Tetrahedron Vol. 41, No. 19, pp. 4025 to 4037, 1985
Printed in Great Britain.

0040-4020/85 $3.00 + .00
Pergamon Press Ltd.

β-CARBONYL RADICALS AS THREE-CARBON BUILDING BLOCKS FOR CARBON-CARBON BOND FORMING REACTIONS

Bernd GIESE* and Hans HORLER

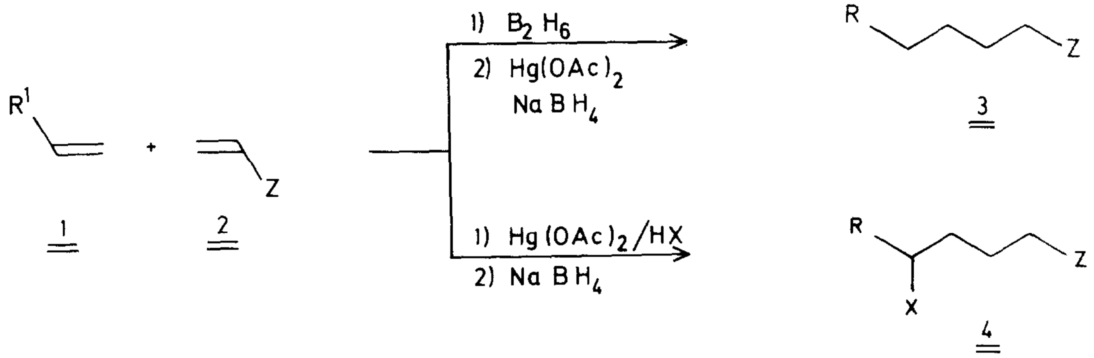
Institut für Organische Chemie und Biochemie
der Technischen Hochschule, Petersenstraße 22
D-6100 Darmstadt, Germany

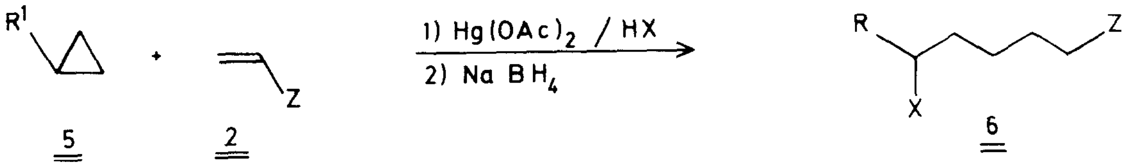
(*Received in Germany* 28 *February* 1985)

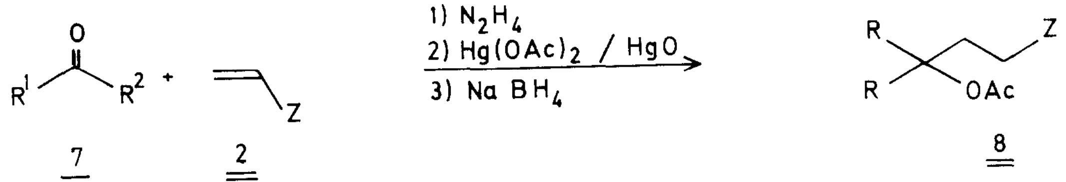
Abstract - From aldehydes, ketones and esters β-carbonyl radicals 47 can be generated via enolization, cyclopropanation, solvomercuration and reduction with $NaBH_4$. Radicals 47 react with electron-poor alkenes 27 to give products of CC-bond forming reactions (Tables 1-3). Carbonyl compounds are therefore precursors of three-carbon building blocks. The products result from reactions with "Umpolung".

INTRODUCTION

Radical reactions make possible the synthesis of CC-bonds under very mild conditions because radicals can add to alkenes with high rates[1] and high chemoselectivity[2]. In the last years, we have developed methods for CC-bond forming reactions[2] starting from alkenes 1[3], cyclopropanes 5[4] and ketones 7[5] leading to products 3, 4, 6 and 8.

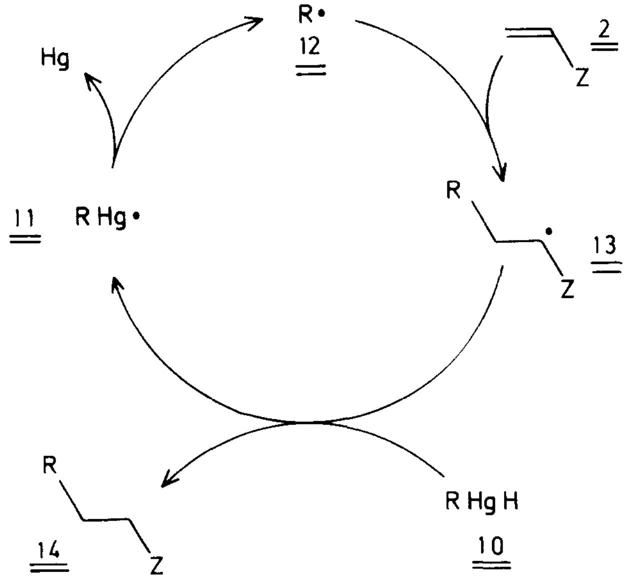






In these reactions, alkyl mercuric salts 9 are reduced with boro- or tinhydrides, to give radicals 12[6] via alkylmercuric hydrides 10[7] and alkylmercuric radicals 11[8]. Nucleophilic alkyl radicals 12 add to electron poor alkenes 2 to form adduct radicals 13 that are trapped by mercuric hydrides 10 to give the products 14 and the alkylmercuric radical 11. Spontaneous decomposition of 11[9] gives back the starting radical 12.

$$\underset{\underline{\underline{9}}}{RHgX} \xrightarrow[\text{or } Bu_3SnH]{NaBH_4} \underset{\underline{\underline{10}}}{RHgH} \longrightarrow \underset{\underline{\underline{11}}}{RHg\bullet} \longrightarrow \underset{\underline{\underline{12}}}{R\bullet}$$



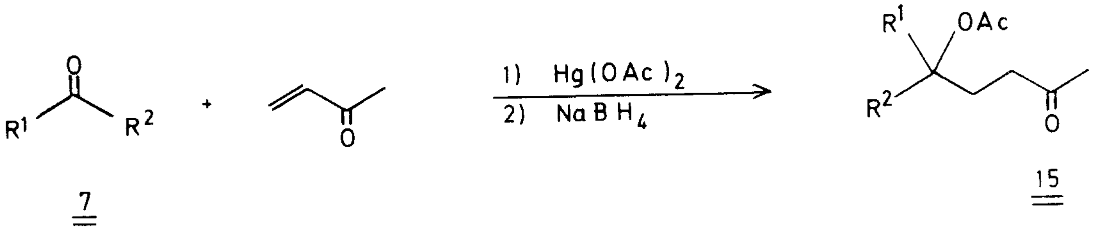
These multistep reactions can be carried out as one step syntheses[2-5] that have been applied by Kozikowski[10], Danishefsky[11], Henning[12] and Burke[13] for the synthesis of target molecules. Barluenga[14] has shown that, in some cases the yield can be increased by working in a two phase system. Grützmacher also [15] observed a similar effect by adding pyridine.

