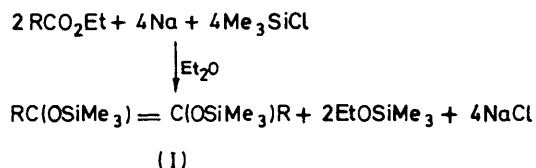# Bis(trimethylsilyloxy)alkenes from the Modified Acyloin Reaction of Schräpler and Rühlmann; Stereochemical Considerations

By **Clive M. Cookson** and **Gordon H. Whitham**,* The Dyson Perrins Laboratory, South Parks Road, Oxford OX1 3QY

The acyloin condensation of ethyl acetate brought about by sodium–ether–chloro(trimethyl)silane gave the Z- and E-isomers of 2.3-bis(trimethylsilyloxy)but-2-ene, (IV) and (V), in the ratio 9 : 1. Stereochemical assignments are based on spectroscopic data and correlation with the diastereoisomeric butane-2,3-diols via hydrogenation. Use of dichloro(dimethyl)silane in the acyloin reaction in place of chloro(trimethyl)silane led to formation of 2,3-bis(ethoxytrimethylsilyloxy)but-2-ene (IX).

In the modified acyloin condensation procedure developed by Schräpler and Rühlmann,[1,2] the intermediate enediol dianion is trapped by chloro(trimethyl)silane as the bistrimethylsilyl ether. For acyclic esters, the

$$2\,RCO_2Et + 4Na + 4Me_3SiCl$$

$$\downarrow Et_2O$$

$$RC(OSiMe_3) = C(OSiMe_3)R + 2EtOSiMe_3 + 4NaCl$$

(1)

bis(trimethylsilyloxy)alkenes (I) formed could be obtained in two diastereoisomeric forms, but there is no direct information on the stereochemistry of the reaction in the literature. We were interested in the stereochemistry of the products (I), since if they could readily be obtained diastereoisomerically pure they might be useful synthetic intermediates.

Treatment of ethyl acetate with sodium and chloro(trimethyl)silane in ether under standard conditions gave a product in yield (after distillation) comparable to that reported.[1,2] Three components were present according to g.l.c., in the ratio 13 : 79 : 8 (in order of elution on a silicone oil column). The first eluted component was isolated by preparative g.l.c. and shown by i.r. and n.m.r. spectroscopy (see Experimental section) to be 2,3-bis(trimethylsilyloxy)but-1-ene (II). This had not been reported previously as a product of the modified acyloin reaction but was a known compound.[3] The second eluted component (79% of the mixture) was also isolated by preparative g.l.c. I.r. and n.m.r. spectroscopy indicated that it was a 2,3-bis(trimethylsilyloxy)but-2-ene (III), probably a single stereoisomer (isomer A). The third component (8%) was not obtained pure by preparative g.l.c. (it is not easy to purify small quantities of trimethylsilyl ethers by g.l.c. owing to their susceptibility to hydrolysis) and satisfactory spectroscopic data were not obtained.

On the assumption that this third component was the other diastereoisomer of isomer A, attempts were made to interconvert the two compounds. The distilled product from the modified acyloin condensation of ethyl acetate was heated under reflux in benzene with a catalytic amount of iodine. After 30 min, g.l.c. showed that the ether (II) had disappeared, isomer A had

diminished in amount from 79 to 34%, and the compound eluted last now constituted 66 rather than 8% of the mixture. That the last compound was the other stereoisomer of III (isomer B) was confirmed by the

(II)   (III)
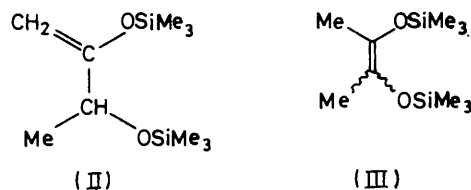
spectroscopic properties of a pure sample obtained by preparative g.l.c. of the isomerised material. The ratio of isomer A to isomer B did not change on prolonged treatment with iodine in benzene and it is considered that the above ratio represents an equilibrium mixture.

