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THE FAVORSKII REARRANGEMENT OF DICHLORINATED METHYLKETONES

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Abstract—Twenty-two dichlorinated methylketones have been submitted to Favorskii rearrangement in NaOMe–MeOH. Distribution of products is strongly dependent on substitution. Primary dichloromethyl-ketones (R_2 = H) gave rise to Favorskii esters only. Results are explained by a cyclopropanone intermediate, which is formed stereospecifically by disrotative closure of a delocalized zwitter-ion. Opening of the cyclopropanone intermediate is affected by steric and electronic influences. On the contrary secondary dichloromethylketones ($R_2 \neq H$) afforded Favorskii esters next to methoxyketones derived from a solvolysis mechanism.

INTRODUCTION

Dihalogenated ketones **1** and **2** by Favorskii rearrangement yield α,β-unsaturated acids (**3**) or derivatives.[1,4] In general the same products are formed from α,α- and α,α'-dihalogeno-ketones in accordance with the cyclopropanone mechanism.

$$\underset{\mathbf{1}}{R_1R_2CHCOCX_2R_3} \xrightarrow{{}^{-}OR_4} R_1R_2C{=}CR_3COOR_4 \quad \underset{\mathbf{2}}{R_1R_2CXCOCHXR_3} \xrightarrow{{}^{-}OR_4} \mathbf{3}$$

If $R_2 = R_3 = H$ (**4**), normally *cis* acrylic acids are formed, provided that precautions are taken to avoid isomerisation at the end of the reaction.[2,3]

In a previous communication we reported that more bulky substituents cause the general reaction path to be modified.[3] Dichloromethylketones of type **4** by Favorskii rearrangement are converted into mixtures of the normal *cis* acrylic esters **5** and α-chloromethyl esters **6**.

$$\underset{\mathbf{4}}{R_1CH_2COCHCl_2} \xrightarrow[CH_3OH]{{}^{-}OCH_3} \underset{\mathbf{5}}{R_1CH{=}^{c}CHCOOMe} + \underset{\mathbf{6}}{R_1CH(CH_2Cl)-COOMe}$$

The amount of the latter increases by changing R_1 from Me to Et, i-Pr and t-Bu.

We now want to examine the Favorskii rearrangement of dichloromethylketones in more detail in order to find a plausible explanation of the phenomenon.

RESULTS AND DISCUSSION

α,α- and α,α'-Dichloromethylketones of general formulae **7**, **8**, **9** or **10** were treated with NaOMe in MeOH at room temperature.

The reaction is followed by using increasing amounts of base and analyzing the mixture. As long as dichloroketone is present, base is disappearing in a rapid reaction. Afterwards the 2-chloromethylester **6** is dehydrochlorinated into 2-methylene-ester in a somewhat slower reaction. In this way it is possible to avoid confusion between different reaction paths. Reaction mixtures were analyzed by gas chromatography; reproductibility is about 3%.

In Table 1 a survey of data is given.

As shown by the Table, important features of Favorskii-rearrangements of dichloromethylketones are:

1. Primary dichloromethylketones (R_2 = H) next to the normal *cis* acrylic esters **5**, yield chloromethyl esters **6** in increasing amount with increasing R_1 group.

2. Secondary dichloromethylketones ($R_2 \neq H$) afford small amounts of chloromethylesters **13**, but variable amounts of methoxy-ketones **14** derived from a methanolysis mechanism.

3. α,α- and α,α'-Dichloromethylketones do not give rise to an identical ratio between products, the ratio between acrylic esters and chloromethylesters though is similar.

4. Stereospecificity is complete for primary dichloromethylketones (R_2 = H). In secondary derivatives ($R_2 \neq H$) the ratio between *cis*- and *trans*-acrylic esters (**11** and **12**) depends on the difference between both alkyl substituents and on the chlorine substitution.

We want to discuss now in detail on the intermediacy of cyclopropanones in the Favorskii-rearrangement, the stereoselectivity of the acrylic Favorskii esters, the opening of the cyclopropanone intermediates and the solvolysis mechanism.

The intermediacy of cyclopropanones. In all but a few cases the Favorskii-rearrangement is believed to proceed via a cyclopropanone intermediate, a supposition which is

$$\underset{\mathbf{7}: R_2 = H \\ \mathbf{8}: R_2 \neq H}{R_1R_2CHCOCHCl_2} \xrightarrow[CH_3OH]{{}^{\ominus}OCH_3} \underset{\mathbf{9}: R_2 = H \\ \mathbf{10}: R_2 \neq H}{R_1R_2CClCOCH_2Cl} + \underset{\mathbf{6}: R_2 = H \\ \mathbf{13}: R_2 \neq H}{R_1R_2CCOOCH_3(CH_2Cl)} + \underset{\mathbf{14}: R_2 \neq H}{R_1R_2C(OCH_3)COCH_2Cl} + \underset{\mathbf{12}: R_2 \neq H}{R_1R_2C{=}^{t}CHCOOCH_3}$$

