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Cyclopropenes, Author Index, Compound Index

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METHODS OF ORGANIC CHEMISTRY

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GEORG THIEME VERLAG STUTTGART · NEW YORK

VOLUME E 17d

CARBOCYCLIC THREE- AND FOUR-MEMBERED RING COMPOUNDS

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Preface

Methods of Organic Chemistry – or synonymously Houben-Weyl – would be severely incomplete in this decade without the coverage of small ring chemistry. The first, and only, Houben-Weyl volume on Carbocyclic Three- and Four-membered Ring Compounds was published 25 years ago. Until that time small ring chemistry was, in the main, considered a domain for mechanistic and physical organic investigations, although many of the basic preparative methods had already been developed and the majority of important transformations thoroughly studied and reasonably well understood. Nevertheless, the notion, which started to evolve slowly in the sixties, of small ring compounds being useful and, frequently, uniquely applicable building blocks for other carbocyclic and also acyclic organic skeletons, has only since fully matured.

Quite a number of cyclopropane and cyclobutane derivatives have gained importance in their own right. For instance, the cyclopropyl group has turned out to be an essential feature in natural and non-natural products with insecticidal, cytostatic, various plant physiological, as well as antiinfective, activities and has, therefore, entered the realm of industrially applied chemistry. A recent survey listed 191 pharmaceutically important compounds containing an aminocyclopropane substructure, the best known example being the widely used broad-spectrum antibiotic Ciprofloxacin.

Yet the discovery of new types of natural small ring compounds continues. For example, a few years ago an antibiotic natural product with an unusual fatty acid side chain containing four adjacent cyclopropyl groups was described, and more recently, a similar compound with five adjacent, and a total of six, cyclopropyl groups has been reported. The vast progress in the development of stereoselective synthetic methodology (see Houben-Weyl Volume E21) has also brought about new methods for stereoselective cyclopropanations, and this has gone hand in hand with efforts towards enantioselective total syntheses of cyclopropyl-group-containing natural and non-natural products. So far these developments have only scratched the surface, as most of these methods are still hampered by severe constraints, and so the race goes on.

In view of this progress, it appeared to be time to publish an up-to-date comprehensive treatment of the methods of preparation and transformation of carbocyclic three- and four-membered-ring compounds. Certainly, the access to cyclopropane derivatives via carbene additions to alkenes, which represents one of the most general methods, has been covered – albeit from a different perspective – in the Houben-Weyl volume on Carbenes (E19b), and cross-references are frequently made to Houben-Weyl E19b in the corresponding sections of this volume. Yet this earlier volume cannot even be considered to be a comprehensive summary of the methods for the synthesis of cyclopropanes, let alone of the preparations and transformations of cyclopropenes, cyclopropanes, cyclopropenones and triafulvenes, all of which are covered here.

Twenty five years ago, all of the material on cyclopropane and cyclobutane chemistry was compiled by two single authors, which at the time must have been a truly Herculean task. Nowadays, this would simply be impossible. Thus, Houben-Weyl E17 has come to life only through the joint efforts of more than 60 authors, some of whom have invested a lot of their time with major contributions. An estimated 20,000

publications were read and evaluated, well over 13,000 references actually being quoted in the three-membered-ring sections alone. An editorial staff of 6 native speakers took care to make the presentation uniform and polish the language, especially of the non-native English writing authors. All the art work was redrawn by a group of 4.

The editor is indebted to all the authors, the editorial staff and the artists for the fruitful collaboration which made this book possible. Special thanks are also due to Ernst Schaumann for his initiation of this venture, his help and his encouragement throughout. We all hope that this handbook will serve the chemical community well and will become an indispensable reference tool for those engaged in Synthetic Organic Chemistry.

Göttingen, December 1996 Armin de Meijere

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2. Cyclopropenes

A. Synthesis

A number of reviews on cyclopropene synthesis have been published.[1, 112–115]

1. By Construction of the System

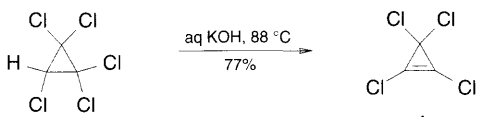
M. S. BAIRD

1.1. From a C_3 Building Block

1.1.1. 1,2-Elimination from Cyclopropanes

1.1.1.1. Dehydrohalogenation

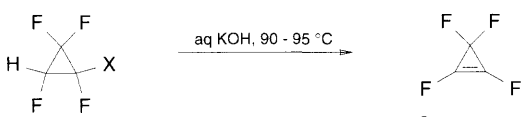
The reaction of pentachlorocyclopropane with potassium hydroxide is the standard route to tetrachlorocyclopropene (**1**).[2–4]



1

Tetrachlorocyclopropene (1); Typical Procedure:[3]
To a solution of 95% KOH (35.5 g) in H_2O (40 mL) was added pentachlorocyclopropane (50.0 g, 0.233 mol). The two-phase mixture was stirred slowly and heated to 75 °C, when a spontaneous reaction occurred. The heat was removed and the temperature rose to 88 °C where it was maintained by occasional ice cooling. After 25 min the mixture was cooled to 50 °C and ice-water (50 mL) and then cold concd HCl (25 mL) were added. The organic layer was taken up in CH_2Cl_2, washed with H_2O, and dried ($CaCl_2$). Fractionation of the CH_2Cl_2 extracts gave tetrachlorocyclopropene; yield: 32.0 g (77%); bp 71–72 °C/98 Torr; $n_D^{21.0}$ 1.5054.

