
C(9)	−0.0234(18)	0.682(3)	0.3113(5)	49(7)
C(10)	0.0904(19)	0.835(3)	0.3259(4)	46(6)
C(11)	−0.2140(18)	0.634(3)	0.3248(4)	60(7)
C(12)	−0.1044(17)	1.129(3)	0.3579(4)	51(6)
C(13)	0.2652(22)	0.770(3)	0.4185(5)	55(7)
C(14)	0.4066(20)	0.617(3)	0.4332(4)	40(7)
C(15)	0.3467(18)	0.438(3)	0.4528(4)	51(7)
C(16)	0.4736(24)	0.294(3)	0.4659(4)	58(8)
C(17)	0.6540(24)	0.317(3)	0.4587(4)	54(8)
C(18)	0.7139(19)	0.502(3)	0.4390(4)	55(7)
C(19)	0.5897(21)	0.647(3)	0.4267(4)	52(7)

[3]) Observed and calculated structure factors may be obtained on request from *G.B.* Crystallographic data has been deposited with the Cambridge Crystallographic Data Centre, University Chemical Laboratory, Lensfield Road, Cambridge CB2 1EW, England.

Table 2. *Bond Lengths* (Å), *Principal Torsion Angles* (°) *and Principal Valence Angles* (°) *with e.s.d.'s in Parentheses for* **13**

Cl–C(17)	1.763(18)	C(1)–O(1)–O(2)–C(13)	71.0(13)
O(1)–O(2)	1.451(14)	O(2)–O(1)–C(1)–C(2)	−61.1(14)
O(1)–C(1)	1.463(20)	O(2)–O(1)–C(1)–C(10)	63.1(13)
O(2)–C(13)	1.393(19)	O(2)–O(1)–C(1)–C(12)	−177.0(10)
O(3)–C(2)	1.416(19)	O(1)–O(2)–C(13)–O(3)	−68.2(13)
O(3)–C(13)	1.432(20)	O(1)–O(2)–C(13)–C(14)	170.7(11)
O(4)–C(4)	1.211(20)	C(13)–O(3)–C(2)–C(1)	−50.5(16)
C(1)–C(2)	1.493(22)	C(13)–O(3)–C(2)–C(3)	−174.0(12)
C(1)–C(10)	1.589(23)	C(2)–O(3)–C(13)–O(2)	58.5(16)
C(1)–C(12)	1.552(22)	C(2)–O(3)–C(13)–C(14)	179.8(8)
C(2)–C(3)	1.524(23)	O(1)–C(1)–C(2)–O(3)	52.2(16)
C(3)–C(4)	1.546(24)	O(1)–C(1)–C(2)–C(3)	172.0(12)
C(4)–C(5)	1.432(24)	C(10)–C(1)–C(2)–O(3)	−69.5(17)
C(5)–C(6)	1.403(25)	C(10)–C(1)–C(2)–C(3)	50.3(19)
C(5)–C(10)	1.420(21)	C(12)–C(1)–C(2)–O(3)	164.5(12)
C(6)–C(7)	1.347(27)	C(12)–C(1)–C(2)–C(3)	−75.7(16)
C(7)–C(8)	1.385(25)	O(1)–C(1)–C(10)–C(5)	−135.1(14)
C(8)–C(9)	1.389(25)	O(1)–C(1)–C(10)–C(9)	42.6(20)
C(9)–C(10)	1.361(23)	C(2)–C(1)–C(10)–C(5)	−15.2(20)
C(9)–C(11)	1.520(20)	C(2)–C(1)–C(10)–C(9)	162.6(16)
C(13)–C(14)	1.492(23)	C(12)–C(1)–C(10)–C(5)	109.6(15)
C(14)–C(15)	1.393(24)	C(12)–C(1)–C(10)–C(9)	−72.6(20)
C(14)–C(19)	1.380(21)	O(3)–C(2)–C(3)–C(4)	65.3(15)
C(15)–C(16)	1.364(24)	C(1)–C(2)–C(3)–C(4)	−58.5(17)
C(16)–C(17)	1.361(25)	C(2)–C(3)–C(4)–O(4)	−149.9(15)
C(17)–C(18)	1.423(25)	C(2)–C(3)–C(4)–C(5)	33.0(19)
C(18)–C(19)	1.344(24)	C(3)–C(4)–C(5)–C(6)	176.8(15)
O(1)–C(1)–C(2)	107(1)	C(3)–C(4)–C(5)–C(10)	1.3(25)
C(1)–C(2)–O(3)	113(1)	C(4)–C(5)–C(10)–C(1)	−11.1(24)
C(2)–O(3)–C(13)	111(1)	C(4)–C(5)–C(10)–C(9)	171.1(17)
O(3)–C(13)–O(2)	109(1)	C(6)–C(5)–C(10)–C(1)	173.6(15)
C(13)–O(2)–O(1)	106(1)	C(6)–C(5)–C(10)–C(9)	− 4.2(24)
O(2)–O(1)–C(1)	107(1)	O(2)–C(13)–C(14)–C(15)	−50.1(19)