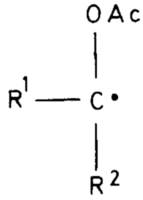
In order to maximize the chain length of the radical chain reaction, the rates between the radicals and the non-radicals have to be greater than those between the radicals themselves. To prevent side reactions, the selectivities of the radicals in the chain have to differ from each other[2]. These conditions are fulfilled if nucleophilic alkyl radicals and electron poor alkenes are used[1,2].

Alkyl groups at the carbon atom of the alkene which is attacked by the radical exert rate reducing steric effects[1,16] that have to be compensated by introducing a second electron-withdrawing substituent at the alkene[17].

A great advantage of these syntheses is that radicals react with a high chemoselectivity[2,18], so that several functional groups are tolerated without protection. Therefore radical reactions can be used in syntheses with complex molecules like carbohydrates[2,19] which show astonishingly high stereoselectivities in CC-bond forming reactions.

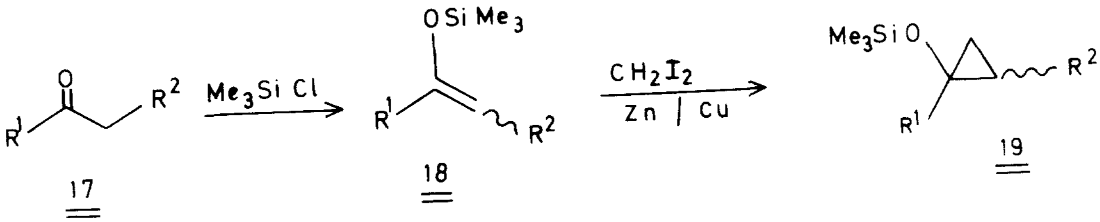
Another aspect of radicals is that they often give products of "Umpolung"[20]. For example the reaction of ketones 7 with methylvinylketone gives CC-chains with heteroatoms in the 1,4-position[5].

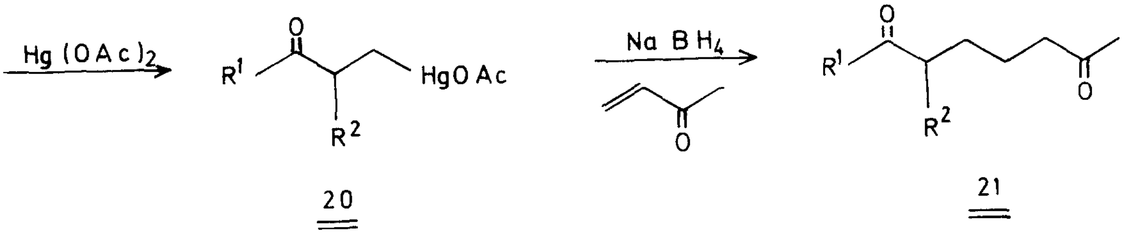



16

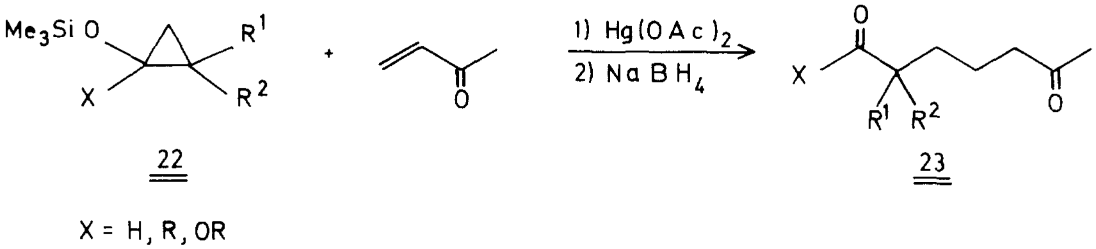
Umpolung occurs via the radical 16 which is a nucleophile[21] and attacks α,β-unsaturated ketones at the olefinic carbon atom with very high regioselectivity

In a previous communication we have shown that ketones[22] can also be used to synthesize CC-chains with heteroatoms at the 1,6 position. Thus ketones 17 give products 21 via silylation (17→18), cyclopropanation (18→19), mercuration (19→20) and radical CC-bond formation with methylvinylketone (20→21).





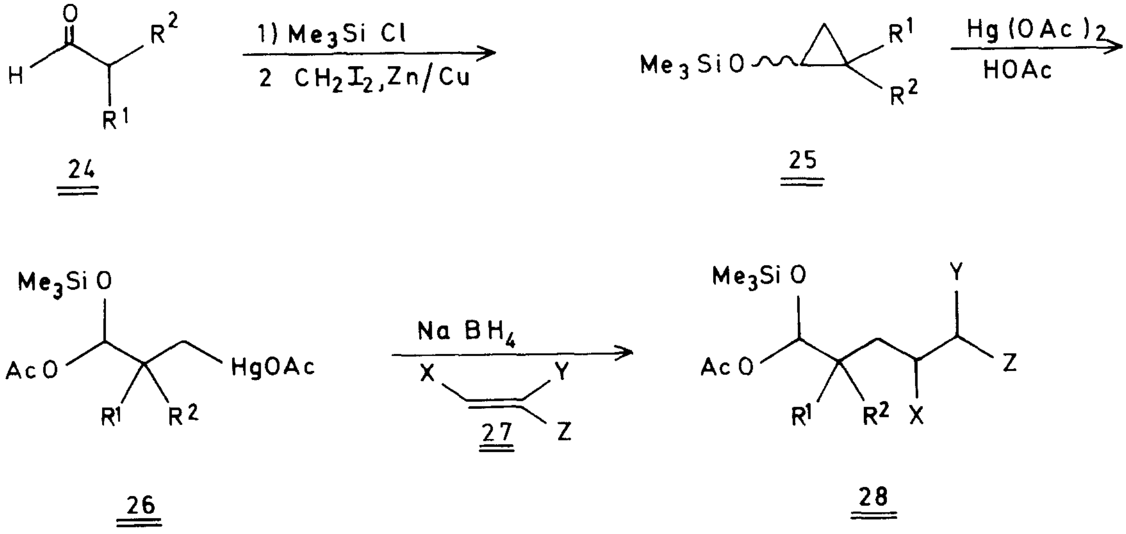
We now describe how aldehydes, ketones, and esters can be used to give CC-bond formation products via cyclopropanes 22, for instance the reaction of cyclopropane 22 with methylvinylketone leads to 23.

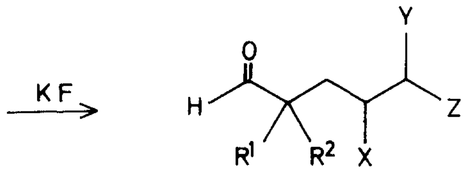


RESULTS

1) Aldehydes

Cyclopropanes 25 can be synthesized from aldehydes 24 via silylation[23] and cyclopropanation[24]. Mercuration of 25 in the presence of acetic acid gives alkylmercuric salts 26 that can be reduced by $NaBH_4$ to radicals which are trapped with alkenes to give products 28. Reaction with KF yields the aldehydes 29. Starting with cyclopropanes 25, the multistep reactions can be carried out as a one-pot synthesis (Table I).