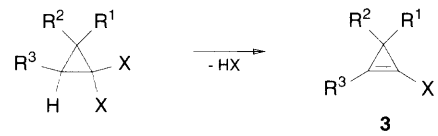
A similar method starting from 1,1,2,3-tetrafluoro-2-halocyclopropanes gave tetrafluorocyclopropene (**2**), although the reported yields (based on starting material converted) were low due to further reaction with nucleophiles.[5]



2 X = Cl 26%
X = F 36%

In many cases, the elimination of hydrogen halide from a 1,1-dihalocyclopropane has been reported to lead to an intermediate 1-halocyclopropene, which again reacts further under the reaction conditions, leading either to a cyclopropane, a methylenecyclopropane, a vinylcyclopropane or to ring-opened products. Such reactions are discussed elsewhere. However, in other cases, as shown below , the 1-halocyclopropenes **3** were isolated.

for references see p 2714

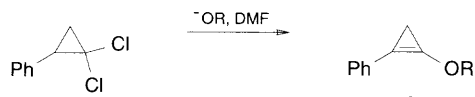


3

R^1	R^2	R^3	X	Conditions	Yield[a] (%)	Ref
Me	H	H	Cl	various	0	6
H	H	Ph	Cl	*t*-BuOK, THF	45	7
H	Me	Ph	Cl	*t*-BuOK, THF	53	7
Me	Me	Ph	Cl	*t*-BuOK, THF	87	7
Me	Ph	Ph	Cl	*t*-BuOK, THF	51	7
Me	CH_2OTHP	Ph	Cl	1. BuLi, −90 to −100 °C, 1 h, Me_2SO_4	51	8
=CH*t*-Bu		*t*-Bu[d]	Br	*t*-BuOK, THF, −30 to −40 °C, 1 h	–[e]	9
H	H	$(CH_2)_8CO_2Me$	Br	KOH, EtOH, reflux	n.r.[d]	10
C_8H_{17}[b]	H	$(CH_2)_7CO_2Me$[b]	Br	KOH, EtOH, reflux	n.r.	10
Cl	Cl	CO_2Et	Cl	KOH, benzene	65	11
Cl	Cl	$CH(OEt)_2$	Cl	KOH, benzene	76	11
Cl	Cl	CHO	Cl	KOH, benzene	n.r.	11
Cl	Cl	COR[c]	Cl	KOH, benzene	n.r.	11
Ph	OMe	H	Cl	*t*-BuOK, 18-crown-6, THF	–[f]	90

[a] n.r. = not reported.
[b] Interchangeable, product was a mixture.
[c] R = Me, Ph.
[d] Either stereoisomer.
[e] Detected in solution by NMR.
[f] 33% trapped in situ with 1,3-diphenylisobenzofuran.

Reaction of 1,1-dichloro-2-phenylcyclopropane with alkoxides gave 1-alkoxy-2-phenylcyclopropenes **4**, but only in the case of isopropoxide (R = i-Pr) were reasonable quantities of the desired product obtained before further reactions with alkoxide could occur (isolated yields were not reported).[12]



4

R = Me, Et, i-Pr

Dehydrohalogenation of 2-chloro-1,1-difluorocyclopropane by passing it repeatedly over moist Ascarite (sodium hydroxide on asbestos) in the gas phase has been used as a route to 3,3-difluorocyclopropene.[13]

The dehydrohalogenation of a monohalocyclopropane is a much more generally applicable procedure. Examples are the dehydrohalogenation of 1-alkyl- or 1-cyano-2-halo-1-methylcyclopropenes to give 3,3-dimethylcyclopropene (**5a**)[15,16] or 3-cyano-3-methylcyclopropene (**5b**).[17]

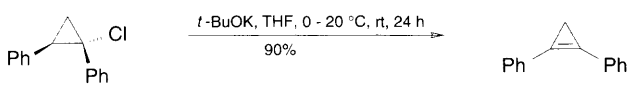
5

5	R	X	Conditions	Yield (%)	Ref
a	Me	Br	*t*-BuOK, DMSO, 90–100 °C	84	20
	Me	Br or Cl	KOH, DMSO, 18-crown-6 or KOH, TEBAC	82–92	15
	Me	Br	*t*-BuOK, DMSO, 90 °C, 2 h	50	16
b	CN	Br	KOH, DMSO, 20 °C, 3 h	30	17