The [1]H n.m.r. spectra of isomers A and B were identical within experimental error, comprising two sharp singlets in the expected positions. No differentiation was obtained by use of Eu(fod)$_3$ as a shift reagent. However, the [13]C n.m.r. spectra of the two isomers showed significant differences, in particular the olefinic carbon absorption for isomer A was at 129·3 and that for isomer B at 134·3 p.p.m. (downfield from internal Me$_4$Si). Since the E-isomers of diastereoisomeric olefins tend to show sp^2 carbon absorption at lower field than the Z-isomers,[4] a tentative assignment of E-stereochemistry to isomer B may be made. This is partly corroborated by the presence of a sharp peak at 1697 cm^{-1} (C=C stretch) in the i.r. spectrum of isomer A; no comparable band was observed in the spectrum of isomer B. In general Z-isomers show stronger C=C stretching absorption than the more symmetrical E-isomers.

To confirm the stereochemical assignment, attempts were made to hydrogenate the two isomers. Although a cleanly stereospecific reaction was not achieved, hydrogenation of isomer A over Adams catalyst in ethyl acetate gave 81% meso- and 19% (±)-2,3-bis(trimethylsilyloxy)butane whereas isomer B gave 27% meso- and 73% (±)-isomer. On the usual assumption of preferential cis-hydrogenation, this result confirms that isomer A, the major product from the modified acyloin reaction, is the Z-isomer (IV) and B the E-isomer (V).

When hydrogenation was performed over palladium–

[1] U. Schräpler and K. Rühlmann, *Chem. Ber.*, 1963, **96**, 2780; 1964, **97**, 1383.
[2] K. Rühlmann, *Synthesis*, 1971, 236.

[3] H. Teichmann and V. Prey, *Annalen*, 1970, **732**, 121.
[4] J. B. Stothers, ' Carbon-13 N.M.R. Spectroscopy,' Academic Press, New York and London, 1972, p. 74.

carbon extensive scrambling occurred, and a mixture of 44% *meso-* and 56% (±)-2,3-bis(trimethylsilyloxy)-butane was obtained from either (IV) or (V). No

Me₃SiO—C(CH₃)=C(CH₃)—OSiMe₃ (IV)

Me₃SiO—C(CH₃)=C(CH₃)—OSiMe₃ (V)

(IV)   (V)
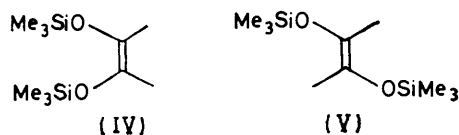
hydrogenation could be achieved with tris(triphenyl-phosphine)rhodium chloride as catalyst, and attempted reduction with di-imide generated from *p*-tolylsulphonyl-hydrazine in refluxing bis-(2-methoxyethyl) ether was unsuccessful.

Our conclusion that the predominant stereoisomer from the modified acyloin condensation of ethyl acetate is the *Z*-isomer (IV) apparently conflicts with a brief report [5] that the cyclopropanes (VI) and (VII) are obtained in the ratio 9 : 1 from the reaction of methylene iodide–zinc–copper couple with the bis(trimethylsilyl-oxy)but-2-enes from ethyl acetate. Since the assignment of stereochemistry to (VI) and (VII) by ¹H n.m.r. is unequivocal, a possible explanation is that traces of iodine in the Simmons–Smith reaction mixture may have caused equilibration of the bis(trimethylsilyloxy)butenes during methylenation.*