29

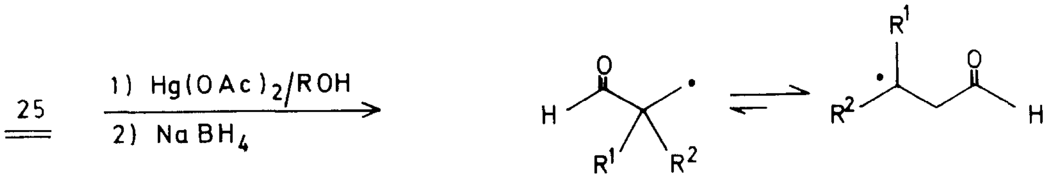
TABLE 1

Formation of products 29a-l from cyclopropanes 25

Cyclopropane			Alkene			Product	Yield
	R^1	R^2	X	Y	Z		(%)
25a	H	C_4H_9	H	H	CN	29a	60
			H	H	$COCH_3$	29b	62
			H	H	CO_2CH_3	29c	50
			H	Cl	CN	29d	65
			H	CH_3	CN	29e	60
			$CO_2C_2H_5$	H	$CO_2C_2H_5$	29f	40
25b	CH_3	CH_3	H	H	CN	29g	52
			H	H	$COCH_3$	29h	55[a]
			H	H	CO_2CH_3	29i	50
			H	Cl	CN	29j	52
			H	CH_3	CN	29k	50
			$CO_2C_2H_5$	H	$CO_2C_2H_5$	29l	30

[a] Isolated as 28h.

It is important that the mercuration is carried out in the presence of acetic acid. Using alcohols as solvent, radicals 30 are generated and rearrangement competes with the CC-bond formation reaction so that in most cases product mixtures arise[25].

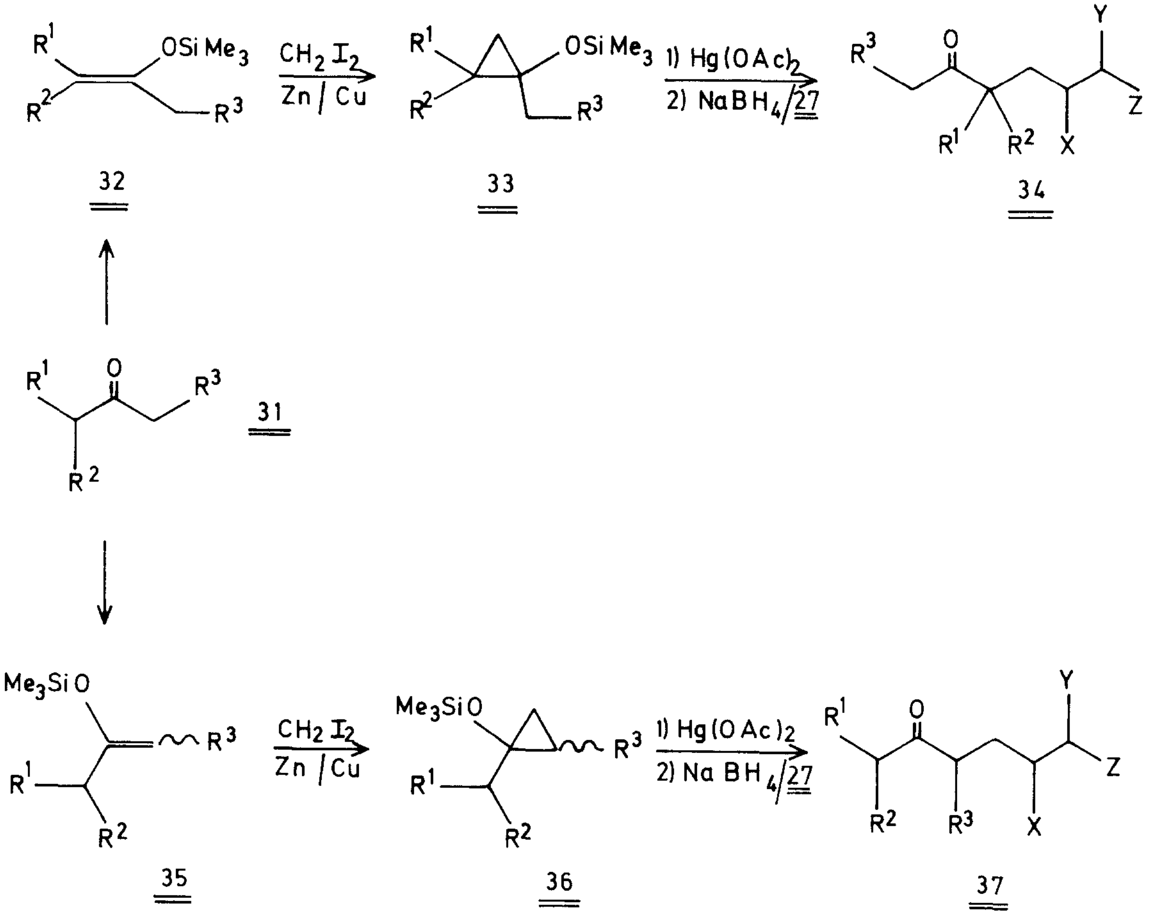


30 a

30 b

2) Ketones

With ketones 31, the regioisomers 34 and 37 can be formed if the method of House[23] is applied to synthesize the isomeric enolethers 32 and 35. These lead to cyclopropanes 33 and 36 which are mercurated and reductively coupled in a radical chain reaction with alkenes 27 (Table 2).



The mercuration of cyclopropanes 33 and 36 can be carried out in alcohols because the rearrangement of ketones 38 is slower[22,26] than the CC-bond forming reaction with the reactive alkenes 27.