3-Methyl-3-vinylcyclopropene; Typical Procedure:[14]
In a three-necked flask provided with stirrer, a thermometer, a pressure-equalizing funnel, and a trap cooled with dry ice in EtOH was placed *t*-BuOK (0.15–0.33 mol) in anhyd DMSO (30–60 mL), and 2-bromo-1-methyl-1-vinylcyclopropane (0.12–0.25 mol) was added at 40 °C over 2–4 h with stirring. During the addition and in the course of the subsequent stirring (2–6 h) the temperature of the reaction mixture was kept in the range of 30–40 °C. The contents of the flask were diluted with decalin (7–15 mL) and added to ice-water. The organic layer was separated, and the aqueous layer was extracted with decalin (3 × 5 mL). The combined extracts were washed with ice-water and with sat. brine to pH 7 and dried ($MgSO_4$). The apparatus for the distillation of the cyclopropene consisted of a Claisen flask with an effective reflux column to which an extension with a receiver and a spiral trap cooled with a mixture of dry ice and EtOH were attached. During vacuum distillation (at 120–180 Torr, depending on the boiling point of the cyclopropene) the corresponding cyclopropene condensed in the receiver. It was redistilled at atmospheric pressure.

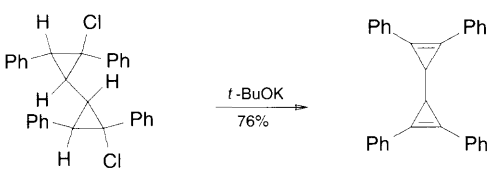
3-Cyano-3-methylcyclopropene (5b); Typical Procedure:[17]
A solution of 1-bromo-2-cyano-2-methylcyclopropane (6 g) in DMSO (5 mL) was added drop-by-drop over 1 h to a mixture of powdered KOH (7.5 g) and anhyd DMSO (20 mL), while cooling with ice under argon. The mixture was stirred for a further 2 h with cooling and then added to a mixture of H_2O (80 mL) and CH_2Cl_2 (40 mL). The aqueous layer was treated again with CH_2Cl_2 (20 mL), and the organic solutions were washed with H_2O, dried ($MgSO_4$), and submitted to fractional distillation under vacuum; yield: 30%; bp 52 °C/12 Torr.

Treatment of *trans*-1-chloro-1,2-diphenylcyclopropane with potassium *tert*-butoxide in tetrahydrofuran[18] gave 1,2-diphenylcyclopropene (**6**) in good yield.



6

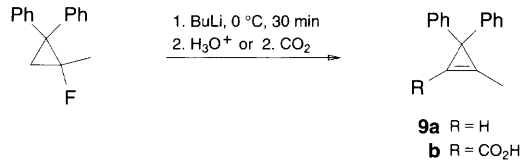
In contrast, the reaction of the stereoisomer with potassium amide in 1,2-dimethoxyethane/liquid ammonia gave only 1,2,3,4-tetraphenylbenzene. On the other hand, reaction of **7** with potassium *tert*-butoxide led to 3,3′-bis(1,2-diphenylcyclopropenyl) (**8**) in 76% yield, which rearranged on heating to 1,2,3,4-tetraphenylbenzene.[19]



7 **8**

for references see p 2714

A monofluorocyclopropane was also dehydrofluorinated to the corresponding cyclopropene **9a**.[21]



9a R = H
b R = CO_2H

Using lithium dialkylamides as the base gave the products **10a**[22] and **10b**[36] as the corresponding amides in poor yield.

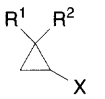
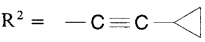
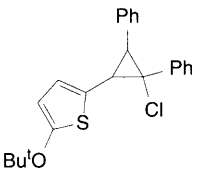
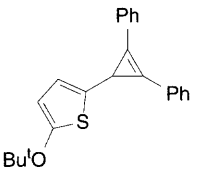
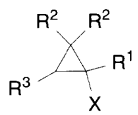
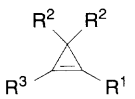
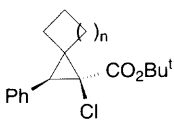
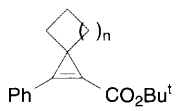
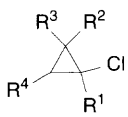
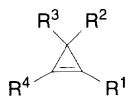
10a R = i-Pr
b R = cyclohexyl

As an example of a more complex structure, the bicyclopropenyl derivative **11** was formed in good yield.[24] Finally, 8-chlorobicyclo[5.1.0]octa-2,4-diene reacted with potassium *tert*-butoxide to give cyclooctatetraene from the *exo*-monochloride.[25]

11

Examples for the formation of cyclopropenes by dehydrohalogenation of monohalocyclopropanes are given in Table 1.