(VI)   (VII)
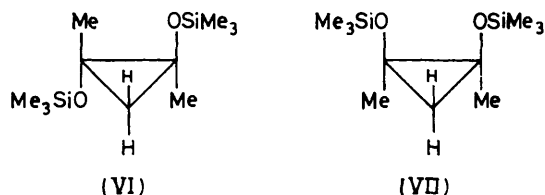
It does not seem profitable to attempt to analyse in detail the origin of the greater thermodynamic stability of the *E*-isomer (V) than of the *Z*-isomer (IV). However it is apparent that the normally observed greater stability of *Z*- than of *E*-1,2-disubstituted alkenes where the substituents are alkoxy [6] or halogen [7] cannot be extrapolated to these silyl ethers.
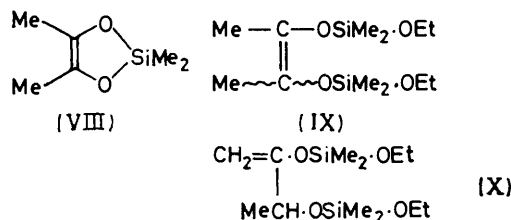
We have also briefly investigated the modified acyloin condensation of ethyl propionate. The *Z*- and *E*-isomers of 3,4-bis(trimethylsilyloxy)hex-3-ene were produced in the ratio 88 : 12 as indicated by g.l.c. and ¹³C n.m.r. Curiously, in contrast to the ethyl acetate product, treatment of this material with iodine in benzene under reflux gave a mixture which still contained a predominance (84%) of the *Z*-isomer.

* A very recent paper (G. A. Russell, D. F. Lawson, H. L. Malkus, R. D. Stephens, G. R. Underwood, T. Takano, and V. Malatesta, *J. Amer. Chem. Soc.*, 1974, **96**, 5830) describes separation of the predominant bistrimethylsilyl ether from ethyl acetate and ascribes the *Z*-configuration to it, in agreement with our conclusion, without discussing the evidence on which this assignment is based.

[5] M. Audibrand, R. Le Goaller, and P. Arnaud, *Compt. rend.*, 1969, **268C**, 2322.

[6] J. T. Waldron and W. H. Snyder, *J. Amer. Chem. Soc.*, 1973, **95**, 5491.

In an attempt to obtain the cyclic ether (VIII) we carried out the modified acyloin reaction on ethyl acetate using dichloro(dimethyl)silane in place of chloro(trimethyl)silane. In fact the product comprised the two diastereoisomers of the bis-ether (IX) (*Z* 89%; *E* 7·5%) together with a small amount (3·5%) of the double-bond isomer (X).

(VIII)   (IX)

Me—C(=)—OSiMe₂·OEt and Me~C~OSiMe₂·OEt (IX)

CH₂=C·OSiMe₂·OEt
| (X)
MeCH·OSiMe₂·OEt

In considering the mechanism of the modified acylion condensation, Rühlmann [2] expressed doubts about a 'conventional' scheme involving an α-diketone as intermediate. The basis for this objection is that only a poor yield of product (III) is obtained when biacetyl is subjected to the reaction. We find, further, that the ratio of the isomers of (III) obtained from biacetyl is 63% *Z* and 37% *E*—significantly different from the ratio reproducibly obtained by starting from ethyl acetate. This provides further evidence that biacetyl is, at least, not the only precursor of (III) in the overall acyloin reaction. A detailed discussion of the mechanism of the acyloin condensation does not seem appropriate here, but a possible way of avoiding the α-diketone would involve the intermediate steps illustrated (Scheme).

OEt   OEt
| |
R C—ONa   →2Na→ R C—ONa → R C—ONa →
| | ‖
R C=O   R C—ONa   R C—ONa

SCHEME
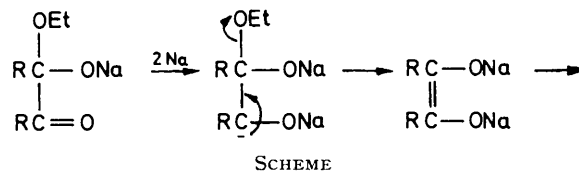
In summary, we have shown that the modified acyloin condensation leads stereoselectively to the *Z*-isomer of the bis(trimethylsilyloxy)alkene, at least in the case of ethyl acetate and ethyl propionate. It may be possible to capitalise on this observation synthetically if conditions for a more highly stereospecific hydrogenation of the products can be developed. Known methods for the stereospecific conversion of 1,2-diols into olefins [8] and epoxides [9] might then be usefully employed as subsequent steps.

