The Reduction of *gem*-Dibromocyclopropanes by Means of Chromium(II) Acetate or Potassium Pentacyanocobaltate

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The reduction of *gem*-dibromocyclopropane(I) with Cr^{II} acetate in DMSO gives monobromocyclopropanes (II and III) exclusively, whereas the same components in aq DMF afford cyclopropyl acetates(IV and V) as the major products in addition to II and III. A similar substitution on cyclopropane carbon is observed in the reduction of I with $K_3Co(CN)_5$ in DMSO, furnishing cyclopropyl cyanides (IX and X) mainly. The stereochemistry of II, III, IV, and V is determined by the NMR coupling constants and chemical shifts, and that of IX and X, by transformation to the corresponding cyclopropyl methyl ketones derived from cyclopropanecarboxylic acids of known configurations. The reaction of II or III with $K_3Co(CN)_5$ is also described.

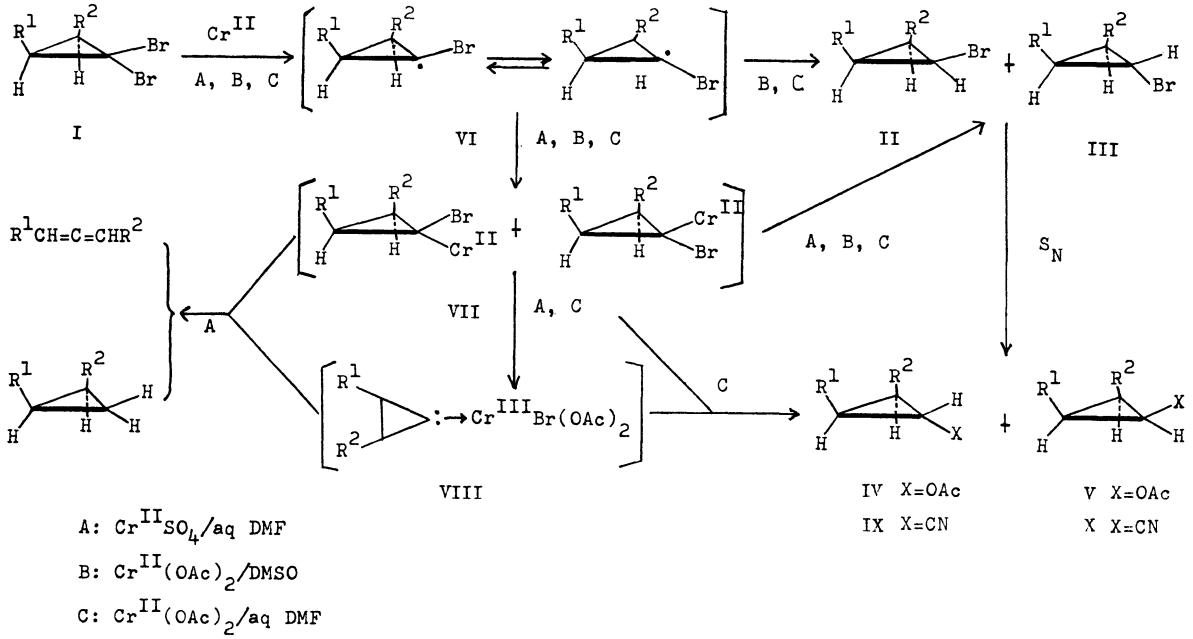
The reduction of *gem*-dibromocyclopropanes (I) with chromium(II) (Cr^{II}) sulfate produces *endo*-monobromocyclopropanes (II), along with allenes and completely reduced cyclopropanes (Scheme 1, route A).[1] We now wish to report on the behavior of I toward Cr^{II} acetate or potassium pentacyanocobaltate ($K_3Co(CN)_5$) in polar solvents (Scheme 1, route B or C). The reaction of these reductants with organic halides is not without precedent,[2] but the observed semireduction of I and the accompanying substitution reaction on cyclopropane carbon appear to be novel. The semireduction to monobromocyclopropanes[3] has been effected by means of Cr^{II} acetate in DMSO (system B), whereas substitution products such as cyclopropyl acetates or cyclopropyl cyanides have been obtained as major products in the reaction of I with Cr^{II} acetate in aqueous DMF (system C) and in that of I with $K_3Co(CN)_5$ in DMSO respectively. Such behavior is in remarkable contrast with that of Cr^{II} sulfate in aqueous DMF (system A[1]).