Table 1. Favorskii rearrangements of dichlorinated methylketones

Compound	R_1	R_2	$R_1R_2C{=}CHCOOCH_3$			$R_1R_2CCCOOCH_3$ $\lvert$ CH_2Cl	$R_1R_2C{-}COCH_2Cl$ $\lvert$ OCH_3
				cis	*trans*		
7a	Pr	H	100	100	—	—	—
7b	iBu	H	100	100	—	—	—
7c	iPr	H	67	100	—	33	—
7d	$MeOOCCH_2CMe_2$	H	50	100	—	50	—
7e	tBu	H	25	100	—	75	—
9e	tBu	H	22	100	—	78	—
8f	Me	Me	41	—	—	5	54
10f	Me	Me	45	—	—	5	50
8g	Et	Me	45	52	48	6	30
10g	Et	Me	66	58	42	6	28
8h	Bu	Me	72	52	48	6	22
8i	iPr	Me	88	64	36	7	5
10i	iPr	Me	74	82	18	7	22
8j	sec Bu	Me	90	65	35	6	4
8k	tBu	Me	95	100	—	5	—
10k	tBu	Me	95	93	7	5	—
8l	cyclohexyl	R_1+R_2	68	—	—	20	12
10l	cyclohexyl	R_1+R_2	61	—	—	16	23
8m	cyclopentyl	R_1+R_2	33	—	—	—	67
10m	cyclopentyl	R_1+R_2	42	—	—	—	58
8n	cyclopropyl	R_1+R_2	—	—	—	—	—
7p	C_6H_5	H	40	100	—	—	60*

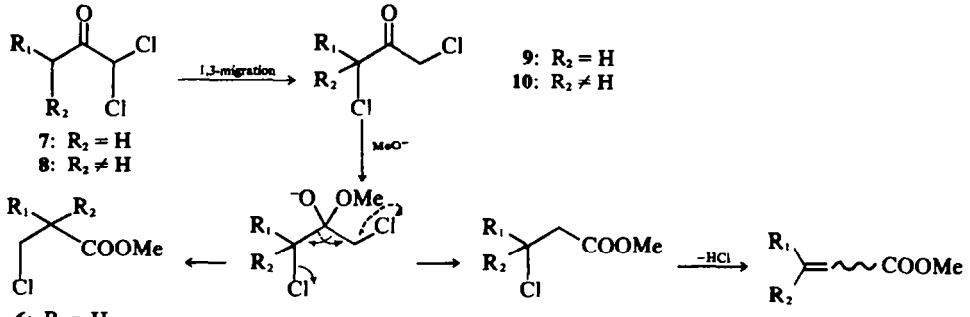
*$C_6H_5C(OMe)_2COCH_3$.

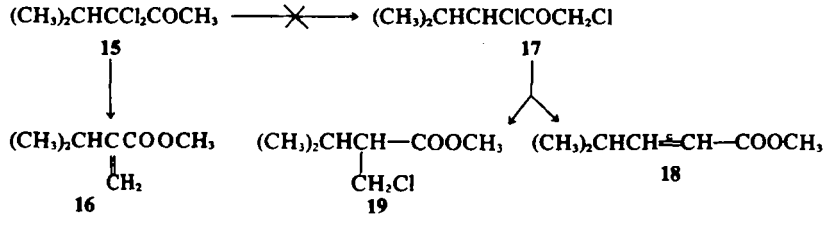
based on a plethora of arguments.[1,4] Amongst other features, the cyclopropanone mechanism in an elegant way explains the fact that α- and α'-halogeno-ketones afford the same products.

We did not consider all mechanisms proposed, but wanted to be sure about two deviations. Semi-benzilic rearrangement was proved to occur in a few special Favorskii-rearrangements.[4] Semi-benzilic rearrangement could explain Favorskii products formed in our case, if 1,1-dichloromethylketones would undergo 1,3-chlorine migration giving 1,3-dichloroketones. Formation of specifically *cis* acrylic esters is problematic though.

1,3-Chlorine migration has been shown to be insignificant in Favorskii-rearrangement of monochloroketones.[5] However as α,α-dichloroketones are more apt to chlorine migration,[6] it was investigated by treatment of 3,3-dichloro-4-methyl-2-pentanone **15** with sodium methylate, which by direct Favorskii-rearrangement would yield methyl 2-isopropylacrylate **16**, while after 1,3-chlorine migration to **17**, methyl *cis*-4-methyl-pentenoate **18** and methyl 2-chloromethyl-3-methyl-butyrate **19** would be formed; **19** eventually might be dehydrochlorinated to **16**.

No trace of compounds **18** and **19** was detected, so we can accept that 1,3-chlorine migration does not occur.





Both 1,3-chlorine migration and semi-benzilic rearrangement are rejected further by deuteration experiments. 1,1-Dichloro-4,4-dimethyl-2-pentanone **7e** was treated with NaOMe in fully deuterated MeOH (CD_3OD), yielding *cis* methyl 3-t-butyl-acrylate **5e** with resp. 7% d_3, 71% d_4 and 22% d_5, and methyl 2-chloromethyl-3,3-dimethylbutyrate **6e** with resp. 7% d_4, 69% d_5 and 24% d_6.