EXPERIMENTAL

Instruments.—I.r. spectra Perkin-Elmer 257; ¹H n.m.r. Perkin-Elmer R32 (90 MHz) or R14 (100 MHz) (CCl₄ solution with Me₄Si as internal standard except for silicon-containing compounds for which C₆H₆ was used); ¹³C

[7] H. G. Viehe, *Chem. Ber.*, 1960, **93**, 1697; H. G. Viehe and E. Franchimont, *ibid.*, 1963, **96**, 3153.

[8] J. N. Hines, M. J. Peagram, E. J. Thomas, and G. H. Whitham, *J.C.S. Perkin I*, 1973, 2332 and references therein.

[9] M. S. Newman and C. H. Chen, *J. Amer. Chem. Soc.*, 1972, **94**, 2149; *J. Org. Chem.*, 1973, **38**, 1173; D. A. Seeley and J. McElwee, *ibid.*, p. 1691.

n.m.r. Brucker HFX 90 (22·63 MHz) with broad band proton decoupling (CDCl₃ solution; chemical shifts in p.p.m. downfield from Me₄Si); g.l.c., analytical, Pye 104 with 5 ft × 4 mm silicone oil (35%) column at 150° or PEGS (10%) at 80°, or Perkin-Elmer F11 with 50 ft SCOT column (SE-30) at 125°; preparative, Pye 105 with 35 ft × 3/8 in silicone oil column (25%) at 200°.

Acyloin Condensation of Ethyl Acetate with Chloro(trimethyl)silane.—Sodium (23 g, 1 mol) was stirred rapidly with a nichrome wire stirrer in refluxing toluene (700 ml) under dry nitrogen until the molten metal was broken up into very small droplets. The flask was then rapidly cooled and the stirrer switched off so that fine 'sodium sand' settled at the bottom of the flask. The toluene was poured off and the solution was washed with dry ether (2 × 70 ml). Ether (700 ml) and chloro(trimethyl)silane (120 g, 1·1 mol) were added and ethyl acetate was dropped into the mixture with stirring during 30 min. An exothermic reaction occurred and after 1 h the sodium appeared to have been almost entirely replaced by sodium chloride, but stirring was continued overnight to ensure complete reaction. The sodium chloride was filtered off, and the filtrate was evaporated and distilled to give a mobile liquid (43·3 g, 74%), b.p. 76—78° at 12 mmHg. G.l.c. analysis showed this to be a mixture of the three isomers of 2,3-bis-(trimethylsilyloxy)butene in the following proportions: 2,3-bis(trimethylsilyloxy)but-1-ene, 13%; (Z)-2,3-bis-(trimethylsilyloxy)but-2-ene, 79%; (E)-2,3-bis(trimethyl-silyloxy)but-2-ene, 8%; relative retention times 1 : 1·28 : 2·02 on PEGS and 1 : 1·20 : 1·38 on silicone oil. The pure compounds were isolated by preparative g.l.c. 2,3-Bis(trimethylsilyloxy)but-1-ene showed τ 9·92 (9H, s, CH·OSi*Me₃*), 9·82 (9H, s, =C·OSi*Me₃*), 8·80 (3H, d, *J* 6·5 Hz, CH·C*H₃*), 6·03 (1H, q, *J* 6·5 Hz, C*H*·CH₃), 6·02 (1H, s, olefinic H), and 5·70 (1H, s, olefinic H); ν$_{max.}$ 2957, 1636, 1252, and 843 cm⁻¹ (Found: C, 51·5; H, 10·5. Calc. for C₁₀H₂₄O₂Si₂: C, 51·7; H, 10·4%). (Z)-2,3-*Bis(trimethyl-silyloxy)but-2-ene* showed τ 9·89 (18H, s, OSiMe₃), 8·31 (6H, s, Me); ν$_{max.}$ 2955, 1697, 1250, and 843 cm⁻¹; δ$_C$ 0·8 (intensity 1000, OSiMe₃), 17·9 (273, Me), and 129·3 (80, olefinic C) (Found: C, 52·0; H, 10·2%). The E-*isomer* (obtained from iodine-catalysed isomerisation) showed an identical ¹H n.m.r. spectrum; ν$_{max.}$ 2955, 1251, and 845 cm⁻¹; δ$_C$ 0·6 (1000, OSiMe₃), 16·6 (272, Me), and 134·3 (75, olefinic C) (Found: C, 51·9; H, 10·3%).