Table 1. Dehydrohalogenation of Monohalocyclopropanes To Give Cyclopropenes

Cyclopropane[a]	Conditions	Cyclopropene	Yield[b] (%)	Ref
 X = Cl or Br				
R^1 = H, Me; R^2 = 	*t*-BuOK, DMSO		31	27
R^1 = Me: R^2 = Me, Ph; R^1-R^2 = $-(CH_2)_3-$	KOH, DMSO, 18-crown-6 or KOH, TEBAC, DMSO		51–92	15
R^1 = Me, Ph; R^2 = Me, Ph, 4-$MeOC_6H_4$	*t*-BuOK, DMSO		47–80	16
R^1 = Me; R^2 = $CH=CH_2$, $CMe=CH_2$, cyclopropyl	*t*-BuOK, DMSO		28–68	14–16, 27–28
R^1 = cyclopropyl; R^2 = cyclopropyl	*t*-BuOK, DMSO		–	29, 30
R^1 = Me, R^2 = $C\equiv CH$[c]; $C\equiv CCMe_3$	*t*-BuOK, DMSO		58–60	31
R^1 = Me; R^2 = 1,1-(ethylenedioxy)ethyl	*t*-BuOK, DMSO		n.r.	32
R^1 = Ph; R^2 = $CPh=CH_2$, $CH=CPh_2$	*t*-BuOK, THF		20–48	33
	*t*-BuOK, THF, rt, 1 h then reflux, 30 min		92[d]	34
				
R^1 = Ph; R^2 = Me; R^3 = CO_2Me; X = Cl[n]	*t*-BuOK KOH, toluene		70 50[m]	35 35
R^1 = CO_2-*t*-Bu; R^2 = Me, Ph; R^3 = Ph; X = Cl	*t*-BuOK, THF, 0–20 °C		67–71[e,f]	22, 36
 n = 1–4	*t*-BuOK, THF, 0–20 °C		66–88[g]	22
				
R^1 = CO_2-*t*-Bu; R^2 = Me; R^3 = CH_2OTHP; R^4 = Ph	*t*-BuOK, THF, 20 °C, 45 min		8	8
R^1 = CN; R^2 = CN; R^3 = H, Cl; R^4 = CN	[l]		–	37

for references see p 2714

Table 1. (cont.)

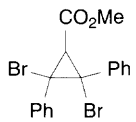
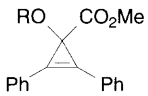
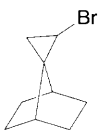
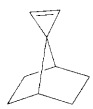
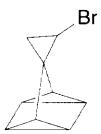
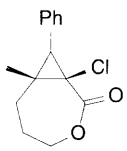
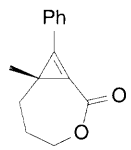
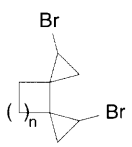
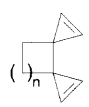
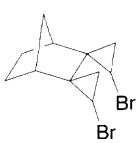
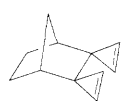
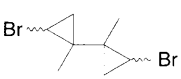
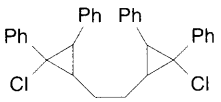
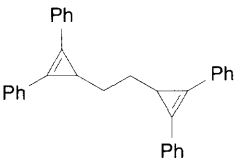
Cyclopropane[a]	Conditions	Cyclopropene	Yield[b] (%)	Ref
R^1 = Ph; R^2 = H; R^3 = Me; R^4 = 2-(PhCH$_2$CH$_2$)C$_6$H$_4$	*t*-BuOK, THF, −78 to 0 °C, 3 h then 25 °C, 10 h		60	38
R^1 = CO_2-*t*-Bu; R^2 = R^3 = R^4 = Ph	*t*-BuOK, THF		71	39
R^1 = Ph; R^2 = Me; R^3 = H; R^4 = Ph	*t*-BuOK, THF, −78 °C, 1 h then 0 °C, 3 h, then 20 °C, 12 h		80–88[h]	40
	DABCO, ROH		–[i]	41
	*t*-BuOK, DMSO		60	42, 43
	*t*-BuOK, DMSO		77	43
	*t*-BuOK		n.r.[j]	45, 46, 116
 n = 1–4	*t*-BuOK, DMSO		5–12	47, 48, 50
	*t*-BuOK, DMSO		20	48
	*t*-BuOK, (5 mol. equiv), DMSO, rt		12[k]	51

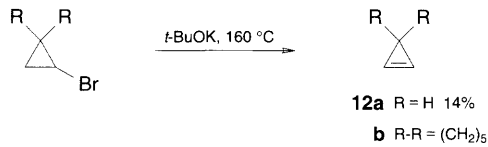
Table 1. (cont.)