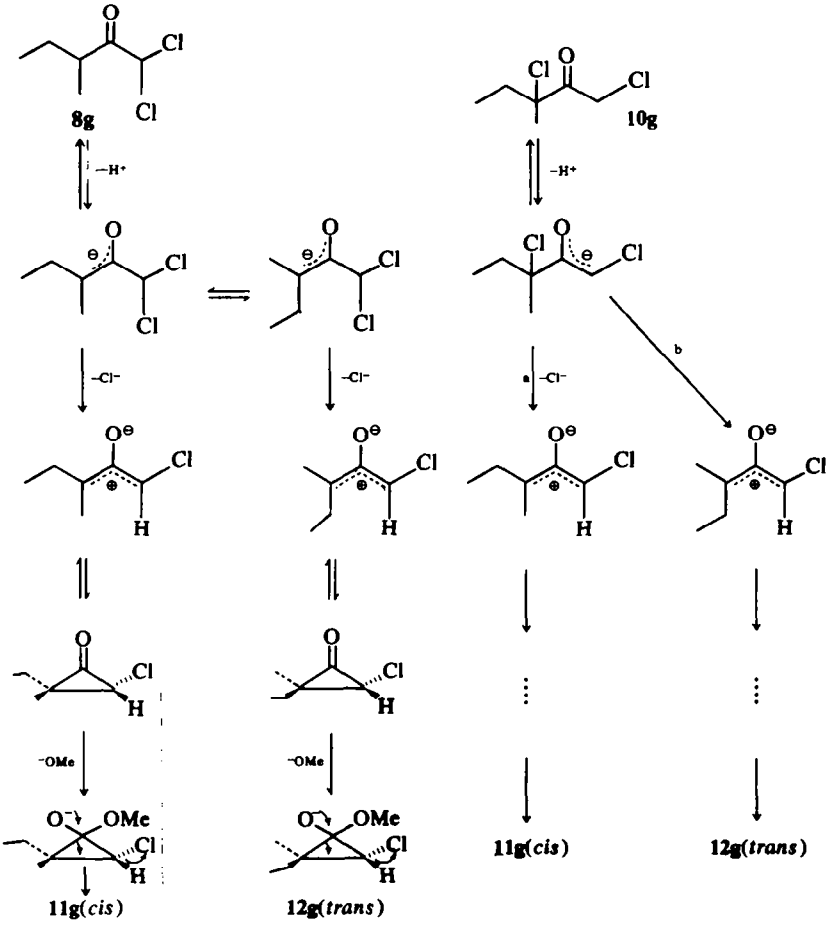
These figures show that before reaction some deuteration of the ketone occurred. They also prove that the reaction did not proceed via 1,3-chlorine migration and subsequent semi-benzilic rearrangement as in this case the relation between d_3-, d_4- and d_5-**5e** would not be identical with the relation between d_4-, d_5- and d_6-**6e**, as can be calculated.

Hence Favorskii-rearrangement of dichlorinated methylketones can be accepted to proceed via the normal cyclopropanone mechanism.

Stereoselectivity of the Favorskii esters. As was found by other authors the acrylic esters formed from primary dichloroketones ($R_2 = H$) are in the *cis*-configuration only.[2] Secondary dichloroketones ($R_2 = Me$) were converted into mixtures of both isomers, with increasing stereoselectivity according as the difference in bulkiness of both groups increases (Table 1).

1,1-Dibromomethylketones were supposed to undergo a concerted anti-parallel 1,3-elimination of hydrogen bromide from the least hindered rotamer, yielding a *cis*-R, Br-substituted cyclopropanone, which subsequently gave *cis*-acrylic ester by a concerted opening of the ring.[2] On the contrary for 1,3-dibromomethylketones neither the cyclopropanone formation nor the ring opening was believed to be important. The stereospecificity would depend on the mere elimination of the halogen anion from the least hindered rotamer of the carbanion formed on opening of the cyclopropanone ring.[7] Still another suggestion was made concerning Favorskii-rearrangement of medium ring 1,3-dibromoketones, where *cis*-ketones yield *trans* ring double bonds and *trans*-ketones yield *cis* ring double bonds.[8]

None of these proposals is useful in the case of dichloroketones. First, deuterium experiments mentioned before showed that enolization occurs faster than Favorskii-rearrangement, excluding a concerted formation of the cyclopropanone ring. Indeed chloro-ketones in this respect differ from bromo-ketones, as was pointed out for monohalogenoketones. Second, secondary α,α- and α,α'-dichloroketones do not afford the same ratio of *cis* and *trans* acrylates. Hence halogen elimination from the carbanion formed on opening of the cyclopropanone ring is inappropriate, as α,α- and α,α'-dichloromethylketones would afford the same anion, yielding an identical ratio between both acrylic esters. Therefore we accept cyclopropanone to be formed in the way proposed by Bordwell, namely by chlorine elimination from the enolate, yielding a delocalized, zwitter-ion, which by a concerted disrotative ring closure affords the cyclopropanone ring.[9,10] Steric hindrance will influence both *cis-trans* isomerism in the enolate ion and chlorine elimination from the enolate ion to give the zwitter-ion. The stereospecificity or -selectivity created in

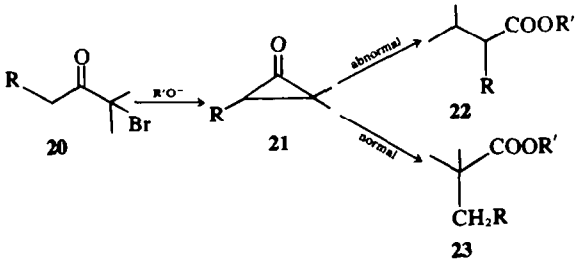


the zwitter-ion is maintained through the cyclopropanone formation and its stereospecific opening by a SN_2-type reaction yielding the acrylic esters.