Isomerisation of (Z)- and (E)-2,3-Bis(trimethylsilyloxy)but-2-ene.—Distilled product from the acyloin condensation of ethyl acetate (5 g) was refluxed for 30 min in benzene (50 ml) with a trace of iodine (20 mg). After cooling, the solution was shaken with mercury for 30 min to remove the iodine. G.l.c. analysis at this point showed the solution to contain (Z)-2,3-bis(trimethylsilyloxy)but-2-ene (34%) and the E-isomer (66%); all the 2,3-bis(trimethylsilyloxy)but-1-ene had disappeared. [The same ratio of 2,3-bis(trimethyl-silyloxy)but-2-ene isomers was found when other samples were refluxed with iodine in benzene for longer periods.] The solution was evaporated and distilled to give a mixture (3·4 g, 68%), b.p. 76—80° at 12 mmHg, containing 31% of (Z)- and 69% of (E)-2,3-bis(trimethylsilyloxy)but-2-ene. Pure samples of the two isomers were obtained by preparative g.l.c.

Both isomers were destroyed during short periods of reflux with iodine in acetonitrile, acetone, or light petroleum.

2,3-Bis(trimethylsilyloxy)butane from Butane-2,3-diol.—Butane-2,3-diol [93% meso- and 7% (±)-isomer [10]] (18·0 g,

0·2 mol) and pyridine (38·8 g, 0·44 mol) were mixed, cooled in an ice-bath, and stirred rapidly under nitrogen, chloro-(trimethyl)silane (43·4 g, 0·4 mol) was added during 30 min, the temperature being kept below 45°. Then the mixture was filtered to remove pyridinium hydrochloride, and, after evaporation of the excess of pyridine, distillation gave 2,3-bis(trimethylsilyloxy)butane (37·4 g, 80%), b.p. 62—64° at 12 mmHg. The ¹H n.m.r. spectra of the diastereo-isomers differed little; the methine protons gave over-lapping multiplets at τ 6·5, but the two methyl doublets, τ 8·91 for meso and 8·96 for (±), were resolved; the trimethylsilyloxy-protons absorbed at τ 9·91; ν$_{max.}$ 2957, 1250, and 843 cm⁻¹. In order to resolve the diastereo-isomers completely by g.l.c. it was necessary to use a silicone oil SCOT column; the two peaks had an integration ratio of 93 : 7 and were therefore attributed to the meso- and (±)-compounds, respectively (retention times were in the ratio 1·06 : 1) (Found: C, 51·0; H, 11·1. C₁₀H₂₆O₂Si₂ requires C, 51·2; H, 11·2%).

Hydrogenation of 2,3-Bis(trimethylsilyloxy)butene over Platinum Oxide.—Hydrogenation was carried out four times (see below). In each case 2,3-bis(trimethylsilyloxy)-butene (0·5 g) in ethyl acetate (10 ml) was hydrogenated at room temperature and pressure over Adams catalyst (30 mg). Hydrogenation was complete in 24 h. 2,3-Bis-(trimethylsilyloxy)butane was produced in the following proportions: (i) from the original products of acyloin condensation, meso 62% and (±) 38%; (ii) from iodine isomerised material, meso 41% and (±) 59%; (iii) from pure (Z)-2,3-bis(trimethylsilyloxy)but-2-ene (from pre-parative g.l.c.), meso 81% and (±) 19%; (iv) from pure (E)-2,3-bis(trimethylsilyloxy)but-2-ene (from preparative g.l.c.), meso 27% and (±) 73%.

