Convenient Synthesis of Ethyl (±)-*cis*- and *trans*-3-(2,2-Dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate

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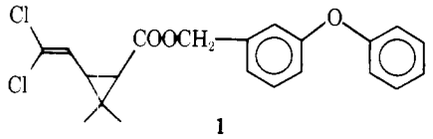
A synthesis of the acid moiety of the insecticide Permethrin (NRDC 143) (1) starting from readily available 2-methyl-3-buten-2-ol (6) is described. Addition of carbon tetrachloride to 6 and subsequent treatment with base gave epoxide 8, which with dimethyl malonate formed the lactone 10. Decarboxylation and lactone opening with thionyl chloride and ethanol gave chloroester 15, which could be cyclized with strong base to the title compound 3. The influence of solvent and base on the cis/trans ratio of 3 was examined.

In recent years appreciable work has been directed toward structural modification of the natural pyrethrins and several new compounds possessing promising potential for pest control have emerged. One of the most powerful pyrethroids is Permethrin (NRDC 143) (1), first reported by



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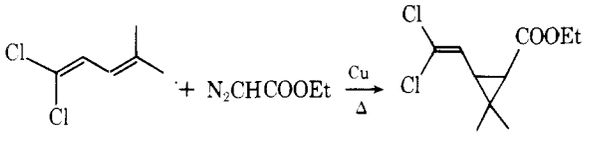
Elliott et al. in 1973,[1] which combines suitable chemical stability, rapid action, and high potency against many insect species with low mammalian toxicity.

Originally the ethyl ester 3 was prepared[2] by copper-catalyzed addition of ethyl diazoacetate to dichlorodiene 2. Al-



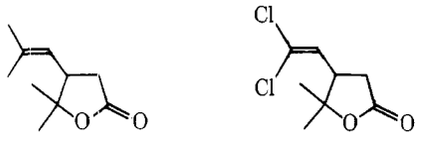
2 3

though this is a very direct and convenient route for small-scale preparations, the toxicity and explosion risks of ethyl diazoacetate make the procedure less suitable for large-scale preparations.

Recently an elegant alternative synthesis of 3 has been presented by Kondo et al.[3] In this paper we report a new procedure based on low cost, readily available starting materials, and well established chemical transformations.

A study of the previous syntheses of acid moieties in natural pyrethrins suggested to us that lactone 5, analogous to pyrocin (4) obtained, e.g., by pyrolysis of the constituents of pyrethrum extract,[4] might be a useful intermediate.

With the requirement that the dichloroethenyl group of 5 should originate not from the reaction of an aldehyde with the

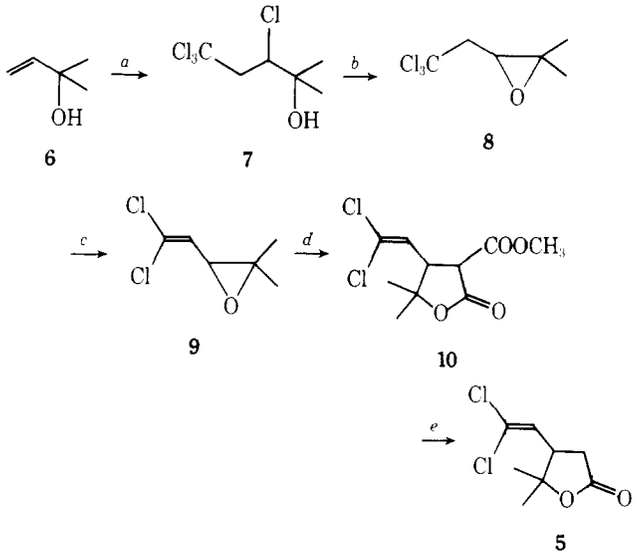


4 5

appropriate Wittig reagent, which would be impractical on a large scale, but from an addition–elimination sequence of an inexpensive tetrahalomethane to an ethylenic bond, antithetic analysis established 2-methyl-3-buten-2-ol (6) as a suitable starting material for 5 (Scheme I).

The peroxide-initiated free-radical addition of carbon tetrachloride to 6 afforded the monoadduct 7 in high yield. Proper dilution minimized the formation of telomers, and with benzoyl peroxide catalyst the reaction time was 15–20 h. Although several other catalysts, e.g., azabis(isobutyronitrile),

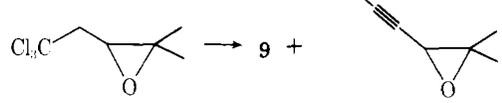
Scheme I



[a] CCl_4, Bz_2O_2. [b] 50% aqueous NaOH, CCl_4, $Bu_4N^+HSO_4^-$. [c] NaOMe, MeOH or NaOMe, CH_2Cl_2. [d] Dimethyl malonate, NaOMe, MeOH. [e] H_2O, DMF.

di-*tert*-butyl peroxide, *tert*-butyl perbenzoate, and dilauroyl peroxide were tested no substantial reduction in reaction time was obtained.