Cyclopropane[a]	Conditions	Cyclopropene	Yield[b] (%)	Ref
	*t*-BuOK		p	52

[a] Attempted dehydrohalogenation of halocyclopropanes has also been reported.[27]
[b] n.r. = not reported.
[c] *Warning!* This compound reacts explosively at 90 °C in the condensed phase.
[d] Major product shown. Ratio 1-(5-*tert*-butoxy-2-thienyl)-2,3-diphenylcyclopropene/3-(5-*tert*-butoxy-2-thienyl)-1,2-diphenylcyclopropene 1 : 1.5.
[e] Cf. ref 39.
[f] A stable cyclopropene was not formed in the absence of substituents on C3.
[g] Related compounds with R^1 or R^2 = H at C3 of the cyclopropane did not cleanly give cyclopropenes.
[h] Product should not be distilled as considerable decomposition occurs; it decomposes slowly at 20 °C.
[i] R = H, Me.
[j] Related systems with 5- and 6-membered rings may be formed and trapped in situ.
[k] With 1.5 mol. equiv of *t*-BuOK the monocyclopropene – monobromocyclopropane derivative (44%) was obtained.
[l] Loss of HCl can occur even on standing, or on treatment with a variety of bases at room temperature or below. In the presence of DPIBF, derived cyclopropenes may be trapped.
[m] Product was acid rather than ester.
[n] Mixture of stereoisomers.
[p] 45% from 1,6-diphenylhexadiene precursor of dichlorodicyclopropylethane derivative.

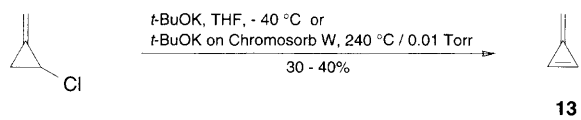
for references see p 2714

The dehydrobromination of monobromocyclopropanes over potassium *tert*-butoxide supported on solid silica at 160 °C occurred with high efficiency to give cyclopropenes **12** in analytical scale reactions, e.g. 75% yield on a 0.05 g scale.[53] However, yields in preparative scale reactions were reported to be low, e.g. in the case of **12a** the yield was 14%.[53]



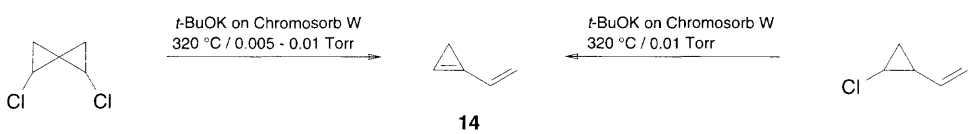
12a R = H 14%
b R-R = $(CH_2)_5$

In the latter case, the corresponding chloride also underwent elimination at 160 °C, although reacting incompletely. The elimination of hydrogen chloride from 1-chloro- or 1-bromo-2-methylenecyclopropane with potassium *tert*-butoxide in tetrahydrofuran at − 40 °C or by the solid base on Chromosorb W led to methylenecyclopropene (**13**) which was distilled into a cold trap and detected directly by NMR.[54]



13

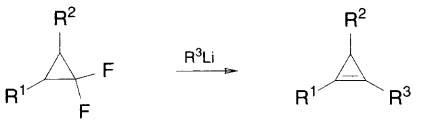
1-Bromo-2-methylenecyclopropane also gave **13** when dehydrobrominated at room temperature and 0.02–0.03 Torr with potassium *tert*-butoxide on Chromosorb W.[55] In a novel variation, 1,4-dichlorospiropentane was converted into the highly unstable 1-vinylcyclopropene (**14**) by reaction with potassium *tert*-butoxide on Chromosorb W at 320 °C[56]



14

The reaction apparently proceeds by an initial monodehydrochlorination followed by cleavage of the derived cyclopropene to a diradical which is converted into the product by loss of Cl and addition of a hydrogen atom. The vinylcyclopropene may also be obtained from 2-chloro-1-vinylcyclopropane by dehydrochlorination under the same conditions. The NMR signals for the product persisted at − 100 °C in tetrahydrofuran, but diminished at temperatures above − 70 °C, and at room temperature a [2 + 2] dimer was observed.