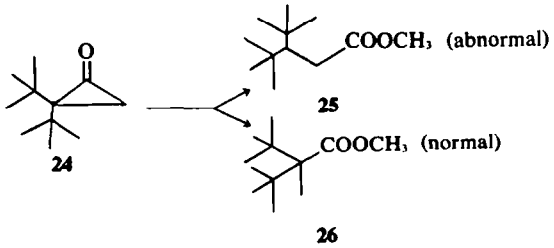
In primary dichloro-ketones, either α,α- or α,α'-derivatives **7** or **9**, differences between hydrogen and resp. alkyl and chlorine are large enough to form one zwitter-ion only. In secondary dichloroketones the difference is smaller and mixtures are produced. For α,α-dichloroketones **8** the ratio will be determined by the *cis-trans* isomerisation of the enolate ion and eventually the rate of chlorine loss of both ions (as shown for **8g** in the scheme). For α,α'-dichloroketones **10** it will depend on the ratio of chlorine elimination from one enolate ion in two directions (**10g**; path a and b). It is clear that both pathways by substitution will be influenced in the same way, but the results do not have to be identical.

Opening of the cyclopropanone intermediate. In general the cyclopropanone ring formed in Favorskii reactions is opened in such a way as to give the more stable carbanion.[1,4]. A chlorinated cyclopropanone, as results from dichloroketones, is opened so that chlorine is eliminated in a concerted reaction. In both cases this general rule is not followed anymore if a bulky alkyl substituent is introduced. Indeed this causes opening to occur at the opposite side. So primary dichloromethyl-ketones **7** and **9** (R_2 = H) with increasing R_1-group afford increasing amounts of "abnormal" opening (Table 1).[3]

(1-Bromo-isopropyl)-alkylketones **20** on the other hand were reported to give "abnormal" opening in 16–80% yield with more bulky substituents.[11]



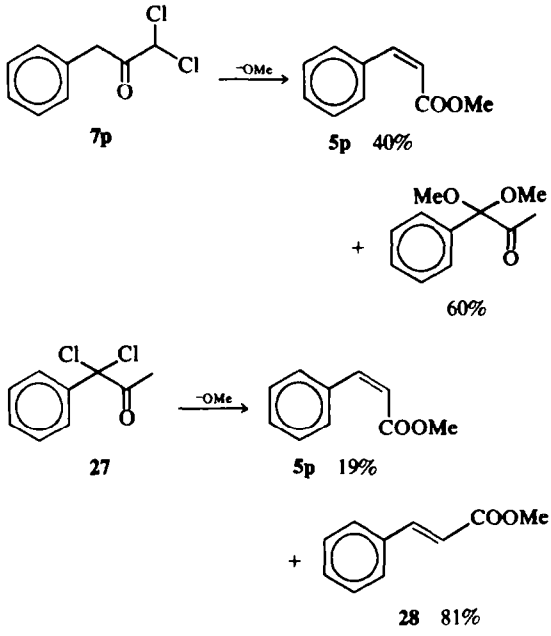
This phenomenon also is supported by alkaline opening of synthesized cyclopropanones, which normally give the more stable carbanion, except in the case of 2,2-di t-butylcyclopropanone **24**, where extreme crowding causes both reaction paths to be followed.[12]



Steric hindrance clearly influences the course of the reaction. Electronic effects are present too though, as follows first from the comparison of **8f** and **8g** with similar steric crowding, but different inductive effect, second from the large influence of a phenylgroup.

Benzyldichloromethylketone **7p**, in contrast with what could be expected from the bulky substituents only yields normal opening giving methyl *cis* cinnamate **5p** next to solvolysis.

1,1-Dichloro-1-phenylpropanone **27** on the other hand does not afford any "normal" atropic acid ester at all, the only product being methyl cinnamate (19% *cis* **5p** and 81% *trans* **28**). So here only abnormal opening occurred, the first product, 3-chloro-3-phenylpropionate, being dehydrohalogenated rapidly in a non specific way.



Steric hindrance (especially for the intermediate cyclopropanones) would be enhanced by putting two alkyl substituents on the same C atom. This led us to examine the secondary dichloroketones (R_2 = Me). These however yielded only small amounts of 2-chloromethylesters **13**. The ratio between normal and abnormal opening by the second alkyl substituent is affected unfavorably, only 5–10% of the cyclopropanone formed was converted into 2-chloromethylesters **13**. But furthermore cyclopropanone formation in the case of secondary dichloromethylketones **8** and **10** was competed by solvolysis yielding methoxyketones **14**. This will be discussed in the following subdivision.

Special attention is drawn to the cyclopentyl- and cyclohexylderivatives (resp. **10m** and **10l**) which, on base treatment, produced spiro-cyclopropanones which were opened in the abnormal way for resp. 0% and 16%. These deviating figures are caused by the special steric features of these compounds. They might be connected with the preference of 5-membered rings for exocyclic double bonds.

As compared with dichloromethylketones, dibromomethylketones did not show any abnormal product, presumably due to better leaving group character of bromine, which will favor the concerted mechanism.