Conversion of chlorohydrin 7 to trichloro epoxide 8 was performed in the same reaction flask by addition of an equimolar amount of 20% aqueous sodium hydroxide and heating to near reflux with tetrabutylammonium hydroxide as phase transfer catalyst (PTC). When purified 8 in methylene chloride was treated with 50% aqueous sodium hydroxide under PTC conditions, rather slow elimination of one or two molecules of hydrogen chloride gave epoxides 9 and 11 in varying proportions.



8 11

Thus, with 2.5 equiv of 50% aqueous sodium hydroxide after 18 h at room temperature no 11 and only 17% of 9 was formed. Addition of another 4 equiv of base to the same reaction mixture and stirring for 24 h gave 59% of 9 and 5% of 11. Further addition of base was essentially without effect upon the remaining 34% of 8. When 10 equiv of base was added to 8, 97% of the acetylenic epoxide 11 was formed after 65 h at room temperature. No intermediate conditions for complete con-

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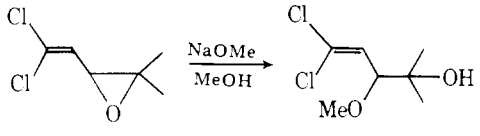
Table I. Cyclization of Chloro Ester 15

run	solvent	base[b]	reaction temp, °C	reaction time, min	product, %[a]							
					cis-3[d]	*trans*-3[e]	18[f]	19[g]	17[h]	15[i]	unknown[c]	total accounted for
1	EtOH	NaOEt (3.5)	reflux	60	6.8	44.3		13.7	3.5		11.0	79.3
2	EtOH	NaOEt (2.0)	reflux	130	5.9	50.0	5.3			9.5	15.4	86.1
3	toluene	NaO-*t*-Am (1.1)	15	80		32.8				46.0		78.8
4	toluene	NaOEt (1.56)	reflux	55	5.0	65.6				9.8		80.4
5	THF	NaO-*t*-Bu (1.5)	0	60	2.0	51.1				26.3	5.3	85.0
6	THF	$NaNH_2$ (2.0)	15	15	3.2	45.7	5.8			10.5		65.2
7	THF	NaO-*t*-Bu (2.0)	−20	90	2.9	49.4				30.0	10.7	93.0
8	THF	NaO-*t*-Bu (2.0)	22	1440	0.9	66.0				1.8	10.1	78.8
9	DMF	NaH (1.55)	24	150	10.7	64.4	19.3					94.4
10	DMF	NaOEt (1.1)	40	90	2.3	5.2	40.3			44.0		91.8
11	DMF	NaO-*t*-Bu (1.3)	−10	60	7.1	45.5	25.2		6.7	2.0		86.5
12	DME	NaO-*t*-Bu (1.5)	−10	120	2.3	61.5		12.3		13.3		89.4
13	dioxane	NaO-*t*-Bu (3.7)	0	200	2.2	70.0				2.9	8.7	83.8

[a] As determined by GC. [b] The figures in parentheses refer to moles of base used per mole of **15**. [c] This percentage refers to one single prominent peak in the gas chromatogram not necessarily corresponding to the same unidentified structure in all runs. [d] Registry no. 63142-56-3. [e] Registry no. 63142-57-4. [f] Registry no. 63406-19-9. [g] Registry no. 68344-70-7. [h] Registry no. 68344-69-4. [i] Registry no. 65771-92-8.

version of **8** exclusively to **9** were found. In contrast, **8** was smoothly converted to **9** in over 90% isolated yield when refluxed in methylene chloride solution with solid sodium methoxide in slight excess.

For preparation of lactone **10** it was not necessary to isolate epoxide **9**. More directly **9** was generated in situ from **8** in methanol with 1 equiv of methanolic sodium methoxide after which addition of dimethyl malonate and another equivalent of methanolic sodium methoxide, successively, completed the reaction.[5] The yield of **10** centered around 70%. When dimethyl malonate was condensed directly with epoxide **9** higher yields (~82%) were obtained. One limiting factor for the yield was revealed when the major byproduct was identified as the hydroxy ether **12** resulting from attack of methoxide on ep-



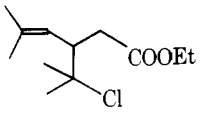
9 **12**

oxide **9**. Although **9** is unsymmetrically substituted and might give rise to two positionally isomeric lactones, no product corresponding to malonate attack at the tertiary epoxide carbon atom was found. The secondary epoxide carbon is preferentially attacked, not only for steric reasons but also because it is allylic.

Contrasting these results, sodiomalonate prepared from sodium hydride and dimethyl malonate in solvents such as dimethylformamide, dioxane, tetrahydrofuran, or dimethoxyethane gave negligible amounts of **10** in reaction with **9**. Diethyl ethoxymagnesiomalonate in refluxing ether solution did not attack **9** at all. Malonic esters have been reported to react in high yield with ethylene oxide in the presence of aluminum trichloride[6] but this condensing agent as well as triethylamine or piperidine at elevated temperatures and under pressure were ineffective in causing reaction with **9**.

Decarboxylation of **10** in refluxing wet dimethylformamide proceeded to the key intermediate **5** in virtually quantitative yield.[7] The stability of **5** is illustrated by the fact that it could be recovered almost quantitatively after prolonged treatment with thionyl chloride in the presence of a range of Lewis acid catalysts, e.g., titanium tetrachloride, aluminum trichloride, stannic chloride, zink chloride, ferric chloride, nickel chloride, or after heating in saturated ethanolic hydrogen bromide at 120 °C for 3 h in an autoclave.