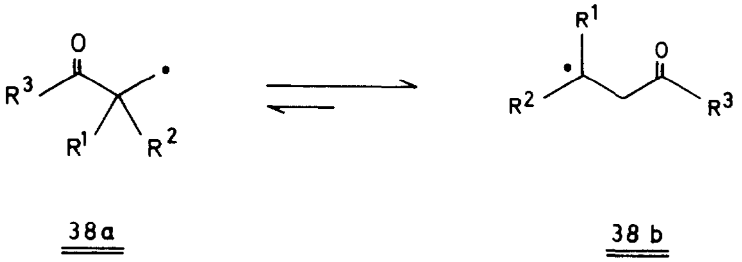


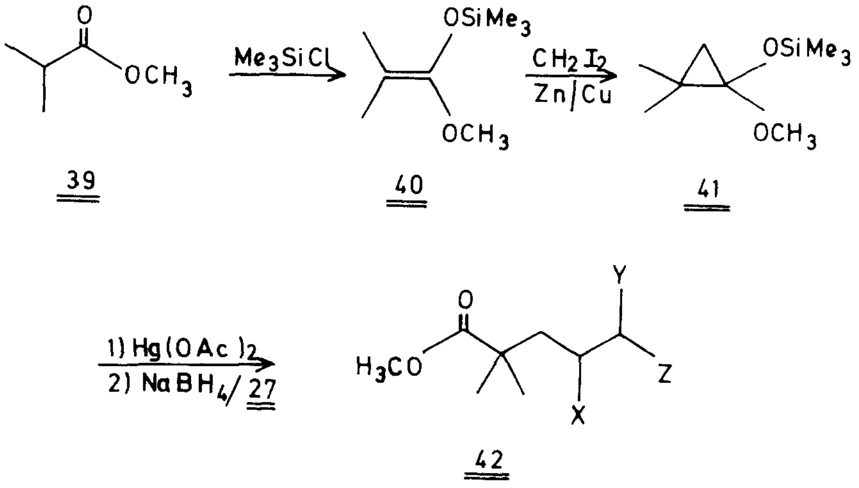
TABLE 2

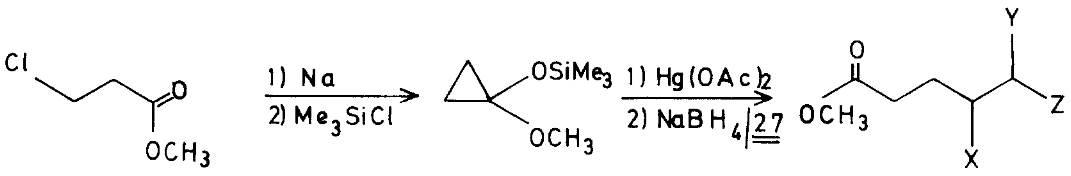
Formation of products 34a-r and 37a-r from cyclopropanes 33 and 36

Cyclopropane			Alkene				Yield (%) of Products	
R^1	R^2	R^3	X	Y	Z		34	37
C_4H_9	H	H	H	H	CN	a	70	65
			H	H	$COCH_3$	b	65	66
			H	H	CO_2CH_3	c	60	55
			H	Cl	CN	d	65	50
			H	CH_3	CN	e	40	45
			$CO_2C_2H_5$	H	$CO_2C_2H_5$	f	61	56
CH_3	CH_3	H	H	H	CN	g	55	73
			H	H	$COCH_3$	h	51	73
			H	H	CO_2CH_3	i	41	70
			H	Cl	CN	j	52	70
			H	CH_3	CN	k	40	50
			$CO_2C_2H_5$	H	$CO_2C_2H_5$	l	50	74
CH_3	$-(CH_2)_3-$		H	H	CN	m	35	65
			H	H	$COCH_3$	n	30	65
			H	H	CO_2CH_3	o	30	60
			H	Cl	CN	p	32	50
			H	CH_3	CN	q	25	40
			$CO_2C_2H_5$	H	$CO_2C_2H_5$	r	30	52

3) Esters

Starting from esters, the cyclopropanes are synthesized either via silylation (39→40) and cyclopropanation (40→41) or from the β-halide via cyclization (43→44)





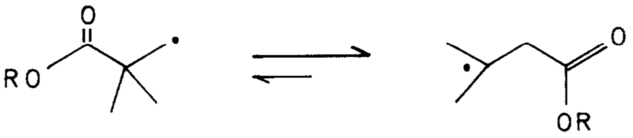
43 44 45

TABLE 3

Formation of products 42 and 45 from cyclopropanes 41 and 44

Cyclopropane	Alkene X	Alkene Y	Alkene Z	Product	Yield (%)
41	H	H	CN	42a	52
	H	H	CO_2CH_3	42c	47
44	H	H	CN	45a	70
	H	H	$COCH_3$	45b	72
	H	CH_3	CN	45e	45
	$CO_2C_2H_5$	H	$CO_2C_2H_5$	45f	50

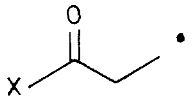
Solvomercuration of the cyclopropanes 41 or 44 and reductive coupling with alkenes 27 give products 42 or 45 (Table 3). As in the syntheses starting from ketones, the rearrangement of radical 46 is slower[27] than the intermolecular reaction with alkenes.



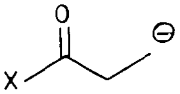
46a 46b

CONCLUSION

Aldehydes, ketones and esters are suitable precursors for radicals 47. The nucleophilicity makes these radicals to analogs of homoenolate anions 48[28]. Whereas anions 48 are mainly used in reactions with carbon-heteroatom double bonds[28] radicals 47 attack carbon-carbon multiple bonds. Both anions and radicals give products of "Umpolung" of the reactivity.



47



48

Since anions 48 yield predominantly CC-chains with heteroatoms in 1,4-position and radicals 47 form CC-chains with heteroatoms in 1,6-position, the radical chemistry is found to complement the ionic chemistry.

Acknowledgement: This work was supported by the Fonds der Chemischen Industrie and the Otto Röhm Gedächtnisstiftung.

EXPERIMENTAL

The structures of products already described in the literature were confirmed by comparing their IR, NMR and mass spectra with the data reported. ^{1}H-NMR spectra were obtained with the Bruker WM 300 spectrometer. Chemical shifts are given in ppm downfield from TMS as internal standard.IR spectra were recorded on Perkin-Elmer 125 and Beckman Accu Lab 4. Reaction solvents were dried according to standard procedures.

Syntheses with aldehydes: Preparation of 29a-1: A solution of cyclopropanes 25a or 25b (3.0 mmol, 10 mL acetic acid), synthesized via literature procedure[24], and mercuric acetate (956 mg, 3.0 mmol) was stirred at room temperature for 1 h. The acetic acid was then evaporated, the residue dissolved in methylene chloride (10 mL) and cooled to 0°C. Alkene 27 (10 mmol) and $NaBH_4$ (250 mg, 6.6 mmol) were added under cooling in an icebath. After 20 min the reaction mixture was concentrated, dissolved in acetone (10 mL) and treated 1 h with a saturated aqueous KF solution (1 mL). Acetone was destilled off and the residue was extracted three times with ether (10 mL). The ether layer was dried over $MgSO_4$, concentrated, chromatographed and destilled in a Kugelrohr. The products 29a-l were formed in 30-65% yields (Table 1).

29a: IR (film) 1720 (CO), 2250 cm^{-1} (CN); ^{1}H-NMR δ0.89 (t, 3H, J=6.5); 1.10-1.90 (m, 10H), 2.10-2.50 (m, 3H), 9.63 (d, 1H, J=2.5), bp (Kugelrohr) 75-80°C (0.07 mm Hg) Anal. Calcd for $C_{10}H_{17}NO$ (167.3): C,71.81; H,10.24; N,8.37. Found: C,71.68; H,10.26; N,8.16.

29b: IR (film) 1710 cm^{-1} (CO); ^{1}H-NMR δ 0.88 (t, 3H, J=7.0), 1.07-1.90 (m, 10H), 2.13 (s, 3H), 2.20-2.63 (m, 3H), 9.63 (d, 1H, J=2.5); bp (Kugelrohr) 70-75°C (0.05 mm Hg). Anal. Calcd for $C_{11}H_{20}O_2$ (184.3): C,71.70; H,10.94. Found: C,71.52; H,11.04.