Solvolysis mechanism. We want to consider now in detail on the methanolysis mechanism as a competitive reaction of the Favorskii rearrangement of dichloromethylketones. The amounts of methoxyketones **14** formed, ranging from 0 to 67%, depend on alkyl substituents and on chlorine substitution (either α,α or α,α'). It decreases from about 50% to naught going from **8f** and **10f** ($R_1 = R_2$ = Me) to **8k** and **10k** (R_1 = tBu, R_2 = Me). Cyclopentyl and cyclohexyl derivatives give deviating figures.

These results support the elegant work of Bordwell *et al.* on Favorskii rearrangement and solvolysis of monohalogenoketones **29** by sodium methylate methanol.[9,10]

$$ArCH_2COCHClR \xrightarrow[R=H,Me]{^-OMe} ArCH_2CHRCOOMe$$

29 **30**

$$+ ArCH_2COCHROMe$$

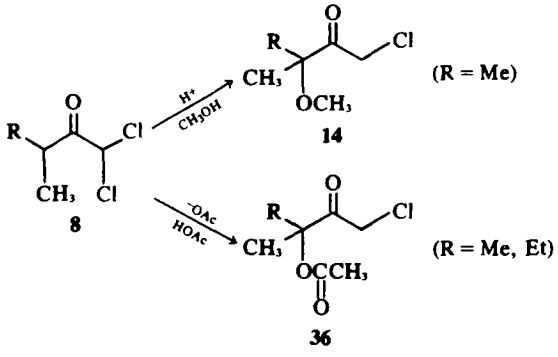
31

Acetone derivatives (R = H) yield Favorskii esters **30** only, while butanone compounds (R = Me) are converted also into methoxyketones **31** in 0–100% yield, according to concentration of base.

If the conclusions of this work are applied here, following reactions are obtained (1,3-dichloromethylketones **10** shown only). Ketone is in equilibrium with enolate **32** and enol **33**. Both are allyl systems, capable of eliminating a halogen anion, yielding resp. a delocalized zwitter-ion **34**, which will lead to cyclopropanone and Favorskii esters, and an allyl carbonium ion **35** which will be solvolyzed yielding 1-chloro-3-methoxy-2-alkanones **14**.

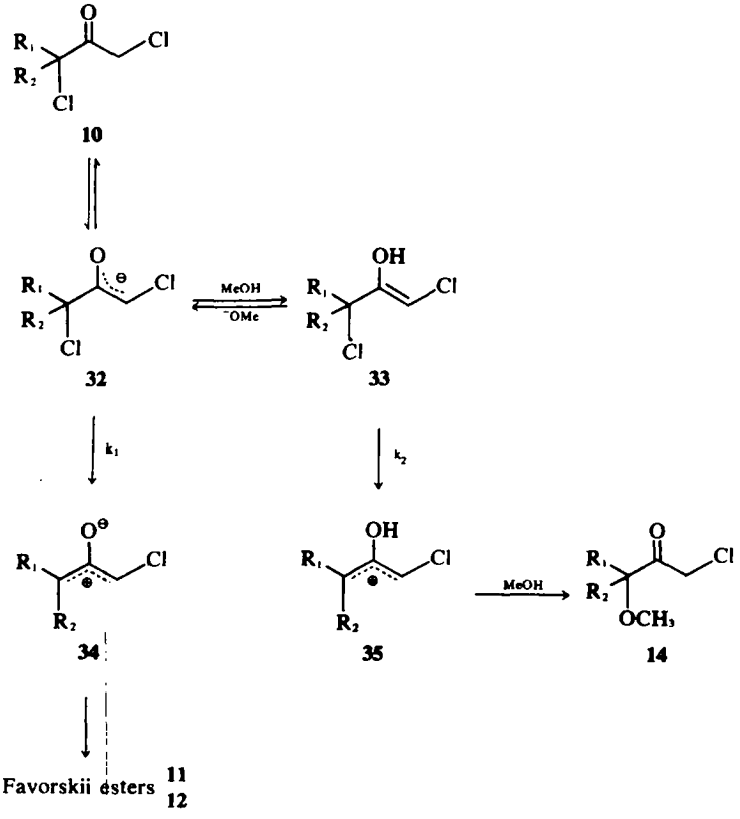
The ratio between both products depends first on concentration of resp. enolate (proportional of base concentration) and enol (± independent of base concentration), second on the ratio k_1/k_2. Solvolysis of allyl halides is speeded up with a factor of thousand by alkyl substitution in either α- or γ-place.[13] Evidently the second alkyl group causes k_2 to increase, so that both reactions become competitive. The influence is largely the same for α,α- and α,α'-derivatives, though results are not identical.

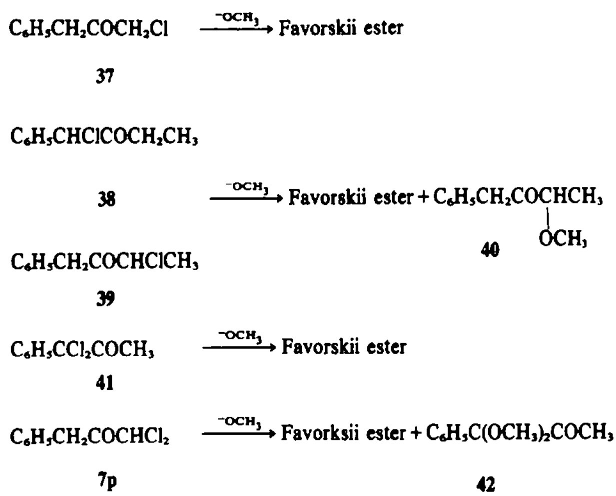
As in mono-haloketones this mechanism is substantiated by acid methanolysis and treatment with sodium acetate in boiling acetic acid, where primary dichloroketones are recovered unchanged, while secondary derivatives are converted into 3-methoxy-1-chloro-methylketones **14** and 3-acetoxy-1-chloro-methylketones **36**.[14]