Although the dehydrofluorination of a monofluorocyclopropane to a cyclopropene has been reported, e.g. **9a,b**,[20,21] the reaction of a 1,1-difluorocyclopropane with an alkyllithium can result in dehydrofluorination, but generally results in the formation of an alkylated cyclopropene **15**, apparently derived by further reaction of the initial cyclopropene.[57]



15

R^1	R^2	R^3	Yield (%)	R^1	R^2	R^3	Yield (%)
Ph	H	Me	68	$-(CH_2)_6-$		Bu	85
Ph	H	Ph	63	$-(CH_2)_6-$		Me	29
Ph	H	Bu	91				

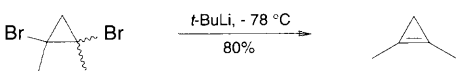
In the cases of 1,1-difluoro-2,2-diphenylcyclopropane or 1,1-difluoro-2-methyl-2-phenylcyclopropane, the reaction did not give cyclopropenes but instead led to ring-opened alkynes.[57]

1,1,3-Trichloro-2,2-dimethylcyclopropane underwent clean dehydrochlorination on reaction with methyllithium at 20 °C giving 1,2-dichloro-3,3-dimethylcyclopropene (**16**), in a reaction apparently initiated by lithium–hydrogen exchange in preference to lithium–halogen exchange, although the product was trapped in situ by an alkene, after ring opening to a vinylcarbene.[59] In related cases a dehalogenation was observed (see Section 1.1.1.2.).

16

1.1.1.2. Dehalogenation

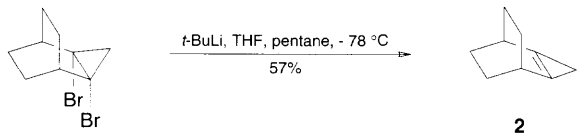
The reaction of either *cis*- or *trans*-1,2-dibromo-1,2-dimethylcyclopropane with *tert*-butyllithium provides an efficient route to 1,2-dimethylcyclopropene (**1**), the product being trapped in 80% yield by cycloaddition to 1,3-diphenylisobenzofuran.[60]



1

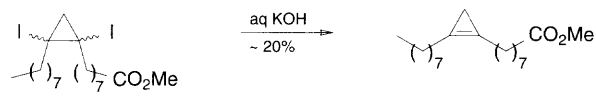
The dibromide itself was obtained from the corresponding dicarboxylic acid by a modified Hunsdiecker reaction. This method could also be applied to the generation and trapping of highly strained cyclopropenes such as bicyclo[4.1.0]hept-1(6)-ene, bicyclo[3.1.0]hex-1(5)-ene,[60] and tricyclo[3.2.2.$0^{2,4}$]non-2(4)-ene (**2**) which was trapped in the presence of 1,3-diphenylisobenzofuran, although two stereoisomers of the product were reported.[61]

for references see p 2714



2

In the case of the 1,2-diiodide **3**, derived by adding iodine to methyl sterculate, the elimination of halogen to give **4** was achieved using aqueous potassium hydroxide, although only in low yield (~ 20%).[64]



3 **4**

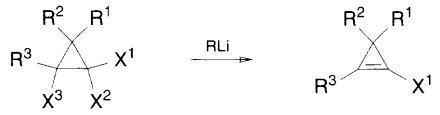
The deiodination was, however, carried out in an essentially quantitative manner by reaction of the mixture of diiodides with butyllithium at − 90 °C and then quenching with water at that temperature to give cyclopropenes **5**, and could be performed in the presence of a methyl ester. Both *cis*- and *trans*-isomers of 1,2-dibutyl-1,2-diiodocyclopropane reacted rapidly with butyllithium at − 80 °C to give the cyclopropene **5a**.[63] Since iodine undergoes 1,2-addition to a range of cyclopropenes, this provides a useful method for protecting the cyclopropene ring. Alternative deprotection methods are the use of zinc and ultrasound,[62] and reaction with diethyl phosphite and sodium hydride.[65] In the latter case the *cis*-di-iodide ($R^1 = R^2 = Bu$) also gave **5a** on reaction with diethyl phosphite/triethylamine for 20 hours at room temperature, but the *trans*-isomer remained largely unreacted under these conditions.[65]

5

5	R^1	R^2	Config[a]	Conditions	Yield[b] (%)	Ref
a	Bu	Bu	*cis*/*trans*	BuLi, − 80 °C	n.r.	63
			cis	$(EtO)_2POH$, NaH, 0 °C, 30 min	84	65
			trans	$(EtO)_2POH$, NaH, 0 °C, 30 min	84	65
b	C_8H_{17}	$(CH_2)_7CO_2Me$	*cis*/*trans*	BuLi, − 80 °C	76	63
c	C_8H_{17}	$(CH_2)_6CH(OH)CO_2Me$	*cis*/*trans*	BuLi, − 80 °C	85	63
d	Bu	$CH_2CH=CH_2$	*cis*/*trans*	BuLi, − 78 °C	86	122
e	Bu	(Z)-$CH_2CH=CH(CH_2)_5Me$	*cis*/*trans*	BuLi, − 78 °C	80	122
f	Bu	$(CH_2)_8ONO_2$	*cis*/*trans*	BuLi, − 78 °C	60[c]	66
g	$(CH_2)_{17}Me$	$(CH_2)_2CO_2Me$	*cis*/*trans*	zinc, ·))	84	62

[a] Configuration of substrate. [b] n.r. = not reported.
[c] Together with about 20% of the corresponding alcohol.