Table 1 summarizes the yields of the isomeric monobromocyclopropanes obtained in the reaction of I with the system B, which proceeded smoothly to afford only

Table 1. Reduction of *gem*-dibromocyclopropanes with Cr^{II} acetate in DMSO (0.3 M)

	Substrate I R^1, R^2	Reaction Temp. (°C)	Reaction Time (hr)	Products (Yield in %)[a] II *endo cis*	Products (Yield in %)[a] III *exo trans*
a	$(CH_2)_4$	45	15	75	7
b	$(CH_2)_6$	50	16	57	18
c	*n*-hexyl, H	50	17	27	46
d	Ph, H	r.t.	20	62	13

a) Yields were based on the consumed I.



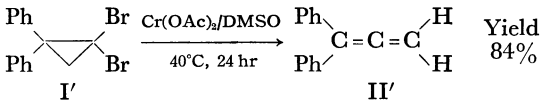
Scheme 1

1) a) H. Nozaki, T. Aratani, and R. Noyori, *Tetrahedron*, **23**, 3645 (1967); b) C. E. Castro, and W. C. Kray, Jr., *J. Amer. Chem. Soc.*, **88**, 4447 (1966) and the refs cited therein; c) J. K. Kochi, and P. E. Mocadlo, *ibid.*, **88**, 4094 (1966).

2) a) D. H. R. Barton, N. K. Basu, R. H. Hesse, F. S. Morehouse, and M. M. Pechet, *ibid.*, **88**, 3016 (1966); b) K. Tarama and T. Funabiki, *Nippon Kagaku Zasshi*, **89**, 88 (1968).

3) a) D. Seyferth, H. Yamazaki, and D. L. Alleston, *J. Org. Chem.*, **28**, 703 (1963); b) D. Seyferth and B. Prokai, *ibid.*, **31**, 1702 (1966); c) T. Ando, H. Yamanaka, F. Namigata, and W. Funasaka, *J. Amer. Chem. Soc.*, **89**, 5719 (1967).

negligible amounts of byproducts, such as allenes and cyclopropanes. The isomer distribution followed the same lines as were observed with other reductants[3]; that is, the predominance of *endo* (or *cis*) products, II, over the stereoisomers, III, holds with the exception of the case of Ic. Unexpectedly, the treatment of 1,1-dibromo-2,2-diphenylcyclopropane (I') with Cr^{II} acetate in DMSO gave 1,1-diphenylallene (II') as the sole isolable product. This is the only case where an allene is obtained.



I' II'

The reaction of I with Cr^{II} salts would probably proceed according to Scheme 1, but several remarkable points of difference have been observed between the two systems, A and B. (1) A more rigorous preference of II over III is observed with the system A. (2) Better yields of allenes are obtained in the system A with the exception of the above-mentioned case of 1,1-dibromo-2,2-diphenylcyclopropane. (3) Totally-reduced cyclopropanes are obtained only in the system A. Rapidly flipping radicals (VI) may be responsible, in part at least, for the formation of II and III in the system B, whereas organochromium intermediates (VII) probably account for the exclusive formation of II in the system A. Allenes and cyclopropanes may originate from the postulated inverse ylides (VIII), which can not be important in the system B.