Transformation of pyrocin (**4**) into a mixture of the chloroesters **13** and **14** has been reported to proceed well by sequential treatment with thionyl chloride in refluxing benzene and saturated ethanolic hydrogen chloride.[8] Careful duplication of these reaction conditions with **5** showed that no reaction occurred during the benzene reflux, whereas GC analysis after the addition of ethanolic hydrogen chloride revealed incomplete conversion (43% of **5** remained) to the desired chloro ester **15** (40%) and the elimination products **16** (1%) and **17** (7%).



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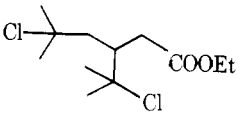

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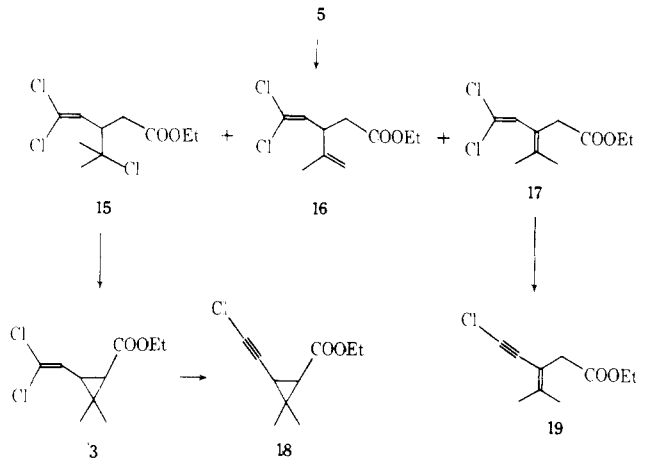
A modified procedure[9] for opening pyrocin (**4**) requires adding a tenfold excess of thionyl chloride to a highly diluted solution of **4** in ethanol, after which the mixture was heated at 60 °C for 4 h to produce **13** in 82% yield. Under these conditions **5** was converted to a mixture of **15** (41%), **16** (32%), and **17** (10%) while 10% of **5** remained unchanged. These results suggested that the combined action of thionyl chloride and ethanol, possibly in the form of ethyl chlorosulfite, was mandatory. A number of experiments along this line were conducted at atmospheric pressure, most often in the presence of catalysts (especially ferric chloride), but in the most successful case no more than 50% of **15** was obtained along with **16** (5%) and **17** (26%). Finally, when the lactone opening was carried out in an autoclave with ferric chloride catalyst the formation of elimination products was strongly suppressed and the conversion to **15** was satisfactory (70–75%). Furthermore unreacted **5** was easily separated and recycled. It was found important that the chloro ester **15** be free of or at least contain very little **16** and **17**, since these compounds had boiling points very close to those of *cis*- and *trans*-**3** and were thus difficult to remove by distillation at a later stage.

Cyclization of **15** to **3** by the action of strong base turned out to be a complex reaction. Due to the presence of two different kinds of chlorine atoms, one located at a tertiary the others at a vinylic position, several modes of reaction may be followed giving rise to a range of undesirable products, just as the desired product, **3**, once formed, may react further. Examples of cyclization under a variety of conditions are given in Table I. Generally, to minimize the formation of byproducts it was

Scheme II



found necessary to ensure that base was never in excess. Therefore, in most instances the base was added gradually to a stirred solution of 15 in the solvent in question. Even then the acetylenic cyclopropane 18 was formed in several cases. Especially with sodium hydride in dimethylformamide, 18 appeared quickly as a result of facile elimination of hydrogen chloride from initially formed *trans*-3. In the presence of excess sodium hydride *trans*-18 formed directly in 69% yield. Apparently *cis*-3 did not undergo elimination for steric reasons since *cis*-18 was not observed. In the other extreme *trans*-18 was not formed at all even in the presence of excess sodium *tert*-butoxide in dimethoxyethane and the combined yield of *cis*- and *trans*-3 was good. That was also the case for sodium *tert*-butoxide in dioxane or tetrahydrofuran, although the cis/trans ratio was lower in these solvents and the reaction time somewhat longer. Sodium ethoxide in ethanol gave only fair yields of 3 and substantial amounts of various byproducts.[10] In contrast alcohol free sodium ethoxide in toluene (Table I, run 4) effected clean cyclization.

An important feature of the cyclization is the cis/trans ratio of the product 3, since pyrethroids derived from 3 may have markedly different insecticidal properties toward various insect species depending on this ratio. The diazo ester synthesis[2] of 3 gives cis/trans ratios ranging from 40:60 to 60:40 depending on the catalyst used. Table I shows a maximum of 14:86 (run 9). Alternative routes for improvement of the proportion of *cis*-3 are under active investigation.