Methanolysis occurs on the alkyl substituted side only. Introduction of a second halogen atom affects the course of the reaction. 1-Chloro-3-phenylacetone **37** by methylate treatment gives Favorskii-rearrangement products only, while both 1-chloro-1-phenyl-2-butanone **38** and 3-chloro-1-phenyl-2-butanone **39** afford 3-methoxy-1-phenyl-2-butanone **40**.

In the dichloro-derivatives, 1,1-dichloro-1-phenylacetone **41** by the same treatment formed acrylic esters only, while 1,1-dichloro-3-phenyl-acetone **7p**, next to 40% Favorskii ester, afforded 60% of 1,1-dimethoxy-1-phenylacetone **42**. Evidently in the last case methanolysis took place twice.





EXPERIMENTAL

NMR spectra were recorded on a Varian A-60 or H.A. 100 spectrometer. IR spectra were measured on a Perkin Elmer 237 spectrometer. Cl analyses were performed by the Schöniger method.

1,1-Dichloromethylketones. Ketones **7c**, **7e**, **8f**, **8g**, **8h**, **8i**, **8j**, **8k**, **8l**, **8m** were prepared by chlorination with N-chlorosuccinimide of the corresponding N-2-(alkylidene)cyclohexylamines[15,16] and subsequent acidic hydrolysis. **7d** was obtained as in ref. **6a**. Compounds **7a**, **7b**, **7p** were synthesized by chlorination of corresponding terminal alkynes.[16]

General procedure of Favorskii-rearrangements. A 10% methanolic soln of dichloromethylketone was treated successively with 0·2 equivts of titrated NaOMe (±1N). After each addition the mixture was analysed by VPC. This procedure was followed until all of the dichloroketone had disappeared.

Then water was added and the mixture was extracted with pentane which after drying on drierite was evaporated under reduced pressure at a temp below 0°. The yield was determined on the mixture and the compounds were identified by IR, NMR and Mass spectrometry after separation by VPC.

α-Chloromethyl esters 6 and 13

All esters were new products. The IR spectra showed a CO stretching vibration at 1735–1740 cm^{-1} and the C–Cl frequency was situated at 710–730 cm^{-1}.

Methyl 2-chloromethyl-3-methylbutanoate **6c**.

```
         Y   X
(CH3)2CH–CH–COOCH3
             |
           ABCH2Cl
```

: NMR 0·92 and 0·97 (two doublets due to chiral center; 6H, 2xd, J 6·5 Hz, $(CH_3)_2$); 1·96 (1H, CH(Y)); 2·48 (1H, CH(X)); 3·52 (CH_B–Cl, 1H): 3·66 (CH_A–Cl, 1H): protons A, B, X and Y give rise to ABXY-pattern: J_{XY} 6·6 Hz, J_{AX} 9·54 Hz, J_{BX} 4·36 Hz, J_{AB} 10·8 Hz; 3·66 (3H, s, OCH_3) *MS*: *m/e* 133/135 (6·5%); 69 (22%); 122/124 (20%); 87 (100%); 55 (20%); 59 (10%).
Cl analysis: Calc: 21·58% Cl, Found: 20·32% Cl, b.p. 87–92°C/15 mm Hg.

Methyl 2-chloromethyl-3-methylbutanoate **6c** underwent rapid dehydrochlorination, resulting in formation of methyl 2-isopropylacrylate.[18]

Methyl 2-chloromethyl-3,3-dimethylbutanoate **6e**. NMR: 0·99 (9H, s, $(CH_3)_3$); 2·51 (1H, X part of ABX pattern, J_{AX} 11·8 Hz, J_{BX} 2·8 Hz); 3·54 (1H, C–H(A), J_{AB} 10·3 Hz); 3·73 (1H, C–H(B)); 3·67 (3H, s, OCH_3).
MS: *m/e* 147/149 (10%); 83 (10%); 122/124 (45%); 59 (10%); 55 (18%); 87 (81%).
Cl analysis: Calc: 19·39% Cl, Found: 19·52% Cl, b.p. 102–105°C/30 mm Hg.

Methyl 2-chloromethyl-2-methylpropionate **13f**. NMR: 1·25 (6H, s, $(CH_3)_2$); 3·52 (2H, s, CH_2Cl); 3·66 (3H, s, OCH_3).

Methyl 2-chloromethyl-2-methylbutanoate **13g**. NMR: 0·83 (3H, t, J 7 Hz, $C\underline{H}_3$–C–C–COOMe); 1·20 (3H, s, $C\underline{H}_3$–C–COOMe); 2·6 (2H, m, $C\underline{H}_2$Me); 3·52 (1H, d, J 10·9 Hz, CHCl); 3·63 (1H, d, J 10·9 Hz, CHCl); 3·64 (3H, s, OCH_3).
MS: *m/e* 164/166 (0·3%); 133/135 (6%); 105/107 (21%); 69 (100%); 136/138 (37%); 101 (39%); 69 (100%); 59 (30%).