29c: IR (film) 1720 cm^{-1} (CO); ^{1}H-NMR δ 0.87 (t, 3H, J=7.0), 1.10-1.19 (m, 10H), 2.09-2.56 (m, 3H), 3.67 (s, 3H), 9.58 (d, 1H), J=2.5); bp (Kugelrohr) 68-70°C (0.05 mm Hg). Anal. Calcd for $C_{11}H_{20}O_3$ (200.3): C,65.97; H,10.07. Found:C,65.72; H,10.11.

29d: IR (film) 1720 (CO), 2250 cm^{-1} (CN); ^{1}H-NMR δ 0.91 (t, 3H, J=7.0), 1.15-2.01 (m, 10H), 2.21-2.50 (m, 1H), 4.53 (t, 1H, J=7.0), 9.63 (d, 1H, J=2.5); bp (Kugelrohr) 75-80°C (0.06 mm Hg). Anal. Calcd for $C_{10}H_{16}ClNO$ (201.7): C,59.55; H,8.00; N,6.94. Found: C,59.76; H,7.74; N,6.76.

29e: IR (film) 1705 (CO), 2240 cm^{-1} (CN); ^{1}H-NMR δ 0.90 (t, 3H, J=7.0), 1.30 (d, 3H, J=7.0), 1.18-1.95 (m, 10H), 2.15-2.83 (m, 2H), 9.57, 9.59 (2d, 1H, J=2.5). Anal. Calcd for $C_{11}H_{19}NO$ (181.3): C,72.88; H,10.56; N,7.73. Found: C,72.79; H,10.60; N,7.47.

29f: IR (film) 1715 (CO), 1740 cm^{-1} (CN); ^{1}H-NMR δ 0.91 (t, 3H, J=7.0), 1.24, 1.26 (2t, 6H, J=7.0), 1.12-1.93 (m, 8H), 2.11-2.98 (m, 4H), 4.14, 4.16 (2q, 4H, J=7.0), 9.61, 9.65 (2d, 1H, J=2.5); bp (Kugelrohr) 105-110°C (0.05 mm Hg). Anal Calcd for $C_{15}H_{26}O_3$ (286.4): C,62.91; H,9.15. Found: C,62.68; H,9.09.

29g: IR (film) 1715 (CO), 2240 cm^{-1} (CN); ^{1}H-NMR δ 1.08 (s, 6H), 1.42-1.76 (m, 4H), 2.20-2.46 (m, 2H), 9.48 (s, 1H); bp (Kugelrohr) 115-120°C (13 mm Hg).

29i: IR (film) 1720 cm^{-1} (CO); ^{1}H-NMR δ 1.07 (s, 6H), 1.38-1.80 (m, 4H), 2.32 (m, 2H), 3.67 (s, 3H), 9.48 (s, 1H); bp (Kugelrohr) 115-120°C (13 mm Hg).

29j: IR (film) 1720 (CO), 2240 cm^{-1} (CN); ^{1}H-NMR δ 1.11 (s, 6H), 1.60-1.86 (m, 4H), 4.49 (t, 1H, J=7.0), 9.50 (s, 1H); bp (Kugelrohr) 120-125°C (13 mm Hg).

29k: IR (film) 1720 (CO), 2240 cm^{-1} (CN); ^{1}H-NMR δ 1.10 (s, 6H), 1.30 (d, 3H, J=7.0), 1.42-1.90 (m, 4H), 2.30-2.62 (m, 1H), 9.50 (s, 1H); bp (Kugelrohr) 123-125°C (14 mm Hg).

29l: IR (film) 1725 cm^{-1}; ^{1}H-NMR δ 1.10-1.80 (m, 14H), 2.10-2.70 (m, 3H), 4.18, 4.20 (2q, 4H, J=7.0), 9.49 (s, 1H); bp (Kugelrohr) 150-155°C (13 mm Hg).

28h: Because aldehyde **29h** was too unstable, the protected aldehyde **28h** was isolated by workup before treatment with KF. IR (film) 840, 870, 1240 (C-Si), 1905 (CO), 1735 cm^{-1}; ^{1}H-NMR δ 0.16 (s, 9H), 0.89 (s, 6H), 1.04-1.76 (m, 4H), 2.08 (s, 3H), 2.16 (s, 3H), 2.42 (t, 2H, J=7.0), 5.75 (s, 1H); bp (Kugelrohr) 68-70°C (0.06 mm Hg). Anal. Calcd for $C_{14}H_{28}O_4$ Si (288.5): C,58.29; H,9.78. Found: C,57.97; H,9.71.

Syntheses with ketones: Preparation of 34a-r and 37a-r: A solution of cyclopropanes **33** or **36** (3.0 mmol, 10 mL aceton:water = 20:1), synthesized via literature procedure[23,24], and mercuric acetate (956 mg, 3.0 mmol) was stirred at room temperature for 1 h. The solvent was then evaporated, the residue dissolved in methylene chloride (10 mL) and cooled to 0°C. Alkene **27** (10 mmol) and $NaBH_4$ (250 mg, 6.6 mmol) suspend in water (1-2 mL) were added. After 20 min the reaction mixture was filtered over $MgSO_4$, concentrated and destilled. The products **34a-r** and **37a-r** were isolated in 25-76% yields (Table 2).

34a: IR (film) 1705 (CO), 2230 cm^{-1} (CN); ^{1}H-NMR δ 0.90 (t, 3H, J=7.0), 1.06-1.84 (m, 10H), 2.14 (s, 3H), 2.22-2.62 (m, 3H),bp (Kugelrohr) 83-85°C (0.05 mm Hg). Anal. Calcd for $C_{11}H_{19}NO$ (181.3): C,72.88; H,10.56; N,7.73. Found: C,72.72; H,10.65; N,7.76.

34b: IR (film) 1705 cm^{-1} (CO); ^{1}H-NMR δ 0.88 (t, 3H), 1.06-1.76 (m, 10H), 2.12 (s, 6H), 2.26-2.40 (m, 3H); bp (Kugelrohr) 82-85°C (0.06 mm Hg). Anal. Calcd for $C_{12}H_{22}O_2$ (198.3): C,72.68; H,11.18. Found: C,72.45; H,11.32.

34c: IR (film) 1705 (CO), 1735 cm^{-1} (CO); ^{1}H-NMR δ 0.90 (t, 3H, J=7.0), 1.15-1.80 (m, 10H), 2.10 (s, 3H), 2.17-2.65 (m, 3H), 3.63 (s, 3H); bp (Kugelrohr) 78-80°C (0.05 mm Hg). Anal. Calcd for $C_{12}H_{22}O_3$ (214.3): C,67.26; H,10.35. Found: C,67.11; H,10.48.

34d: IR (film) 1705 (CO), 2225 cm^{-1} (CN); ^{1}H-NMR δ 0.90 (t, 3H, J=7.0), 1.11-2.08 (m, 10H), 2.15 (s, 3H), 2.29-2.55 (m, 1H), 4.46, 4.48 (2t, 1H, J=7.0); bp (Kugelrohr) 94-96°C (0.06 mm Hg). Anal. Calcd for $C_{11}H_{18}ClNO$ (215.7): C,61.25; H,8.41; N,6.49. Found: C,61.31; H,8.48; N,6.57.