Unexpectedly, the treatment of I with the system C gave cyclopropyl acetates (IV and V) in addition to monobromocyclopropanes (II and III), as is shown in Table 2.[4] The stereochemistry of IV and V was determined by means of the NMR chemical shifts and coupling constants of the acetoxy methyl protons and the acetoxy-substituted methine protons.[5]

Table 3 summarizes the reactions of I with $K_3Co(CN)_5$ in DMSO.[6] The stereochemistry of the resulting cyclopropyl cyanides (IX and X) was determined by transformation to the corresponding cyclopropyl methyl ketones (XI and XII), as is shown in Table 4.[5] The authentic samples were obtained by the reaction of methyllithium with cyclopropanecarboxylic acids (XIII and XIV) of know configurations (Table 5).[7]

The *endo*/*exo* ratios of monobromocyclopropanes given in Tables 2 and 3 are nearly the same as those obtained in the reduction of I with the system B and are consistently larger than one. Reversely, the *endo*/*exo* or *cis*/*trans* ratios of the substitution products, V/IV and X/IX, were smaller than one. The attempted reaction of two isolated monobromocyclopropanes, II and III, with Cr^{II} or Cr^{III} acetate in DMSO or in aqueous DMF afforded no cyclopropyl acetates, IV and V, but only complex mixtures, which could not be investigated

Table 2. Reduction of *gem*-dibromocyclopropanes with Cr^{II} acetate in aqueous DMF (0.3 M)

	Substrate I R^1, R^2	Reaction Temp. (°C)	Reaction Time (hr)	Products (Yield in %)[a] II	III	IV *exo trans*	V *endo cis*
a	$(CH_2)_4$	80	14	5	1	53	15
b	$(CH_2)_6$	80	14	25	0	45	4
c	*n*-hexyl, H	75	18	12	20	27	4
d	Ph, H	70	17	34	7	11	1

a) Yields were based on the consumed I.

Table 3. Reduction of *gem*-dibromocyclopropanes with $K_3Co(CN)_5$ in DMSO (0.3 M)

	Substrate I R^1, R^2	Reaction Temp. (°C)	Reaction Time (hr)	Products (Yield in %)[a] II	III	IX *exo trans*	X *endo cis*
a	$(CH_2)_4$	70	16	11	1	46	20
b	$(CH_2)_6$	80	16	nil[c]	nil[b]	44	30[c]
c	*n*-hexyl, H	75	16	27	32	8	6
d	Ph, H	70	16	27	9	26	7[d]

a) Yields were based on the consumed I.
b) Not isolated.
c) As the stereochemistry of IXb and Xb could not be determined because of the absence of the corresponding cyclopropanecarboxylic acid of known configuration, the assignment was made on the basis of glc retention times and NMR chemical shifts of acetyl methyl protons of the corresponding cyclopropyl methyl ketones derived from IXb and Xb as shown in Table 4.
d) Phenylallene was also obtained in a 17% yield.

Table 4. Transformation of cyclopropyl cyanides to cyclopropyl methyl ketones

	R^1, R^2	IX *exo trans*	X *endo cis*	XI *exo trans*	XII *endo cis*	Yield %[a]
a	$(CH_2)_4$	70 :	30	81 :	19	62
b	$(CH_2)_6$	60 :	40	85 :	15	65
c	*n*-hexyl, H	57 :	43	60 :	40	67
d	Ph, H	100 :	0	100 :	0	67

a) Yields were based on the consumed IX and X.

Table 5. Transformation of cyclopropanecarboxylic acids to cyclopropyl methyl ketones

	R^1, R^2	XIII *exo trans*	XIV *endo cis*	XI *exo trans*	XII *endo cis*	Yield %[a]
a	$(CH_2)_4$	88 :	12	85 :	15	48
c	*n*-hexyl, H	68 :	32	66 :	34	65
d	Ph, H	57 :	43	60 :	40	75

a) Yields were based on the consumed XIII and XIV.