Acyloin Condensation of Ethyl Propionate.—The procedure was the same as for the condensation of ethyl acetate, using sodium (4·6 g, 0·2 mol), chloro(trimethyl)silane (24 g, 0·22 mol), and ethyl propionate (10·2 g, 0·1 mol). Distillation gave 3,4-bis(trimethylsilyloxy)hex-3-ene (7·6 g, 59%) as a mobile liquid, b.p. 88—90° at 12 mmHg, consisting of 88% Z- and 12% E-isomer (g.l.c.). The ratio of retention times (Z : E) on silicone oil was 1 : 1·10; τ 9·88 (18H, s, OSiMe₃), 9·02 (6H, t, *J* 7 Hz, CH₃), and 7·99 (4H, q, *J* 7 Hz, CH₂); ν$_{max.}$ 2957, 1677, 1250, and 844 cm⁻¹; δ$_C$ (Z-isomer) 0·8 (intensity 1000, OSiMe₃), 12·8 (319, CH₃), 25·0 (338, CH₂), and 135·3 (73, olefinic C); (E-isomer) 0·6 (121, OSiMe₃), 11·5 (36, CH₃), 23·1 (34, CH₂), and 138·5 (8, olefinic C).

Isomerisation of (Z)- and (E)-3,4-Bis(trimethylsilyloxy)hex-3-ene.—The product from the condensation of ethyl propionate (5 g) was refluxed in benzene (50 ml) with a trace of iodine (20 mg). After 30 min the solution con-tained 84% (Z)- and 16% (E)-3,4-bis(trimethylsilyloxy)-hex-3-ene (g.l.c.) and these proportions did not change during a further 2 h reflux, even though more iodine (20 mg) was added.

Acyloin Condensation of Ethyl Acetate with Dichloro-(dimethyl)silane.—The usual procedure was used, with sodium (4·6 g, 0·2 mol), dichloro(dimethyl)silane (14·2 g, 0·11 mol), and ethyl acetate (8·8 g, 0·1 mol). The products were the three isomers of 2,3-bis(ethoxydimethylsilyloxy)-butene (5·5 g, 38%), b.p. 102—103° at 12 mmHg. G.l.c. indicated the proportions: 2,3-bis(ethoxydimethylsilyloxy)-but-1-ene 3·5%, (Z)-2,3-bis(ethoxydimethylsilyloxy)but-

[10] M. Gianni, J. Saavedra, R. Myhalyk, and K. Wursthorn, *J. Phys. Chem.*, 1970, **74**, 210.

2-ene 89%, (E)-2,3-bis(ethoxydimethylsilyloxy)but-2-ene 7·5%; τ 6·23 (4H, q, J 7 Hz, $CH_2 \cdot CH_3$), 8·21 (6H, s, $=C \cdot CH_3$), 8·81 (6H, t, J 7 Hz, $CH_2 \cdot CH_3$), and 9·87 (12H, s, $OSiMe_2O$); $\nu_{max.}$ 2965, 1696, 1259, and 843 cm^{-1}; m/e 133 (100%), 28 (88), 75 (85), 103 (79), 292 (M^+, 76), and 177 (62).

The 2,3-bis(ethoxydimethylsilyloxy)butenes (2·9 g, 0·01 mol) were hydrolysed by heating under reflux and stirring in ether (20 ml) with M-hydrochloric acid (0·75; 0·04 mol. equiv. water) for 2 h. The mixture was then dried (3 h reflux with anhydrous calcium carbonate) and evaporated. Distillation gave a homogeneous fraction, b.p. 78—82°, consisting mainly of ethanol, followed by a fraction, b.p. 105—118°, which separated into two phases. ^{1}H N.m.r. and i.r. spectra showed that the lower layer was mainly acetoin, and the upper phase consisted of unidentified siloxanes.

Treatment of Biacetyl with Sodium and Chloro(trimethyl)-silane.—The procedure was the same as usual, with sodium (4·6 g, 0·2 mol), chloro(trimethyl)silane (24 g, 0·22 mol), and biacetyl (8·6 g, 0·1 mol). The reaction was vigorous and was complete within 30 min. The product consisted largely of undistillable polymeric material, but distillation did give 2,3-bis(trimethylsilyloxy)but-2-ene (1·0 g, 9%), b.p. 77—78° at 12 mmHg shown by g.l.c. to consist of 63% Z- and 37% E-isomer. No 2,3-bis(trimethylsilyloxy)but-1-ene or other volatile compounds were detected.