34e: IR (film) 1705 (CO), 2230 cm^{-1} (CN); ^{1}H-NMR δ 0.89 (t, 3H, J=7.0), 1.30 (d, 3H, J=7.0), 1.08-1.88 (m, 10H), 2.16 (s, 3H), 2.28-2.78 (m, 2H); bp (Kugelrohr) 87-90°C (0.06 mm Hg). Anal. Calcd for $C_{12}H_{21}NO$ (193.3): C,73.80; H,10.84; N,7.17. Found: C,73.84; H,10.90; N,7.34.

34f: IR (film) 1715 cm^{-1} (CO); ^{1}H-NMR δ 0.88 (t, 3H, J=7.0), 1.22, 1.24 (2t, 6H, J=7.0), 1.04-1.72 (m, 8H), 2.16, 2.18 (2s, 3H), 2.26-2.92 (m, 4H), 4.14, 4.16 (2q, 4H, J=7.0); bp (Kugelrohr) 97-100°C (0.06 mm Hg). Anal. Calcd for $C_{16}H_{28}O_5$ (300.4): C, 63.37; H,9.40. Found: C,63.73; H,9.44.

34g: IR (film) 1690 (CO), 2225 cm^{-1} (CN); ^{1}H-NMR δ 1.15 (s, 6H), 1.38-1.80 (m, 4H), 2.14 (s, 3H), 2.35 (t, 2H, J=6.5); bp (Kugelrohr) 57-60°C (0.05 mm Hg). Anal.Calcd for $C_9H_{15}NO$ (153.2): C,70.55; H,9.87; N,9.14. Found: C,70.25; H,9.88; N,9.03.

34h: IR (film) 1700 cm^{-1} (CO); ^{1}H-NMR δ 1.12 (s, 6H), 1.30-1.67 (m, 4H), 2.14 (s, 6H), 2.42 (m, 2H); bp (Kugelrohr) 57-60°C (0.05 mm Hg). Anal. Calcd for $C_{10}H_{18}O_2$ (170.3): C,70.55; H,10.66. Found: C,70.35; H,10.72.

34i: IR (film) 1700 (CO), 1735 cm^{-1} (CO); ^{1}H-NMR δ 1.11 (s, 6H), 1.32-1.68 (m, 4H), 2.12 (s, 3H), 2.30 (m, 2H), 3.66 (s, 3H); bp (Kugelrohr) 63-65°C (0.07 mm Hg). Anal. Calcd for $C_{10}H_{18}O_3$ (186.3): C,64.49; H,9.74. Found: C,64.25; H,9.75.

34j: IR (film) 1690 (CO), 2200 cm^{-1} (CN); ^{1}H-NMR δ 1.17 (s, 6H), 1.60-2.08 (m, 4H), 2.15 (s, 3H), 4.48 (t, 1H, J=7.0); bp (Kugelrohr) 73-76°C (0.08 mm Hg). Anal. Calcd for $C_9H_{14}ClNO$ (187.7): C,57.60; H,7.52; N,7.46. Found: C,57.27; H,7.49; N,7.63.

34k: IR (film) 1690 (CO), 2230 cm^{-1} (CN); ^{1}H-NMR δ 1.15 (s, 6H), 1.32 (d, 3H, J=7.0), 1.23-1.83 (m, 4H), 2.14 (s, 3H), 2.20-2.70 (m, 1H); bp (Kugelrohr) 64-66°C (0.06 mm Hg). Anal. Calcd for $C_{10}H_{17}NO$ (167.3): C,71.81; H,10.25, N,8.37. Found: C,71.45; H,10.23; N,8.06.

34l: IR (film) 1700 (CO), 1730 cm^{-1} (CO); ^{1}H-NMR δ 1.00-1.38 (m, 12H), 1.48-1.76 (m, 2H), 2.14 (s, 3H), 2.29-2.92 (m, 3H), 4.12, 4.14 (2q, 4H, J=7.0); bp (Kugelrohr) 103-105°C (0.07 mm Hg). Anal Calcd for $C_{14}H_{24}O_5$ (272.3): C,61.74; H,8.88. Found: C,61.64; H,8.97.

34m: IR (film) 1700 (CO), 2250 cm^{-1} (CN); ^{1}H-NMR δ 1.09 (s, 3H), 1.20-1.94 (m, 10H), 2.13-2.54 (m, 4H); bp (Kugelrohr) 98-100°C (0.05 mm Hg). Anal. Calcd for $C_{11}H_{17}NO$ (179.3): C,73.70; H,9.56; N,7.81. Found: C,73.53; H,9.54; N,7.62.

34n: IR (film) 1700 cm^{-1} (CO); ^{1}H-NMR δ 1.06 (s, 3H), 1.15-1.90 (m, 10H), 2.12 (s, 3H), 2.20-2.65 (m, 4H); bp (Kugelrohr) 77-80°C (0.05 mm Hg). Anal. Calcd for $C_{12}H_{20}O_2$ (196.3): C,73.43; H,10.27. Found: C,73.18; H,10.49.

34o: IR (film) 1705 (CO), 1740 cm^{-1} (CO); ^{1}H-NMR δ 1.06 (s, 3H), 1.20-1.94 (m, 10H), 2.12-2.50 (m, 4H), 3.65 (s, 3H); bp (Kugelrohr) 88-91°C (0.05 mm Hg). Anal. Calcd for $C_{12}H_{20}O_3$ (212.3): C,67.89; H,9.50. Found: C,67.67; H,9.57.

34p: IR (film) 1705 (CO), 2250 cm^{-1} (CN); ^{1}H-NMR δ 1.13 (s, 3H), 1.54-2.11 (m, 1oH), 2.22-2.56 (m, 2H), 4.50 (t, 1H, J=6.5); bp (Kugelrohr) 82-85°C (0.05 mm Hg). Anal. Calcd for $C_{11}H_{16}ClNO$ (213.7): C,61.82; H,7.55; N,6.55. Found: C,61.83; H,7.48; N,6.55.

34q: IR (film) 1705 (CO), 2245 cm^{-1} (CN); ^{1}H-NMR δ 1.09 (s, 3H), 1.32 (d, 3H, J=7.0), 1.44-1.94 (m, 10H), 2.16-2.74 (m, 3H); bp (Kugelrohr) 87-90°C (0.06 mm Hg). Anal. Calcd for $C_{12}H_{19}NO$ (193.3): C,74.57; H,9.91; N,7.25. Found: C,74.38; H,9.88, N,7.10.

34r: IR (film) 1700 (CO), 1740 cm$_{-1}$ (CO); ^{1}H-NMR δ 1.09 (s, 3H), 1.22 (t, 6H, J=7.0), 1.31-1.94 (m, 8H), 2.12-2.70 (m, 5H), 4.12, 4.14 (2q, 4H, J=7.0); bp (Kugelrohr) 116-119°C (0.07 mm Hg). Anal. Calcd for $C_{16}H_{26}O_5$ (298.4): C,64.41; H,8.78. Found: C,64.10; H,8.72.