3,3',10,10b-Tetramethyl-4a,7a-dihydronaphtho[2,1-e][1,2,4]trioxin-6(5H)-one (**14**). Condensation of **9** (14.5 mg, 0.0771 mmol) and acetone (0.2 ml) gave on workup **14** as a yellow solid, m.p. 79–81° (13 mg, 64% yield). R_f 0.22. IR (CH_2Cl_2): 1692*s* (> C=O). ^{1}H-NMR (360 MHz, $CDCl_3$): 1.09 (*s*, 3H); 1.60 (*s*, 3H); 1.72 (*s*, 3H); 2.62 (*s*, 3H); 2.85 (*dd*, *J* = 18 and 3, 1H); 2.94 (*dd*, *J* = 18 and 3, 1H); 4.48 (*t*, *J* = 3, 1H); 7.33 (*t*, *J* = 7, 1H); 7.45 (*d*, *J* = 7, 1H); 7.95 (*d*, *J* = 7, 1H). MS: 262 (10, M^+), 189 (14), 173 (100), 161 (76), 129 (15), 128 (12), 115 (19), 105 (12), 91 (13). Anal. calc. for $C_{15}H_{18}O_4$ (262.33): C 68.67, H 6.93; found: C 68.88, H 6.75.

cis-3-Methyl-6,7a-diphenyl-4a,7a-dihydro-3H,5H-[1,2,4]trioxino[3,2-e]pyrrole (**16**). 2,5-Diphenyl-2-hydroperoxypyrrole (**15**) (360 mg, 1.4 mmol) was prepared *in situ* by the *meso*-tetraphenylporphine-sensitized photooxygenation of 2,5-diphenylpyrrole [11]. Acetaldehyde (5 ml) and *Amberlyst-15* (1 g) were then added and the mixture stirred overnight at r.t. The resin was removed by filtration and excess aldehyde and solvent were evaporated. The residue was purified by chromatography over a column of silica gel (CH_2Cl_2) to give **16** as a colorless oil. R_f 0.30 (100 mg, 24% yield). ^{1}H-NMR (360 MHz, $CDCl_3$): 8.22 (*m*, 2H); 7.65–7.5 (*m*, 6H); 7.38 (*m*, 2H); 5.68 (*q*, *J* = 5.5, 1H); 4.68 (*d*, *J* = 4, 1H); 3.24 (*d*, *J* = 17, 1H); 2.90 (*dd*, *J* = 17 and 4 Hz, 1H), and 1.33 (*d*, *J* = 5.5, 3H). ^{13}C-NMR (90.6 MHz, $CDCl_3$): 174.5 (*s*, C=N); 136.1, 134.0, 133.5, 131.8, 129.4, 128.9, 128.7, 128.6, 128.4, 128.3, 128.1, 127.3, 106.4 (*s*, –C–O); 98.7 (*d*, H–C–O); 76.2 (*d*, H–C–O); 41.1. MS: 295 (0.6 M^+), 267 (1.0), 251 (1.1), 235 (8), 222 (10), 206 (4), 191 (2), 149 (5), 131 (4), 115 (4), 105 (100), 77 (53). Anal. calc. for $C_{18}H_{17}NO_3$ (295.34): C 73.20, H 5.80, N 4.74; found: C 72.90, H 5.52, N 4.99.