Methyl 2-chloromethyl-2-methylhexanoate **13h**. Compound **13h** was only identified by GC–MS coupling.
MS: *m/e* 192/194 (0·5%); 161/163 (2%); 133/135 (5%); 97 (4%); 136/138 (40%); 101 (100%); 69 (18%); 59 (15%); 55 (65%); 41 (37%).

Methyl 2-chloromethyl-2,3-dimethylbutanoate **13i**. NMR: 0·86 and 0·87 (two doublets due to asymmetric arbon atom; 6H, 2xd, J 6·5 Hz, $(CH_3)_2$); 1·14 (3H, s, CH_3); 2·06 (1H, septuplet, J 6·5 Hz, $C\underline{H}Me_2$); 3·52 (1H, d, J 10 Hz, CHCl); 3·77 (1H, d, J 10 Hz, CHCl).
MS: *m/e* 147/149 (3·5%); 119/121 (5%); 83 (21%); 136/138 (36%); 101 (100%); 69 (25%); 59 (10%); 55 (16%); 41 (40%).

Methyl 2-chloromethyl-2,3-dimethylpentanoate **13j**. This compound is a mixture of two diasteroisomers (45/55%). NMR: 0·8–1·8 (9H, m, $CH_3CH_2CH(CH_3)$–); 1·12 and 1·14 (3H, 2xs, $C\underline{H}_3$–C–COOMe); 3·64 (3H, s, OCH_3); 3·47, 3·52, 3·69, 3·74 (resp. H_B, $H_{B'}$, H_A, $H_{A'}$: two AB-systems; J_{AB} = 10·4 Hz and $J_{A'B'}$ 10·4 Hz). A small long range interaction is found for $H_{A'}$ with the α–CH_3-group.
MS: *m/e* 133/135 (3%); 97 (13%); 136/138 (20%); 101 (100%); 69 (16%); 59 (9%); 55 (18%); 41 (31%).

Methyl 2-chloromethyl-2,3,3-trimethylbutanoate **13k**. NMR: 0·95 (9H, s, $(CH_3)_3$); 1·23 (3H, s, CH_3); 3·63 (3H, s, OCH_3); 3·36 (1H, d, CH_BCl, J 10·3 Hz); 4·10 (1H, d, CH_ACl, J 10·3 Hz); H_A showed a small long range coupling with the α-methylgroup.
MS: *m/e* 192/194 (0·5%); 161/163 (4·5%); 133 (7%); 97 (5%); 136/138 (42%); 101 (100%); 69 (7·5%); 59 (5%); 55 (10%); 41 (28%).

Methyl 2-chloromethyl cyclohexylcarboxylate **13l**. NMR: 1·2–2·2 (10H, m, ring-CH_2); 3·48 (2H, s, CH_2Cl); 3·65 (3H, s, OCH_3).
MS: *m/e* 190/192 (6%); 159/161 (4·5%); 155 (60%); 154 (5%); 95 (100%); 94 (59%); 81 (32%); 41 (23%). C, H, Cl analysis: calc 56·69% C, 7·87% H, 18·53% Cl. Found: 56·93% C, 8·12% H, 18·42% Cl.

α,β-Unsaturated esters 5,11

cis-*Methyl 4,4-dimethyl-2-pentenoate* **5e**. NMR: 1·19 (9H, s, $(CH_3)_3$); 3·63 (3H, s, OCH_3); 5·53 (1H, d, J 13 Hz, =$C\underline{H}$–COOMe); 5·94 (1H, d, J 13 cps, $C\underline{H}$=C–COOMe). IR: 1730 cm^{-1} ($\nu_{C=O}$); 1635 cm^{-1} ($\nu_{C=C}$).

cis-*Methyl 3-methyl-2-heptenoate* **11h**. NMR: 0·94 (3H, t, J 7 Hz, CH_3–C–C–C–C=); 1·2–1·6 (4H, m, $MeCH_2CH_2$) 1·88 (3H, d, J 1·2 Hz, CH_3–C=); 2·62 (2H, t, J 7 Hz, CH_2–C=) 3·6 (3H, s, OCH_3); 5·54 (1H, m, =CH–). IR: 1730 cm^{-1} ($\nu_{C=O}$); 1650 cm^{-1} ($\nu_{C=C}$).

cis-*Methyl 3,4-dimethyl-2-pentenoate* **11i**. NMR: 1·01 (6H, d, J 7 Hz, $(CH_3)_2$); 1·78 (3H, d, J 1·4 Hz, CH_3–C=); 3·60 (3H, s, OCH_3); 4·00 (1H, m, J 7 Hz, $C\underline{H}Me_2$); 5·49 (1H, m, CH=). IR: 1730 cm^{-1} ($\nu_{C=O}$); 1650 cm^{-1} ($\nu_{C=C}$).

trans *Methyl-3,4-dimethyl-2-pentenoate* **12i**. NMR: 1·09 (6H, d, J 7 Hz, $(CH_3)_2$); 2·12 (3H, d, J 1·3 Hz, CH_3–C=); 2·27 (1H, septuplet, J 7 Hz, CHMe$_2$); 3·64 (3H, s, OCH_3); 5·63 (1H, m, CH=). IR: 1720 cm^{-1} ($\nu_{C=O}$); 1650 cm^{-1} ($\nu_{C=C}$).