Experimental Section

Melting points were determined on a Büchi apparatus and are uncorrected. NMR spectra were recorded on a JEOL PMX-60 spectrometer with tetramethylsilane as internal standard. The chemical shifts are expressed in δ values (ppm) downfield from tetramethylsilane. Coupling constants are given in hertz. Analytical gas chromatography (GC) was carried out on a Hewlett-Packard 5840 A instrument equipped with FID on a 4-mm × 2-m column with 5% OV 210 on Chromosorb W as the stationary phase. IR spectra were recorded on a Perkin-Elmer Model 177 Grating IR spectrometer. Elemental analyses were performed by Novo Microanalytical Laboratory, Novo Industry A/S, DK-2880 Bagsvaerd, Denmark, supervised by Rolf E. Amsler.

4-Methyl-1,1,1,3-tetrachloropentan-4-ol (7). To a solution of vinyl alcohol 6 (86 g, 1 mol) in carbon tetrachloride (950 mL) was added moist benzoyl peroxide (1.5 g) and the mixture was refluxed with azeotropic removal of water using a Dean-Stark apparatus. After 4 h a new portion of benzoyl peroxide (1–1.5 g) was added and the reflux continued for 20 h with gradual temperature increase from 75 to 78–80 °C. After this time GC analyses of a number of runs showed the conversion of 6 to be 90–95%, partly to 7 and partly (~10–20%) to products of higher molecular weight. If the reaction mixture was not kept dry by removal of water the reflux temperature was lowered 5 to 10 °C and the reaction time appreciably increased. The solvent was removed under reduced pressure and the remaining viscous oil was distilled to give 168 g (70%) of 7 as a colorless liquid: bp 77 °C (0.35 mm); n^{24}_D 1.4972; IR (neat) 3450, 1389, 1375 cm^{-1}; NMR ($CDCl_3$) δ 1.38 (6 H, s), 2.17 (1 H, br s), 3.08 (1 H, dd, J = 16 and 7 Hz), 3.50 (1 H, dd, J = 16 and 2 Hz), 4.13 (1 H, dd, J = 7 and 2 Hz).

Anal. Calcd for $C_6H_{10}Cl_4O$: C, 30.03; H, 4.20; Cl, 59.10. Found: C, 29.91; H, 4.15; Cl, 59.29.

3,4-Epoxy-4-methyl-1,1,1-trichloropentane (8). To the reaction mixture obtained as described above a solution of sodium hydroxide (40 g, 1 mol) in water (160 mL) and tetrabutylammonium hydrogen sulfate (0.2–0.5 g) as phase transfer catalyst was added. The two-phase system was vigorously stirred at 60–70 °C for 8 h after which the organic layer was separated, dried (Na_2SO_4), and distilled to give 165 g (81%) of 8: bp 76 °C (10 mm); n^{25}_D 1.4668; IR (neat) 1386, 1381, 1251, 800 cm^{-1}; NMR ($CDCl_3$) δ 1.37 (3 H, s), 1.40 (3 H, s), 2.90–3.33 (3 H, m).

Anal. Calcd for $C_6H_9Cl_3O$: C, 35.41; H, 4.46; Cl, 52.27. Found: C, 35.29; H, 4.37; Cl, 52.39.

1,1-Dichloro-3,4-epoxy-4-methylpent-1-ene (9). To a solution of 8 (40.8 g, 0.2 mol) in methylene chloride (150 mL) was added dry sodium methoxide (11.9 g, 0.22 mol) and the mixture was stirred at ambient temperature for 1 h and then under reflux for 2 h when GC analysis revealed 98% of 9. The reaction mixture was acidified with 4 N hydrochloric acid and the organic layer was separated, dried (Na_2SO_4), and evaporated under reduced pressure to leave a colorless oil. Distillation afforded 30.7 g (92%) of 9 as a colorless liquid: bp 58 °C (10 mm); n^{24}_D 1.4760; IR (neat) 1620, 1386, 1381, 1251, 875, 793 cm^{-1}; NMR ($CDCl_3$) δ 1.33 (3 H, s), 1.40 (3 H, s), 3.43 (1 H, d, J = 8 Hz), 5.73 (1 H, d, J = 8 Hz).

Anal. Calcd for $C_6H_8Cl_2O$: C, 43.14; H, 4.83; Cl, 42.45. Found: C, 43.14; H, 4.78; Cl, 42.57.

1-Chloro-3,4-epoxy-4-methylpent-1-yne (11). To a solution of 8 (20.4 g, 0.1 mol) in methylene chloride (100 mL) was added 50% aqueous sodium hydroxide (75 g) and tetrabutylammonium hydrogen sulfate (0.1 g) and the binary system was vigorously stirred at ambient temperature for 65 h when GC analysis revealed complete consumption of 8 and 97% of 11. The organic layer was separated and combined with another methylene chloride extract of the aqueous layer. Drying (Na_2SO_4) and careful evaporation of the solvent below 30 °C (100 mm) left an oil which upon distillation afforded 11.0 g (84%) of 11 as a colorless liquid: bp 60–63 °C (40 mm); n^{25}_D 1.4569; IR (neat) 2230, 1384, 1380, 1250, 890, 795 cm^{-1}; NMR ($CDCl_3$) δ 1.38 (3 H, s), 1.43 (3 H, s), 3.21 (1 H, s).

Anal. Calcd for C_6H_7ClO: C, 55.19; H, 5.41; Cl, 27.15. Found: C, 55.29; H, 5.33; Cl, 27.26.