37a: IR (film) 1705 (CO), 2230 cm^{-1} (CN); ^{1}H-NMR δ 0.89 (t, 3H, J=7.0), 1.09-1.93 (m, 10H), 2.23-2.72 (m, 6H); bp (Kugelrohr) 82-85°C (0.05 mm Hg). Anal. Calcd for $C_{11}H_{19}NO$ (181.3): C,72.88; H,10.56; N,7.23. Found: C,72.77; H,10.45; N,7.20.

37b: IR (film) 1705 cm^{-1} (CO); ^{1}H-NMR δ 0.89 (t, 3H, J=7.0), 1.08-1.77 (m, 10H), 2.15 (s, 3H), 2.25-2.57 (m, 6H); bp (Kugelrohr) 80-83°C (0.05 mm Hg). Anal. Calcd for $C_{12}H_{22}O_2$(198.3): C,72.68; H,11.18. Found: C,72.81; H,11.19.

37c: IR (film) 1705 (CO), 1735 cm^{-1} (CO); ^{1}H-NMR δ 0.90 (t, 3H, J=7.0), 1.10-1.80 (m, 10H), 2.17-2.55 (m, 6H), 3.67 (s, 3H); bp (Kugelrohr) 88-90°C (0.05 mm Hg). Anal. Calcd for $C_{12}H_{22}O_3$ (214.3): C,67.26; H,10.35. Found: C,67.25; H,10.39.

37d: IR (film) 1705 (CO), 2230 cm^{-1} (CN); ^{1}H-NMR δ 0.90 (t, 3H, J=7.0), 109-1.92 (m, 10H), 2,42, 2.52 (2t, 4H, J=7.0), 4.50 (t, 1H, J=7.0); bp (Kugelrohr) 85-88°C (0.06 mm Hg). Anal. Calcd for $C_{11}H_{18}ClNO$ (215.7): C,61.25; H,8.41; N,6.41. Found: C,69.90; H,8.41; N,6.29.

37e: IR (film) 1705 (CO), 2235 cm^{-1} (CN); ^{1}H-NMR δ 0.89 (t, 3H, J=7.0), 1.31 (d, 3H, J=7.0), 1.10-1.95 (m, 10H), 2.28-2.75 (m, 5H); bp (Kugelrohr) (0.07 mm Hg). Anal. Calcd for $C_{12}H_{21}NO$ (195.3): C,73.80; H,10.84; N,7.17. Found: C,73.63; H,10.88; N,6.88.

37f: IR (film) 1705 (CO), 1735 cm^{-1} (CO); ^{1}H-NMR δ 0.89 (t, 3H, J=7.0), 1.24, 1.26 (2t, 6H, J=7.0), 1.08-1.98 (m, 8H), 2.20-2.94 (m, 7H), 4.14, 4.16 (2q, 4H J=7.0); bp (Kugelrohr) 115-119°C (0.05 mm Hg). Anal. Calcd for $C_{16}H_{28}O_5$ (300.4): C,63.97; H,9.40. Found: C,63.71; H,9.37.

37g: IR (film) 1705 (CO), 2240 cm^{-1} (CN); ^{1}H-NMR δ 1.08 (d, 6H, J=7.0), 1.50-1.88 (m 4H), 2.18-2.80 (m, 5H); bp (Kugelrohr) 63-65°C (0.05 mm Hg). Anal. Calcd for $C_9H_{15}NO$ (163.2): C,70.55; H,9.87; N,9.14. Found: C,70.38; H,9.88; N,8.96.

37h: IR (film) 1705 cm^{-1} (CO); ^{1}H-NMR δ 1.13 (d, 6H, J=7.0), 1.39-1.80 (m, 4H), 2.13 (s, 3H), 2.25-2.90 (m, 5H); bp (Kugelrohr) 67-70°C (0.05 mm Hg). Anal. Calcd for $C_{10}H_{18}O_2$ (170.3): C,70.55; H,10.66. Found: C,70.31; H,10.94.

37i: IR (film) 1710 (CO), 1740 cm^{-1} (CO); ^{1}H-NMR δ 1.08 (d, 6H, J=7.0), 1.42-1.80 (m, 4H), 2.18-2.76 (m, 5H), 3.66 (s, 3H); bp (Kugelrohr) 61-64 °C (0.07 mm Hg). Anal. Calcd for $C_{10}H_{18}O_3$ (186.3): C,64.49; H,9.74. Found: C,64.24; H,9.83.

37j: IR (film) 1710 (CO), 2240 cm^{-1} (CN); ^{1}H-NMR δ 1.12 (d, 6H, J=7.0), 1.60-2.21 (m, 4H), 2.58 (t, 2H, J=7.0), 2.64 (sept 1H, J=7.0), 4.53 (t, 1H, J=7.0); bp (Kugelrohr) 68-70 °C (0.07 mm Hg). Anal. Calcd for $C_9H_{14}ClNO$ (187.8): C,57.60; H,7.52; N,7.46. Found: C,57.84; H,7.55; N,7.33.

37k: IR (film) 1710 (CO), 2240 cm^{-1} (CN); ^{1}H-NMR δ 1.10 (d, 6H, J=7.0), 1.33 (d, 3H, J=7.=), 1.44-1.94 (m, 4H), 2.38-2.76 (m, 4H); bp (Kugelrohr) 65-69 °C (0.06 mm Hg). Anal. Calcd for $C_{10}H_{17}NO$ (167.3): C,71.81; H,10.25; N,8.37. Found: C,71.54; H,10.29; N,8.40.

37l: IR (film) 1710 (CO), 1735 cm^{-1} (CO); ^{1}H-NMR δ 1.09 (d, 6H, J=7.0), 1.62-2.00 (m, 2H), 2.44-2.94 (m, 6H), 4.16, 4.18 (2q, 4H, J=7.0); bp (Kugelrohr) 90-93 °C (0.06 mm Hg). Anal. Calcd for $C_{14}H_{24}O_5$ (272.3): C,61.74; H,8.88. Found: C,61.65; H,8.93.

37m: IR (film) 1705 (CO), 2235 cm^{-1}(CN); ^{1}H-NMR δ 0.99, 1.09 (2d, 3H, J=6.5), 1.16-1.94 (m, 10H), 2.14-2.60 (m, 4H); bp (Kugelrohr) 92-95 °C (0.06 mm Hg). Anal. Calcd for $C_{11}H_{17}NO$ (179.3): C,73.70; H,9.56; N,7.81. Found: C,73,47; H,9.48; N,7.67.

37n: IR (film) 1705 cm^{-1} (CO); ^{1}H-NMR δ 0.95, 1.05 (2d, 3H, J=6.5), 1.17-1.87 (m, 10H), 2.11 (s, 3H), 2.20-2.75 (m, 4H); bp (Kugelrohr) 80-83 °C (0.05 mm Hg). Anal. Calcd for $C_{12}H_{20}O_2$ (196.3): C,73.43; H,10.27. Found: C,73.26; H,10.30.

37o: IR (film) 1705 (CO), 1735 cm^{-1} (CO); ^{1}H-NMR δ 1.01, 1.11 (2d, 3H, J=6.5), 1.22-1.98 (m, 10H), 2.18-2.66 (m, 4H), 3.66 (s, 3H); bp (Kugelrohr) 100-103 °C (0.06 mm Hg). Anal. Calcd for $C_{12}H_{20}O_3$ (212.3): C,67.89; H,9.50. Found: C,67.48; H,9.40.