4) On the synthesis of cyclopropanols, see: a) U. Schöllkopf, *Angew. Chem. Intern. Ed. Engl.*, **7**, 588 (1968); b) C. H. Depuy, *Accounts Chem. Res.*, **1**, 33 (1968); c) D. T. Longone and W. D. Wright, *Tetrahedron Lett.*, **1969**, 2859.

5) a) C. H. Depuy, G. M. Dappen, K. L. Eilers, and R. A. Klein, *J. Org. Chem.*, **29**, 2813 (1964); b) Jean-Louis Pierre, *Ann. Chim.*, **1966** 383; c) Idem., *Bull. Soc. Chim. Fr.*, **1966** 1040; d) J. P. Freeman, *J. Org. Chem.*, **29**, 1379 (1964); e) H. Weitkamp and F. Korte, *Tetrahedron*, **20**, 2125 (1964).

6) The reduction of Ib with $K_3Co(CN)_5$ in aqueous DMF gave *endo*-IIb exclusively, but Ia, Ic, and Id gave complex mixtures which were not investigated.

7) a) P. S. Skell and R. M. Etter, *Proc. Chem. Soc.*, **1961**, 443; b) K. Hofman, O. Tucker, W. R. Miller, A. C. Young, Jr., and F. Tausig, *J. Amer. Chem. Soc.*, **76**, 1799 (1954); c) A. Burger and W. L. Yost, *ibid.*, **70**, 2198 (1948).

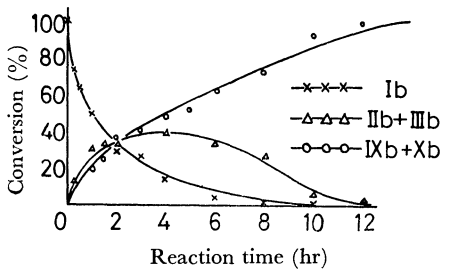


Fig. 1. Reduction of Ib with $K_3Co(CN)_5$ in DMSO followed by glc (HVSG 10%, 1.5 m, 130°C).

Table 6. Transformation of monobromocyclopropanes to cyclopropyl cyanides with $K_3Co(CN)_5$ in DMSO (0.1M)

	R^1, R^2	II *endo cis*	III *exo trans*	IX *exo trans*	X *endo cis*	Total yield %[b]
a	$(CH_2)_4$	100 : 0		83 : 17		88
		0 : 100		77 : 23		67
b	$(CH_2)_6$	100 : 0		56 : 44		60
		0 : 100		43 : 57		65
c	*n*-hexyl, H	100 : 0		63 : 37		62
		0 : 100		42 : 58		78
d	Ph, H	100 : 0		61 : 39		60
		0 : 100		68 : 32		70

a) All reactions were performed at 70—80°C for 15—20 hr.
b) Yields were based on the consumed amount of II or III.

further. We are tempted to assume that IV and V originate from chromium carbenoids (VII) or from chromium inverse ylides (VIII).

The reaction of Ib with $K_3Co(CN)_5$ in DMSO was monitored by means of glc. The results, shown in Fig. 1, indicated the initial formation of IIb and IIIb from Ib followed by the subsequent conversion of IIb and IIIb to cyclopropyl cyanides, IXb and Xb. In fact, the treatment of isolated II or III with $K_3Co(CN)_5$ in DMSO afforded a mixture of IX and X, as is shown in Table 6. The observed formation of a mixture, IX and X, from either II or III possibly involves an S_N-type reaction on a cyclopropane ring, accompanied by no ring-cleavage.[8] We may point out that the isomer ratios in this kind of S_N reactions are largely controlled thermodynamically, but a full explanation must await further investigations in the future.

Experimental

All the boiling points are uncorrected. Glc analyses and separations were performed using a 2-*m* column of HVSG (30%) and He as the carrier gas. The NMR spectra were obtained on a 60 MHz instrument (JEOL C-60-H spectrometer), and the chemical shifts are given in ppm from a TMS internal standard. The mass spectra were obtained on a Hitachi RMU 6D spectrometer. The microanalyses were performed by Mrs. K. Fujimoto at Prof. Sisido's Laboratory and by the Elemental Analyses Center of Kyoto University. The $K_3Co(CN)_5$[2b] and anhydrous Cr^{II} acetate[11] were prepared by the recorded methods.