The elimination of halogen by reaction with an alkyllithium is also readily applied to tri- and tetrahalocyclopropanes giving either mono- or dihalocyclopropenes **6** or **7**. The reaction occurs rapidly at − 90 to 20 °C for 1,1-dibromides with a halogen at C2, but even with trichlorides reaction occurs in a few minutes at 20 °C. One advantage of the use of an alkyllithium is that, with a second equivalent of reagent, a lithium–halogen exchange occurs leading to a 1-lithiocyclopropene; the generation of such species in this way and their trapping by electrophiles are discussed in Section 4.2.1.3.2.

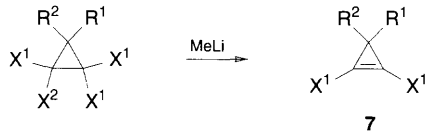


6

R^1	R^2	R^3	X^1	X^2	X^3	Conditions[1]	Yield (%)	Ref
H	H	*t*-Bu	Br	Br	Cl	MeLi, −40 °C, 5 min	52	70, 71
H	H	*t*-Bu	Cl	Cl	Cl	MeLi, Et_2O, 25−35 °C, 5 min	29	70, 71
H	H	i-Bu	Br	Br	Br	MeLi, Et_2O	57	70, 71
H	H	i-Bu	Cl	Cl	Br	MeLi, Et_2O	57	70, 71
H	H	C_8H_{17}	Br	Br	Br	MeLi, Et_2O	56	71
H	H	C_8H_{17}	Cl	Cl	Br	MeLi, Et_2O	94	71
Me	H	H	Cl	Cl	Br	MeLi, Et_2O	–[a, b]	72
H	Me	Me	Br	Br	Br	MeLi, Et_2O	–[c]	71
						MeLi, Et_2O	82[d]	74
Me	Me	H	Cl	Cl	Br	MeLi, Et_2O	–[e]	71
Me	Me	H	Br	Br	Br	MeLi, Et_2O	31	71
Me	Me	Me	Br	Br	Br	MeLi, Et_2O	43	71
Me	Me	Me	Cl	Cl	Br	MeLi, Et_2O	38	71
H	H	C_5H_{11}	Br	Br	Br	MeLi, Et_2O	–	75
H	H	CH_2Br	Br	Br	Br	MeLi, Et_2O, −78 °C	–[g]	77
H	H	CH_2OH	Br	Br	Br	MeLi, Et_2O, −78 to −20 °C	84[h]	77
H	H	CO_2Me	Br	Br	Br	MeLi, Et_2O, −85 °C	–[i]	78
Me	CH_2CH_2OH	H	Br	Br	Br	MeLi, Et_2O, −78 to −50 °C	76	73
Me	CH_2CH_2OMe	H	Br	Br	Br	MeLi, Et_2O, −78 to −50 °C	92	73
H	$-(CH_2)_6-$		Br	Br	Cl	MeLi, Et_2O	41	70, 71
H	$-(CH_2)_5-$		Br	Br	Cl	MeLi, Et_2O	–[k]	70
H	Pr	Pr	Cl	Cl	Br	MeLi, −78 °C	–[m]	58
H	Bu	Bu	Cl	Cl	Br	MeLi, −78 °C	–[m]	58

[a] Trapped with furan (55%).
[b] Trapped with cyclopentadiene.
[c] *cis*-2,3-dimethyl.
[d] Product (3*S*), optically pure cyclopropene as trapped by 1,3-diphenylisobenzofuran and shown by X-ray crystallography.
[e] Only product by crude NMR.
[f] Trapped with 1,3-diphenylisobenzofuran.
[g] Trapped with 1,3-diphenylisobenzofuran (70%) and furan (79%).
[h] Trapped with 1,3-diphenylisobenzofuran (55%).
[i] Trapped with a range of 1,3-dienes as [4+2] adducts.
[k] Trapped by addition of benzenethiol (54%).
[l] The reaction has also been applied to vinylcyclopropenes.[120]
[m] Yield not reported.

for references see p 2714



7

7	R^1	R^2	X^1	X^2	Conditions	Yield (%)	Ref
a	H	H	Br	Br		–[a]	76, 77
b	H	Me	Br	Br	–78 °C	–[b]	78, 79
c	H	i-Pr	Br	Br	–78 °C	70	78, 79
d	H	C_5H_{11}	Br	Br	–78 °C	–[c]	78, 79
e	Me	Me	Br	Br	–78 to 20 °C	48[g]	80
f	Me	Me	Cl	Cl	20 °C, 30 min	–[f]	59
				Br	–40 °C, 1 min	61[d]	59, 117
g	Me	CH_2Cl	Cl	Cl	0 °C	82	67, 68
h	Me	$CH_2N(i\text{-}Pr)_2$	Cl	Cl	0 °C	83	67, 68
i	Me	CH_2OMe	Cl	Cl	0 °C	78[e]	67, 68
j	Me	CH_2Ph	Cl	Cl	0 °C	–[g]	67
k	Me	$CH_2SCH_2CH=CH_2$	Cl	Cl	0 °C	65	68
l	Me	CH_2CH_2OMe	Br	Br	–78 °C	80	80
m	Me	CH_2CH_2Br	Br	Br	–78 °C	84	80