37p: IR (film) 1705 (CO), 2230cm^{-1} (CN); ^{1}H-NMR δ 0.97, 0.99, 1.07, 1.09 (4d, 3H, J=6.5), 1.32-2.05 (m, 10H), 2.22-2.64 (m, 2H), 4.45, 4.57 (2t, 1H, J=6.5); bp (Kugelrohr) 97-100 °C (0.05 mm Hg). Anal. Calcd for $C_{11}H_{16}ClNO$ (213.7): C,61.82; H,7.55; N,6.55. Found: C,61.40; H,7.49; N,6.42.

37q: IR (film) 1705 (CO), 2240 cm^{-1} (CN); ^{1}H-NMR δ 0.98, 1.00, 1.08, 1.10 (4d, 3H, J=6.5), 1.32, 1.33 (2t, 3H, J=7.0), 1.20-2.78 (m, 3H); bp (Kugelrohr) 95-99 °C (0.07 mm Hg). Anal. Calcd for $C_{12}H_{19}NO$ (193.3): C,74.57; H,9.91; N,7.25. Found: C,74.26; H,9.97; N,7.10.

37r: IR (film) 1705 (CO), 1735 cm^{-1} (CO); ^{1}H-NMR δ 0.98, 0.99, 1.07, 1.08 (4d, 3H, J=6.5), 1.22 (t, 6H, J=7.0), 1.40-3.94 (m, 13H), 4.11, 4.13 (2q, 4H, J=7.0); bp (Kugelrohr) 115-119 °C (0.05 mm Hg). Anal. Calcd for $C_{16}H_{26}O_5$ (298.4): C,64.41; H,8.78. Found: C,64.35; H,8.64.

Syntheses with esters: Preparation of 42 and 45: A solution of cyclopropanes 41 or 44 (3.0 mmol, 10 mL ethanol), synthesized via literature procedure^{29}, and mercuric acetate (956 mg, 3.0 mmol) was stirred at room temperature for 30 min. The alcohol was then evaporated, the residue dissolved in methylene chloride (10 mL) and cooled to 0 °C. Alkene 27 (10 mmol) and $NaBH_4$ (250 mg, 6.6 mmol) suspended in water (1-2 mL) were added. After 15 min the reaction mixture was filtered over $MgSO_4$, concentrated and destilled. The products 42 and 44 were formed in 45-72% yields (Table 3).

REFERENCES

1. B. Giese, Angew. Chem. 95 (1983) 771; Angew. Chem. Int. Ed. Engl. 22 (1983) 753.
2. B. Giese, Angew. Chem. 97 (1985) 555.
3. B. Giese, G. Kretzschmar, Angew. Chem. 93 (1981) 1015; Angew. Chem. Int. Ed. Engl. 20 (1981) 965; B. Giese, K. Heuck, Chem. Ber. 112 (1979) 3759; Tetrahedron Lett. 21 (1980) 1829; B. Giese, U. Lüning, Synthesis 1982, 735.
4. B. Giese, W. Zwick, Chem. Ber. 112 (1979) 3766; ibid. 115 (1982) 2526; ibid. 116 (1983) 1264.
5. B. Giese, U. Erfort, Angew. Chem. 94 (1982) 133; Angew. Chem. Int. Ed. Engl. 21 (1982) 130; Chem. Ber. 116 (1983) 1240.
6. B. Giese, J. Meister, Chem. Ber. 110 (1977) 2558.
7. G.M. Whitesides, J. San Filipo, J. Am. Chem. Soc. 96 (1974) 870; R.P. Quirk, R.E. Lea, J. Am. Chem. Soc. 98 (1976) 2558; M. Devaud, J. Organomet. Chem. 220 (1982)C 27; G.A. Russell, D. Guo, Tetrahedron Lett. 25 (1984) 5239.
8. J. Casanova, H.R. Rogers, J. Am. Chem. Soc. 96 (1974) 1342.
9. H.L. Roberts in H.J. Emeleus, A.G. Sharpe: "Advances in Inorganic Chemistry and Radiochemistry", Vol. 11, Academic Press, New York 1968, p. 309.
10. A.P. Kozikowski, T.R. Nieduzak, J. Scripko, Organometallics 1 (1982) 675.
11. S. Danishefsky, S. Chackalamannil, B.J. Uang, J. Org. Chem. 47 (1982) 2231.
12. R. Henning, H. Urbach, Tetrahedron Lett. 24 (1983) 5343.
13. S.D. Burke, W.B. Fobare, D.M. Arminsteadt, J. Org. Chem. 47 (1982) 3348.
14. J. Barluenga, J. Lopez-Prado, P.J. Campos, G. Asensio, Tetrahedron 39 (1983) 2863.
15. H.F. Grützmacher, R. Schmuck, Chem. Ber. 113 (1980) 1192.
16. B.Giese, S. Lachhein, Angew. Chem. 93 (1981) 1016; Angew. Chem. Int. Ed.Engl. 20 (1981) 967.
17. B. Giese, H. Harnich, S. Lachhein, Synthesis 1983, 733.
18. G.E. Keck, J.B. Yates, J. Am. Chem. Soc. 104 (1982) 5829; D.J. Hart Science 223 (1984) 883.
19. B. Giese, J. Dupuis, Angew. Chem. 95 (1983) 633; Angew. Chem. Int. Ed. Engl. 22 (1983) 622; B. Giese, K. Gröninger, Tetrahedron Lett. 25 (1984) 2743.
20. D. Seebach, Angew. Chem. 91 (1979) 259; Angew. Chem. Int. Ed. Engl. 18 (1979) 239.
21. B. Giese, R. Engelbrecht, U. Erfort, Chem. Ber. 118 (1985) 1289.
22. B. Giese, U. Erfort, Angew. Chem. 94 (1982) 133; Angew. Chem. Int. Ed. Engl. 21 (1982) 133.
23. H.O. House, L.J. Czuba, H.D.Olmstead, J. Org. Chem. 34 (1969) 2324.
24. G.M. Rubottom, M.J. Lopez, J. Org. Chem. 38 (1973) 2097; R. Le Goaller, J.L. Pierre, Bull. Soc. Chim. Fr. 1973, 1531; S. Murai, Y. Kuroki, K. Hasegawa, S. Tsutsumi, J. Org. Chem. 38 (1973) 4354.
25. B. Giese, H. Horler, Tetrahedron Lett. 24 (1983) 3221.
26. D.A. Lindsay, J. Lusztyk, K.U. Ingold, J. Am. Chem. Soc. 106 (1984) 7087.
27. S. Wollowitz, J. Halpern, J.Am. Chem. Soc. 106 (1984) 8319.
28. D. Hoppe, Angew. Chem. 96 (1984) 930; Angew. Chem. Int. Ed. Engl. 23 (1983) 932
29. G. Rousseau, N. Slougui, Tetrahedron Lett. 23 (1983) 1251; K. Rühlmann, F. Raddatz, T. Kiriakidis, Z. Chemie 1970, 194.