4-(2,2-Dichloroethenyl)-5,5-dimethyl-3-methoxycarbonyltetrahydrofuran-2-one (10). Sodium (53.0 g, 2.3 mol) was dissolved in methanol (800 mL) to give ~760 mL of sodium methoxide solution. Epoxide 8 (203.5 g, 1 mol) was dissolved in methanol (200 mL) and part of the sodium methoxide solution (400 mL, ~1.2 mol) was added dropwise at 15–20 °C during 1–1.5 h. After complete addition the reaction mixture was stirred for 30 min at ambient temperature.

A. For the isolation of dichloroethenyl epoxide 9 the reaction mixture was concentrated under reduced pressure below 40 °C and the remaining oil acidified with 4 N hydrochloric acid while cooled in an ice bath. Extraction twice with methylene chloride, drying (Na_2SO_4), and evaporation of the solvent left a slightly colored liquid which upon distillation afforded 138.6 g (83%) of 9: bp 62–68 °C (13 mm); n^{25}_D 1.4755; spectroscopic data as above.

B. For the preparation of 10 dimethyl malonate (137.0 g, 1.04 mol) was added to the mixture all at once and the remaining part of the sodium methoxide solution was added dropwise during 15 min without cooling. After stirring at ambient temperature for 16 h the mixture was heated at 35–40 °C for 8 h and then concentrated under reduced pressure. Water (800 mL) was added and the pH adjusted to 9–10 with 4 N hydrochloric acid. The resulting precipitate was filtered, washed with water till neutral, and air dried to give 187 g (70%) of 10. The purity was 98–99% by GC. An analytical sample was obtained by recrystallization from hexane–ethanol (3:1): mp 100–102 °C; IR (KBr) 1770, 1735, 1620, 1394, 1381 cm^{-1}; NMR ($CDCl_3$) δ 1.33 (3 H, s), 1.56 (3 H, s), 3.43–4.07 (2 H, m), 3.83 (3 H, s), 5.82 (1 H, d, J = 9 Hz).

Anal. Calcd for $C_{10}H_{12}Cl_2O_4$: C, 44.97; H, 4.53; Cl, 26.54. Found: C, 44.90; H, 4.43; Cl, 26.75.

C. Extraction of the aqueous phase twice with methylene chloride, drying (Na_2SO_4), and evaporation under reduced pressure left a brown oil which upon distillation gave unreacted dimethyl malonate (12.3 g, 9%) and then 21.9 g (11%) of 1,1-dichloro-3-methoxy-4-methylpent-1-en-4-ol (12): bp 40 °C (0.15 mm); n^{25}_D 1.4690; IR (neat) 3460, 2980, 2935, 2830, 1616, 1386, 1372, 1091 cm^{-1}; NMR ($CDCl_3$) δ 1.16 (3 H, s), 1.24 (3 H, s), 2.39 (1 H, s), 3.36 (3 H, s), 3.80 (1 H, d, J = 10 Hz), 5.85 (1 H, d, J = 10 Hz).

Anal. Calcd for $C_7H_{12}Cl_2O_2$: C, 42.23; H, 6.08; Cl, 35.62. Found: C,

42.36; H, 6.01; Cl, 35.69.

4-(2,2-Dichloroethenyl)-5,5-dimethyltetrahydrofuran-2-one (5). A suspension of methoxycarbonyl lactone **10** (267 g, 1 mol) in a mixture of dimethylformamide (600 mL) and water (27 mL, 1.5 mol) was heated under reflux (**10** dissolves at 120–140 °C) for 4–12 h (the reaction time for unidentified reasons may vary considerably from one run to another). When the decarboxylation was complete as evidenced by GC monitoring the methanol (produced during the decarboxylation), water, and dimethylformamide were removed by distillation through a short column under reduced pressure (10–50 mm). To the residue consisting of melted lactone **5** was added methanol (500 mL) and water (150 mL) and the solution was chilled to induce crystallization. The crystalline mass was filtered and the methanol distilled off the mother liquor to produce a second crop of product. The combined yield of **5** was 198 g (95%). Recrystallization from hexane–ethanol (2:1) gave an analytically pure sample of **5**: mp 116–119 °C; IR (KBr) 1760 (very broad), 1618, 1389, 1378, 1255 cm^{-1}; NMR ($CDCl_3$) δ 1.33 (3 H, s), 1.50 (3 H, s), 2.16–3.07 (2 H, m), 3.07–3.60 (1 H, m), 5.82 (1 H, d, J = 9 Hz).

Anal. Calcd for $C_8H_{10}Cl_2O_2$: C, 45.96; H, 4.82. Cl, 33.91. Found: C, 45.89; H, 4.85; Cl, 34.02.