cis-*Methyl 3,4-dimethyl-2-hexenoate* **11j**. NMR: 0·87 (3H, t, J 7 Hz, CH_3–C–C–C=); 1·00 (3H, d, J 7 Hz, CH_3–C–C=); 1·32 (2H, m, CH_2); 1·74 (3H, d, J 1·3 Hz, CH_3–C=) 3·57 (3H, s, OCH_3); 3·82 (1H, m, CH–C=); 5·52 (1H, m, CH=). IR: 1730 cm^{-1} ($\nu_{C=O}$); 1645 cm^{-1} ($\nu_{C=C}$).

trans-*Methyl 3,4-dimethyl-2-hexenoate* **12j**. NMR: 0·83 (3H, t, J 7 Hz, CH_3–C–C–C=); 1·03 (3H, d, J 7 Hz, CH_3–C–C=); 1·32 (2H, m, CH_2); 2·03 (3H, d, J 1·3 Hz, CH_3–C=); 2·1 (1H, m, CH–C=); 3·57 (3H, s, OCH_3); 5·51 (1H, m, =CH–). IR: 1725 cm^{-1} ($\nu_{C=O}$); 1645 cm^{-1} ($\nu_{C=C}$).

1-*Chloro-3-methoxy-2-alkanones* **14**

All ketones are new compounds. Their IR spectra revealed the carbonyl stretching vibration at 1740–1745 cm^{-1} and the C–Cl frequency at 720–780 cm^{-1}.

1-*Chloro-3-methoxy-3-methyl-2-butanone* **14f**. NMR: 1·31 (6H, s, $(CH_3)_2$); 3·22 (3H, s, OCH_3); 4·38 (2H, s, CH_2Cl).
MS: *m/e* 135/137 (0·6%); 77/79 (2%); 73 (100%); 49 (6%); 43 (13%).
Cl analysis: Calc: 23·58% Cl, Found: 21·78% Cl. b.p. 72–74°C/15 mm Hg.

1-*Chloro-3-methoxy-3-methyl-2-pentanone* **14g**. NMR: 0·78 (3H, t, J 7 Hz, CH_3–C–C–OMe); 1·25 (3H, s, CH_3–C–OMe); 1·64 (2H, m, CH_2); 3·20 (3H, s, OCH_3); 4·32 (2H, s, CH_2Cl).
MS: *m/e* 149/151 (0·2%); 135/137 (2·5%); 87 (100%); 55 (39%); 77 (4·5%); 49 (3%).
Cl analysis: Calc: 21·58% Cl, Found: 20·12% Cl. b.p. 82–85°C/15 mm Hg.

1-*Chloro-3-methoxy-3-methyl-2-heptanone* **14h**. NMR: 0·90 (3H, t, J 7 Hz, CH_3CH_2–); 1–1·9 (6H, m, $CH_2CH_2CH_2$); 1·26 (3H, s, CH_3–C–OMe); 3·21 (3H, s, OCH_3); 4·31 (2H, s, CH_2Cl).
MS: *m/e* 135/137 (1·2%); 115 (100%); 83 (5%); 77/79 (2%); 49/51 (2%); 59 (28%).
Cl analysis: Calc: 18·44% Cl, Found: 19·11% Cl.

1-*Chloro-3-methoxy-3,4-dimethyl-2-pentanone* **14i**. NMR: 0·80 and 0·94 (two nonequivalent methylgroups: 6H, 2xd, J 7 Hz, $(CH_3)_2$); 1·20 (3H, s, CH_3); 1·86 (1H, m, J 7 Hz, CHMe$_2$); 3·20 (3H, s, OCH_3); 4·25 (2H, s, CH_2Cl).
MS: *m/e* 163/165 (0·2%); 135/137 (4%); 101 (100%); 77/79 (6%); 49/51 (25%); 69 (72%); 43 (92%); 41 (80%).
Cl analysis: Calc: 19·89% Cl, Found: 18·22% Cl.

1-*Chloro-3-methoxy-3,4-dimethyl-2-hexanone* **14j**. NMR: 0·9–1·2 (12H, CH$_3$–CH$_2$–CH(CH$_3$)–C–CH$_3$); 3·18 (3H, s, OCH_3); 4·26 (2H, s, CH_2Cl).
MS: *m/e* 115 (100%); 83 (28%); 77/79 (4%); 59 (86%); 55 (41%); 43 (25%).

1-*Chloro-3-methoxy-methylcyclohexylketone* **14l**. NMR: ±1·6 (10H, m, ring CH_2); 3·14 (3H, s, OCH_3); 4·26 (2H, s, CH_2Cl).
MS: *m/e* 113 (100%); 81 (61%); 77 (6·5%); 55 (12%); 45 (30%); 41 (17%). Found: C, 56·43; H, 7·57; Cl, 17·22. Calc: C, 56·69; H, 7·87; Cl, 18·63%.

1-*Chloro-3-methoxy-methylcyclopentylketone* **14m**. NMR: 1·6–1·9 (8H, m, ring CH_2); 3·15 (3H, s, OCH_3); 4·29 (2H, s, CH_2Cl).
MS: *m/e* 99 (100%); 67 (65%); 77/79 (2·7%); 49/51 (3%); 45 (30%); 41 (20%).
Cl analysis: Calc: 20·11% Cl, Found: 20·65% Cl.

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