*cis-3-(*tert*-Butyl)-6,7a-diphenyl-4a,7a-dihydro-3*H,5H*-[1,2,4]trioxino[3,2-e]pyrrole* (**17**). The above procedure, but using **15** (300 mg, 1.2 mmol) and pivalaldehyde (5 ml) gave the trioxane **17** as a colorless solid, m.p. 113–119, R_f 0.33 (80 mg, 20% yield). ^{1}H-NMR (360 MHz, $CDCl_3$): 8.09 (*m*, 2H); 7.52 (*m*, 6H); 7.37 (*m*, 2H); 5.17 (*s*, 1H); 4,65 (*d*, *J* = 4, 1H); 3.16 (*d*, *J* = 17, 1H); 2.82 (*dd*, *J* = 17 and 4, 1H); and 0.94 (*s*, 9H). ^{13}C-NMR (90.6 MHz, $CDCl_3$): 174.4 (*s*, C=N); 136.2, 135.6, 133.6, 133.5, 131.6, 129.4, 128.9, 128.7, 128.6, 128.4, 128.2, 127.3, 106.1 (*d*, H–C–O); 106.1 (*s*, –C–O); 76.2 (*d*, H–C–O); 41.9 (*t*, CH_2); 35.0 (*s*, CMe_3), and 24.6 (*q*, Me). MS: No molecular peak, 275 (2), 260 (4), 235 (14), 222 (9), 219 (5), 206 (4), 130 (4), 115 (3), 105 (100). Anal. calc. for $C_{21}H_{23}NO_3$ (337.42): C 74.75, H 6.87, N 4.15; found: C 74.51, H 6.62, N 4.39.

REFERENCES

[1] *C.W. Jefford, D. Jaggi, J. Boukouvalas & S. Kohmoto,* J. Am. Chem. Soc. *105,* 6497 (1983).

[2] *C.W. Jefford, J. Boukouvalas & S. Kohmoto,* Helv. Chim. Acta *66,* 2615 (1983); *C.W. Jefford, J. Boukouvalas, S. Kohmoto & H.G. Grant,* Anal. Chim. Acta *157,* 199 (1984).

[3] *C.W. Jefford, S. Kohmoto, J. Boukouvalas & U. Burger,* J. Am. Chem. Soc. *105,* 6498 (1983); *C.W. Jefford, J. Boukouvalas & S. Kohmoto,* Chimia *37,* 429 (1983); *C.W. Jefford, D. Jaggi, J. Boukouvalas, S. Kohmoto & G. Bernardinelli,* Helv. Chim. Acta *67,* 1104 (1984); *C.W. Jefford, H.G. Grant, D. Jaggi, J. Boukouvalas & S. Kohmoto,* Helv. Chim. Acta, in press; *C.W. Jefford, J. Boukouvalas, S. Kohmoto & G. Bernardinelli,* Tetrahedron, in press.

[4] *C.W. Jefford, J.C. Rossier & G.D. Richardson,* J. Chem. Soc., Chem. Commun. *1983,* 1064; *C.W. Jefford, J. Boukouvalas & S. Kohmoto,* ibid. *1984,* 523; J. Photochem. *25,* 537 (1984).

[5] *W.S. Johnson,* Acc. Chem. Res. *1,* 1 (1968); *H.O. House,* 'Modern Synthetic Reactions', 2nd edn., ed. W.A. Benjamin, Menlo Park, California, 1972, pp. 593, 609.

[6] *C.W. Jefford, J.C. Rossier, S. Kohmoto & J. Boukouvalas,* Synthesis, in press.

[7] *V. Subramanyam, C.L. Brizuela & A.H. Soloway,* J. Chem. Soc., Chem. Commun. *1976,* 508; *M. Schulz & K. Kirsche,* in 'Organic Peroxides', Vol. 3, ed. D. Swern, R.E. Krieger, Malabar, Florida, original, 1972, reprint, 1981, pp. 109–110; *W. Adam & A. Rios,* Chem. Commun. *1971,* 822; *G.B. Payne & C.W. Smith,* J. Org. Chem. *22,* 1682 (1957); *M. Miura, M. Nojima & S. Kusabayashi,* J. Chem. Soc., Chem. Commun. *1981,* 581; *H. Yamamoto, M. Akutagawa, H. Aoyama & Y. Omote,* J. Chem. Soc., Perkin Trans. 1 *1980,* 2300.

[8] *C.W. Jefford, G. Bernardinelli, J.-C. Rossier, S. Kohmoto & J. Boukouvalas,* Tetrahedron Lett., in press.

[9] *P. Main, S.J. Fiske, S.E. Hull, L. Lessinger, G. Germain, J.P. Declerq & M.M. Woolfson* (1980). MULTAN-80, A System for Computer Programs for the Automatic Solution of Crystal Structure from X-Ray Diffraction Data, University of York.

[10] *J.M. Stewart, P.A. Machin, C.W. Dickinson, H.L. Ammon, H. Heck & H.D. Flack* (1976). The X-Ray System. Version of March 1976. Tech. Rep. TR-446. Computer Science Center, University of Maryland, College Park, Maryland.

[11] *G. Rio, A. Ranjon, O. Pouchot & M.J. Scholl,* Bull. Soc. Chim. Fr. *1969,* 1667.