Opening of Dichloro Ethenyl Lactone 5 at Atmospheric Pressure. In a typical experiment dry ethanol (45 mL) was saturated with dry hydrogen chloride gas and added dropwise to a mixture of **5** (30.0 g, 0.144 mol), $FeCl_3 \cdot 6H_2O$ (1.5 g), and thionyl chloride (43.5 mL, 0.598 mol) during 10 min with a temperature drop to −10 °C. The reaction mixture was heated in an oil bath at 83 °C for 50 min when GC analysis revealed a product mixture consisting of **16** (4.1%), **17** (29.9%), **15** (47.4%), and **5** (11.1%). It was not possible to obtain a pure sample of **15** by distillation of this mixture. One fraction was a 43:57 mixture of olefinic esters **16** and **17**, respectively: bp 67 °C (0.04 mm); n^{24}_D 1.4833; IR (neat) 2985, 1745, 1648, 1618 cm^{-1}; NMR ($CDCl_3$) of **16** δ 1.26 (3 H, t, J = 7 Hz), 1.77 (3 H, br s), 2.09–2.85 (2 H, m), 3.23–3.93 (1 H, m), 4.15 (2 H, q, J = 7 Hz), 4.83 (2 H, br s), 5.79 (1 H, d, J = 10 Hz); NMR ($CDCl_3$) of **17** δ 1.26 (3 H, t, J = 7 Hz), 1.77 (6 H, br s), 3.22 (2 H, s), 4.15 (2 H, q, J = 7 Hz), 6.50 (1 H, br s).

Anal. Calcd for $C_{10}H_{14}Cl_2O_2$: C, 50.65; H, 5.95; Cl, 29.90. Found: C, 50.74; H, 5.87; Cl, 30.12.

Opening of Dichloro Ethenyl Lactone 5 in Autoclave. Preparation of Ethyl 3-(2,2-Dichloroethenyl)-4-chloro-4-methylpentanoate (15). Dry ethanol (150 mL) was saturated with dry hydrogen chloride gas and added dropwise to a mixture of **5** (70.0 g, 0.335 mol), $FeCl_3 \cdot 6H_2O$ (3.5 g), and thionyl chloride (101.5 mL, 1.395 mol) during 10 min. The reaction mixture was transferred to a glass lined 500-mL Parr autoclave equipped with manometer, gas outlet valve, and mechanical stirrer and heated with stirring in an oil bath at 75 °C for 55 min when a pressure of ~200 psi had been developed. The autoclave was cooled to room temperature and the superpressure released through the gas outlet valve after which volatile material was removed under reduced pressure at 50 °C. The remaining oil was dissolved in methylene chloride (400 mL), washed three times with water, and dried (Na_2SO_4) and the solvent was evaporated under reduced pressure to leave a brown oil which when dissolved in pentane (500 mL) and chilled deposited unreacted **5**. Filtration gave 14.6 g of **5** and a mother liquor with the following GC analysis: **15** (84%), **16** (1.5%), **17** (2.9%), and **5** (7.3%). Careful distillation through a short column afforded 65 g (71%) of pure **15**: bp 87–89 °C (0.2 mm); n^{24}_D 1.4826; IR (neat) 1736, 1621, 1390, 1375 cm^{-1}; NMR ($CDCl_3$) δ 1.27 (3 H, t, J = 7 Hz), 1.57 (3 H, s), 1.62 (3 H, s), 2.13–3.45 (3 H, m), 4.15 (2 H, q, J = 7 Hz), 5.88 (1 H, d, J = 10 Hz).

Anal. Calcd for $C_{10}H_{15}Cl_3O_2$: C, 43.90; H, 5.53; Cl, 38.87. Found: C, 43.78; H, 5.54; Cl, 38.61.

Preparation of Ethyl 3-(2,2-Dichloroethenyl)-4-methylpent-4-enoate (16) and Ethyl 3-(2,2-Dichloroethenyl)-4-methylpent-3-enoate (17). To a solution of **15** (30.1 g, 0.11 mol) in dimethylformamide (50 mL) was added dry lithium carbonate (14.8 g, 0.2 mol) and the mixture was heated under reflux for 1 h. After cooling the solid material was removed by filtration and the filtrate carefully acidified with 4 N hydrochloric acid (400 mL) and extracted with methylene chloride (3 × 75 mL). The pooled extracts were dried (Na_2SO_4) and the solvent removed under reduced pressure to leave a brown liquid. Distillation through a short column afforded 18.9 g (80%) of a colorless oil. GC analysis revealed this to be a 75:25 mixture of **16** and **17**, respectively: bp 75 °C (0.15 mm); n^{25}_D 1.4785; further data as listed above.

Preparation of Ethyl (±)-*cis,trans*-3-(2,2-Dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate (3). Cyclization of Chloro Ester 15. A. With Sodium Ethoxide in Toluene. Metallic sodium (1.8 g, 0.078 mol) was dissolved in an excess of dry ethanol and the solution evaporated to dryness under reduced pressure. The last traces of ethanol were removed azeotropically by addition of benzene and evaporation at 70 °C (20 mm). The remaining alcohol free sodium ethoxide was suspended in dry toluene (100 mL) and the chloro ester **15** (13.7 g, 0.05 mol) added all at once, after which the mixture was heated under reflux in an oil bath for 55 min. After a few minutes the mixture became homogeneous and then precipitation of sodium chloride started and proceeded until the end of the reaction. After cooling the wine red reaction mixture was acidified with 4 N hydrochloric acid (200 mL) and the toluene layer was separated and combined with a methylene chloride extract (30 mL) of the aqueous layer. The combined organic layers were dried (Na_2SO_4) and the solvents removed under reduced pressure to leave an oil which upon distillation afforded 9.4 g (79%) of **3** as a 9:91 mixture of the cis and trans isomer, respectively: bp 65 °C (0.05 mm); lit.[3] bp 77 °C (0.3 mm); n^{25}_D 1.4856; IR (neat) 1725, 1615, 1381, 1369, 1226, 1178 cm^{-1}; NMR ($CDCl_3$) of *trans*-**3** δ 1.18 (3 H, s), 1.27 (3 H, t, J = 7 Hz), 1.28 (3 H, s), 1.58 (1 H, d, J = 6 Hz), 2.22 (1 H, dd, J = 8 and 6 Hz), 4.13 (2 H, q, J = 7 Hz), 5.60 (1 H, d, J = 8 Hz).