General Procedure of the Reactions of gem*-Dibromocyclopropane Derivatives with Cr^{II} Acetate or $K_3Co(CN)_5$ in DMSO or Aqueous DMF.* In a nitrogen atmosphere, Cr^{II} acetate (or KCN and Co^{II} chloride) was dissolved in freshly-distilled (over CaH_2) DMSO or in aqueous DMF (1: 1) so as to give *ca.* a 0.3M solution by heating with stirring at 60—70°C for 30 min; then, the solution was maintained at an appropriate reaction temperature (20—80°C). To this we added, drop by drop, a solution (*ca.* 1.5M) of *gem*-dibromocyclopropanes in the same solvent. The atomic ratio of bromine: Cr^{II} (or Co^{II}) was taken to be 1: 1.5—2.0 unless otherwise stated. Heating and stirring were continued until the reddish-brown solution (or blue solution) turned green (or colorless). The mixture was then treated with water and extracted with *n*-hexane, ether, or benzene. The extract was washed with water, dried (Na_2SO_4), and concentrated *in vacuo*. The products were separated and identified as usual. The following description is concerned with cases which are not sufficiently covered by Tables 1, 2, and, 3. Incidentally, the reactions of monobromocyclopropanes with $K_3Co(CN)_5$ in DMSO shown in Table 6 were also performed by this procedure.

*Reaction of 1,1-Dibromo-2-*n*-hexylcyclopropane (Ic) in DMSO.* Dibromide Ic (0.10 g, 0.35 mmol) was treated with a solution of Cr^{II} acetate (0.25 g, 1.5 mmol) in DMSO (30 m*l*) at 50°C for 17 hr. The glc separation of the reaction mixture gave *cis*-1-bromo-2-*n*-hexylcyclopropane (0.02 g, 27%) and a *trans* isomer 0.035 g, 46%). The *cis*-bromide formed an oil; bp 75°C/18 mmHg (bath temp.), IR (neat): 1248 cm^{-1}, NMR $\delta(CCl_4$, 10%): 2.99 (*m*, 1H, >C<u>H</u>Br, J_{cis}=6.6 Hz), 1.37 (*m*, 10H, methylenes), 0.89 (*m*, 4H, methyl and methine), and 0.44 (*m*, 2H, -C<u>H</u>$_2$CHBr-).

Found: C, 52.9; H, 8.2%. Calcd for $C_9H_{17}Br$: C, 52.7; H, 8.4%. The *trans*-bromide also formed an oil; bp 70°C/18 mmHg (bath temp.), IR (neat): 1234 cm^{-1}, NMR $\delta(CCl_4$, 20%): 2.48 (*m*, 1H, >C<u>H</u>Br, J_{trans}=3.3 Hz), 1.32 (*m*, 11H, methylenes and methine), and 0.87 (*m*, 5H, methyl and -C<u>H</u>$_2$CHBr-).

Found: C, 52.7; H, 8.3%. Calcd for $C_9H_{17}Br$: C, 52.7; H, 8.4%.

Identification of Substitution Products (IV, V, IX, and X). The substitution products, IV, V, IX, and X, were unstable, so that the isolation of each stereoisomer was hard to accomplish. Each mixture of IV and V, or of IX and X, was obtained in an analytically-pure form by preparative tlc; the results of the analyses are shown in Table 7. High-sensitivity glc analyses of the mixtures gave the isomer ratio, which was in accord with the NMR analyses of the mixtures (Table 7). The ratios have been given above in Tables 2, 3, and 6. The attempted isolation of stereoisomers by preparative glc did not give satisfactory results.