[a] After trapping by 1,3-diphenylisobenzofuran. The neat dibromide must be handled with *great care* as it decomposes violently even at room temperature.
[b] Trapped with methyl methacrylate (41%).
[c] Trapped with methyl methacrylate (70%).
[d] Yield 88% if Et_2O not removed.
[e] Sole product according to NMR of crude mixture.
[f] Detected by trapping with halogen or by ring opening and addition of the derived vinylcarbene to alkenes.
[g] Direct trapping led to yield of up to 92% of derived products.
[h] A series of 4-phenyl-substituted 3-benzylcyclopropenes has also been reported.[119]

1,2-Dichloro-3-chloromethyl-3-methylcyclopropane (7 g); Typical Procedure:[67,68]
1.5 M MeLi in Et_2O (3.2 mL) was added to a stirred solution of 1,1,2,2-tetrachloro-3-chloromethyl-3-methylcyclopropane (1.0 g,. 4.1 mmol) in Et_2O (10 mL) under N_2 at 0 °C. After 0.5 h, the reaction was quenched with H_2O (1 mL) at –40 °C; the organic layer was washed with H_2O at that temperature. The solvent was removed carefully at 14 Torr and the residue was flash distilled at 20 °C/14 Torr; yield: 0.57 g (82%).

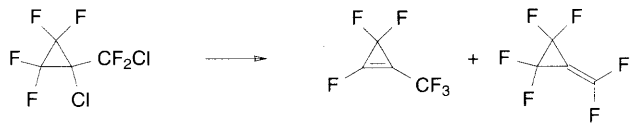
In the case of 1,1,2-trifluoro-2,3,3-trihalocyclopropanes, the two halogens were eliminated using zinc in a variety of solvents to give 1,3,3-trifluoro-2-halocyclopropenes **8**.[5,69]

8

X^1	X^2	X^3	Conditions	Yield (%)	Ref
Cl	Cl	Cl	Zn, EtOH, $ZnCl_2$, reflux	50	69
F	Cl	Cl	Zn, EtOH, $ZnBr_2$	85[a]	5
			Zn, $(MeOCH_2CH_2)O_2$, 160 °C	35[a]	69

[a] Explosive in air at 1 atm.

Reaction of 3-chloro-3-(chlorodifluoromethyl)-1,1,2,2-tetrafluorocyclopropane with zinc in dioxane gave a small quantity of perfluoro-1-methylcyclopropene (**9**); the major product (20 : 1) was the highly toxic perfluoro(methylenecyclopropane) (**10**).[81]



9 minor **10** major

The elimination of halogen has also been achieved using solid methyllithium adsorbed on glass helices in the formation of **11a** and the cyclopropene distilled directly into a cold receiver.[56]

11

11	X	Conditions	Yield (%)	Ref
a	Cl	MeLi on glass helices, 25 °C, 0.01 Torr	~ 85	56
b	Br	BuLi, − 75 to − 20 °C	—[a]	82

[a] Detected by NMR, characterized by cycloaddition to dienes.

1-Bromo-2-trimethylsilylcyclopropene (11a):[56]

Preparation of MeLi Adsorbed on Glass Helices ("Methyllithium Column"):

The reaction column was connected to a 500-mL, 3-neck flask containing glass helices (60 g). The system was evacuated for about 30 min and then filled with N_2. 1.6 M MeLi in Et_2O (30 mL) was then added to the flask through a rubber septum and mixed with the glass helices. The solvent was removed in vacuo leaving the glass helices coated with MeLi. The coated helices were then transferred to the column. After the column had been reconnected to the apparatus, the system was pumped for ~ 6 h to give a final pressure of 0.01 Torr.

1-Bromo-2-trimethylsilylcyclopropane (**11a**):

1-Bromo-2,2-dichloro-1-trimethylsilylcyclopropane (40 mg, 0.15 mmol) was passed through the "methyllithium column" at 25 °C and 0.01 Torr yielding the compound in ~ 85% yield. The ^1H NMR spectrum (CD_2Cl_2) was recorded at − 90 °C and showed two singlets at $\delta = 0.11$ (9 H) and 1.38 (2 H).

The debromination of 1,1,2-tribromo- and 1,1,2,2-tetrabromocyclopropanes to give the bromocyclopropenes **12** occurred on reaction with a dialkyl phosphite and either an amine or sodium hydride.[65]

for references see p 2714