Anal. Calcd for $C_{10}H_{14}Cl_2O_2$: C, 50.65; H, 5.95; Cl, 29.90. Found: C, 50.59; H, 5.93; Cl, 30.01.

B. With Sodium *tert*-Butoxide in Dioxane. Sodium hydride (1.6 g of a 55–60% dispersion in mineral oil, ~0.04 mol) was washed twice with light petroleum (20 mL of boiling range 40–60 °C) and suspended in dry dioxane (20 mL). To the suspension was added dry *tert*-butyl alcohol (3.0 g, 0.04 mol) and the mixture was heated at 90 °C to induce hydrogen evolution. After 1 h no more hydrogen was evolved and the suspension of sodium *tert*-butoxide was cooled in an ice bath while a solution of **15** (2.74 g, 0.01 mol) in dioxane (10 mL) was added dropwise during 20 min. Stirring at 0 °C was continued for 3 h when the reaction mixture was poured into 4 N hydrochloric acid (200 mL) and extracted with methylene chloride (3 × 30 mL). The combined extracts were dried (Na_2SO_4) and evaporated under reduced pressure to leave a yellow oil. Distillation afforded 1.66 g (70%) of colorless **3** as a 4:96 mixture of the cis and trans isomer, respectively: bp 73–75 °C (0.09 mm); n^{25}_D 1.4853; further data as above.

C. With Sodium *tert*-Butoxide in Dimethoxyethane. A suspension of sodium *tert*-butoxide in dimethoxyethane (40 mL) was prepared in analogy with the procedure described above from sodium hydride (3.0 g, ~0.075 mol) and *tert*-butyl alcohol (4.5 g, 0.061 mol). This suspension was added to a stirred solution of **15** (11.0 g, 0.04 mol) in dimethoxyethane (50 mL) at −10 °C during 2 h and stirring was continued at this temperature for 1 h after which the reaction mixture was acidified with a solution of dry hydrogen chloride gas in dry ether and then diluted with water (400 mL). Extraction with methylene chloride (3 × 30 mL), drying (Na_2SO_4) of the combined extracts, and evaporation of the solvent under reduced pressure gave an oil, which upon distillation yielded 6.2 g (65%) of **3** as a 14:86 mixture of the cis and trans isomer, respectively: bp 69 °C (0.07 mm); n^{25}_D 1.4865; NMR ($CDCl_3$) of *cis*-**3** δ 1.32 (3 H, t, J = 7 Hz), 1.32 (6 H, s), 1.63–2.40 (2 H, m), 4.15 (2 H, q, J = 7 Hz), 6.30 (1 H, d, J = 8 Hz).

Ethyl (±)-*trans*-3-(1-Chloroethynyl)-2,2-dimethylcyclopropanecarboxylate (18). Sodium hydride (0.8 g of a 55–60% dispersion in mineral oil) was freed of dispersing oil and suspended in dry dimethylformamide (20 mL). A solution of **3** (2.4 g, 0.01 mol) in dimethylformamide (20 mL) was added dropwise during 20 min and the mixture stirred at room temperature for 4 h. Acidification with 4 N hydrochloric acid (100 mL), extraction with methylene chloride (3 × 15 mL), drying of the combined extracts (Na_2SO_4), and evaporation of the solvent under reduced pressure left a dark oil which was distilled to give 1.2 g (60%) of *trans*-**18**: bp 48 °C (0.05 mm); n^{23}_D 1.4751; IR (neat) 2220, 1735, 1420, 1330, 1280, 1170, 1050 cm^{-1}; NMR ($CDCl_3$) δ 1.22 (3 H, s), 1.25 (3 H, t, J = 7 Hz), 1.26 (3 H, s), 1.66 (1 H, d, J = 6 Hz), 1.92 (1 H, d, J = 6 Hz), 4.13 (2 H, q, J = 7 Hz).

Anal. Calcd for $C_{10}H_{13}ClO_2$: C, 59.86; H, 6.53; Cl, 17.67. Found: C, 59.82; H, 6.41; Cl, 17.80.

Registry No.—**5**, 63142-59-6; **6**, 115-18-4; **7**, 16278-75-4; **8**, 65948-62-1; **9**, 40646-47-7; **10**, 64280-76-8; **11**, 68344-68-3; **12**, 68344-67-2; **16**, 63722-97-4; carbon tetrachloride, 56-23-5; dimethyl malonate, 108-59-8.