Transformation of Cyclopropyl Cyanides (IX and X) to the Corresponding Cyclopropyl Methyl Ketones (XI and XII). A mixture of IX and X was treated with excess amounts of methylmagnesium iodide in ether under gentle refluxing. The reaction mixture was then worked up as usual. A

8) S_N-type reactions of vinylic halides with $K_4Ni_2(CN)_6$ in methanol have been recorded to give α,β-unsaturated nitriles in good yields. See Ref. 9. The S_N-type reaction of *endo*-rich cyclopropyl halides with Ag^I nitrate in methanol gave almost equimolar mixtures of *exo*-rich methoxycyclopropanes and ring-opened methanolysates See Ref. 10.

9) a) E. J. Corey and L. S. Hegedus, *J. Amer. Chem. Soc.*, **91**, 1233 (1969); b) I. Hashimoto, N. Tsuruta, M. Ryang, and S. Tsutsumi, *J. Org. Chem.*, **35**, 3748 (1970).

10) a) D. B. Ledlie and E. A. Nelson, *Tetrahedron Lett.*, **1969**, 1175; b) U. Schöllkopf, E. Ruban, P. Tonne, and K. Riedel, *ibid.*, **1970**, 5077.

11) J. H. Balthis, Jr., and J. C. Bailar, Jr., "Inorganic Syntheses." Coll. Vol., 1, p. 122 (1939).

TABLE 7. PHYSICAL PROPERTIES OF SUBSTITUTION PRODUCTS OBTAINED

Compd	Bp °C/mmHg (bath temp.)	IR (cm^{-1})	NMR (δ ppm, in CCl_4)	Ratio
IVa+Va[a]	60/2	1741, 1230	3.93 (*t*, J_{cis}=7.5 Hz)+3.68 (*t*, J_{trans}=2.8 Hz), 2.04 (*s*, *edno*-OAc)+1.94 (*s*, *exo*-OAc), 1.77—1.20 (*m*, methylenes and methines)	2 : 8
IVb+Vb[b]	75/1	1748, 1225	3.99 (*t*, J_{cis}=7.6 Hz)+3.42 (*t*, J_{trans}=3.0 Hz), 1.99 (*s*, *endo*-OAc)+1.94 (*s*, *exo*-OAc), 1.50—0.89 (*m*, methylenes and methines)	1 : 9
IVc+Vc[c]	65/1	1748, 1232	4.06 (*m*, J_{cis}=6.3 Hz)+3.72 (*m*, J_{trans}=3.8 Hz), 1.99 (*s*, *cis*-OAc)+1.97 (*s*, *trans*-OAc), 1.34—0.10 (*m*, methylenes and methines)	1 : 9
IVd+Vd[d]	80/2	1746, 1235	7.12 (*m*, aromatic), 4.15 (*m*), 2.30—2.15 (m), 1.21 (*m*), 2.00 (*s*, *trans*-OAc)+1.70 (*s*, *cis*-OAc)	11 : 1
IXa+Xa[e]	85/4	2235, 2210 (*exo*-CN) (*endo*-CN)	2.30—1.03 (*m*, methylenes and methines)	
IXb+Xb[f]	90/3	2245, 2215 (*exo*-CN) (*endo*-CN)	2.11 (*m*, methines), 1.46 (*m*, methylenes), 0.70 (*m*, methine)	
IXc+Xc[g]	75/1	2245, 2225 (*trans*-CN) (*cis*-CN)	2.08 (*m*, methine), 1.33 (*m*, methyl, methylenes and methine), 0.90 (*m*, methine)	