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(10) One of these was identified as the acetylenic ester **19**: NMR ($CDCl_3$) δ 1.22 (3 H, t, J = 7 Hz), 1.78 (3 H, s), 1.98 (3 H, s), 3.14 (2 H, s), 4.14 (2 H, q, J = 7 Hz); IR (neat) 2200, 1735, 1442 cm^{-1}.

Reductive Silylation of Benzoates: Convenient Synthesis of Aroylsilanes[1]

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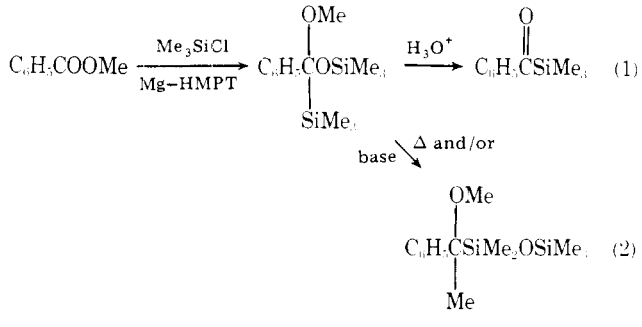
Reductive silylation of benzoates Σ-C_6H_4COOR (**1**) by means of trimethylchlorosilane/magnesium/hexamethylphosphorictriamide affords a very convenient synthesis of a wide variety of aroyltrimethylsilanes Σ-$C_6H_4C(O)SiMe_3$ (**3**), through the formation of the corresponding ketals **2** which can be isolated. Scope and limitations of this new synthesis have been studied. The intermediate ketals undergo an unusual quantitative isomerization in the presence of base and/or heat, yielding substituted disiloxanes **8**.

We have reported the use of the reagent trimethylchlorosilane/magnesium/hexamethylphosphorictriamide (Me_3SiCl/Mg/HMPT) to reductively silylate two benzoates.[2] With methyl benzoate we showed that reaction 1 led to benzoyltrimethylsilane upon hydrolysis of the intermediate ketal and at the same time that this intermediate ketal underwent the unusual isomerization into the substituted disiloxane under the influence of heat and/or base (reaction 2).



(1)

(2)

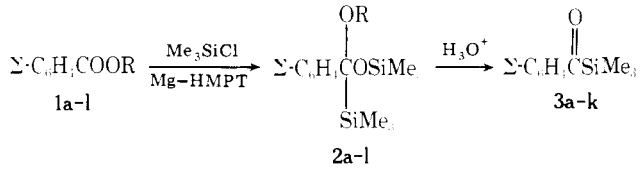
With trimethylsilyl benzoate we showed that the reductive silylation leads directly to a trisilylated compound and postulated the possible intermediacy of a ketal.

In order to learn the scope and limitations of reaction 1 as a very useful synthetic route to aroyltrimethylsilanes and to learn more about the factors governing the formation and the stability of the intermediate ketal, and its isomerization, we studied the behavior of a wide variety of substituted benzoates **1** (Table I) in the presence of Me_3SiCl/Mg/HMPT.

Results and Discussion

Ketals 2: Their Formation, Stability, and Hydrolysis to Acylsilanes 3. Under well-defined experimental conditions (i.e., excess of trimethylchlorosilane relative to HMPT, reaction and workup temperatures lower than 50–60 °C, and contact between basic reagent and ketal avoided), alkyl benzoates **1a–l** lead to the stable and isolable ketals **2** (Table II).[3] All these O-alkyl O-silyl mixed ketals of acylsilanes belong to a new class of compounds; symmetric ketals only have been reported to date.[4] A mechanism accounting for this silylation reaction has been previously proposed by us.[2]

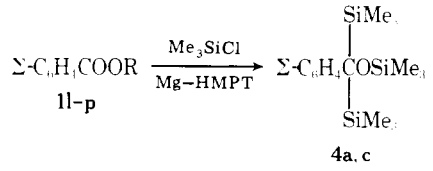
Acidic hydrolysis of these ketals **2a–l** leads to the corresponding acylsilanes **3a–k.**



This pathway is very convenient for the synthesis of substituted aroyltrimethylsilanes[5] and presents the advantage, in comparison with the two most usual methods,[6] of using directly commercially available starting compounds, of having a very easy and rapid workup, and of giving good yields (Table II).

The yields of ketals and acylsilanes seem to be not greatly affected by the nature and the position of the Σ group in **1**. In contrast, the nature of the R group seems to be more important as illustrated by *tert*-butyl *p*-methylbenzoate **1l**, which gives a poor yield of the corresponding acylsilane **3c**; also trimethylsilyl benzoate **1m** does not afford any acylsilane.[2]

As **1m**, compounds **1l–q**[7] undergo reductive silylation of the



ester function leading to the trisilylated derivatives **4** in good yields[8] (Table III), regardless of whether there is an excess of HMPT or not.

In order to explain the reductive silylation of such esters, we postulated the formation of an unstable ketal;[2] the acylsilane resulting from its decomposition would then be silylated, giving **4**.

Further evidence for this pathway is found in the behavior

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