a) Found: C, 69.9; H, 9.1%. Calcd for $C_9H_{14}O_2$: C, 70.1; H, 9.2%. MS *m/e* (relative abundance): 154 (4), 112 (28), and 43 (100).
b) Found: C, 72.7; H, 9.8%. Calcd for $C_{11}H_{18}O_2$: C, 72.5; H, 10.0%. MS *m/e* (relative abundance): 154 (3), 140 (68), and 80 (100).
c) Found: C, 71.7; H, 11.1%. Calcd for $C_{11}H_{20}O_2$: C, 71.7; H, 10.9%. MS *m/e* (relative abundance): 184 (3), 142 (10), and 68 (100).
d) Found: C, 75.1; H, 6.8%. Calcd for $C_{11}H_{12}O_2$: C, 75.0; H, 6.9%. MS *m/e* (relative abundance): 176 (5), 134 (50), and 105 (100). For another route to IVd+Vd, see Ref. 5d.
e) Found: C, 79.2; H, 9.1; N, 11.4%. Calcd for $C_8H_{11}N$: C, 79.3; H, 9.2; N, 11.6%. MS *m/e* (relative abuudance): 121 (23) and 67 (100).
f) Found: C, 80.9; H, 9.9; N, 9.4%. Calcd for $C_{10}H_{15}N$: C, 80.5; H, 10.1; N, 9.4%. MS *m/e* (relative abundance): 149 (18) and 54 (100).
g) Found: C, 79.6; H, 11.1; N, 9.1%. Calcd for $C_{10}H_{17}N$: C, 79.4; H, 11.3; N, 9.3%. MS *m/e* (relative abundance): 151 (2) and 54 (100).

TABLE 8. PHYSICAL PROPERTIES OF CYCLOPROPYL METHYL KETONES

Compd	Bp °C/mmHg (bath temp.)	IR (cm^{-1})	NMR (δ ppm, in CCl_4)	Ratio
XIa+XIIa[a]	54/0.5	1689	2.17 (*s*, *endo*-acetyl)+2.14 (*s*, *exo*-acetyl), 1.95—1.05 (*m*, methylenes and methines)	2 : 8
XIb+XIIb[b]	64/0.5	1689	2.17 (*s*, *endo*-acetyl)+2.14 (*s*, *exo*-acetyl), 2.00—0.70 (*m*, methylenes and methines)	1 : 5
XIc+XIIc[c]	52/0.5	1700	2.18 (*s*, *cis*-acetyl)+2.14 (*s*, *trans*-acetyl), 1.98—0.91 (*m*, methylenes and methines)	4 : 6

a) Found: C, 78.1; H, 10.3%. Calcd for $C_9H_{14}O$: C, 78.2; H, 10.2%. MS *m/e* (relative abundance): 138 (24) and 95 (100). For analytical data of XIa+XIIa from the corresponding acids, Found: C, 78.3; H, 10.2%. Calcd for $C_9H_{14}O$: C, 78.2; H, 10.2%.
b) Found: C, 79.2; H, 11.1%. Calcd for $C_{11}H_{18}O$: C, 79.5; H, 10.9%. MS *m/e* (relative abundance): 166 (6) and 95 (100).
c) Found: C, 78.4; H, 11.9%. Calcd for $C_{11}H_{20}O$: C, 78.5; H, 12.0%. MS *m/e* (relative abundance): 168 (4) and 55 (100). For analytical data of XIc+XIIc from the corresponding acids, Found: C, 78.5; H, 12.0%. Calcd for $C_{11}H_{20}O$: C, 78.5; H, 12.0%.

mixture of XI and XII was obtained in an analytically-pure form by preparative glc. The physical properties are shown in Table 8. High-sensitivity glc analyses of the mixture gave the isomer ratio, which was in accord with the NMR analyses of the mixture (Table 8). The ratios have been given above in Tables 4 and 5.

Transformation of Cyclopropanecarboxylic Acids (XIII and XIV) to the Corresponding Cyclopropyl Methyl Ketones (XI and XII). A mixture of XIII and XIV was treated with excess amounts of methyllithium in ether under gentle refluxing. The reaction mixture was then worked up as usual. A mixture of XI and XII was obtained in an analytically-pure form by preparative glc. The analytical data are shown in Table 8.

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