and concentrated, the viscous residue was mixed with 100 ml. of methanol and 20 ml. of water and then refluxed for 2 hr. and concentrated. The residual mixture was extracted with ether and the ethereal solution was washed successively with dilute, aqueous hydrochloric acid and aqueous sodium bicarbonate and then dried and concentrated. Distillation of the residue separated 26.0 g. (55%) of the keto ester as a colorless liquid, b.p. 72–74° (0.2 mm.), n^{25}_{D} 1.4590, with infrared absorption[14] at 1740 (ester C═O) and 1710 cm.$^{-1}$ (C═O).

Anal. Calcd. for $C_9H_{14}O_3$: C, 63.51; H, 8.29. Found: C, 63.46; H, 8.57.

Saponification of a 2.00-g. (11.8 mmoles) sample of the keto ester with 1.4 g. (25 mmoles) of potassium hydroxide in refluxing aqueous methanol for 12 hr. followed by the usual isolation procedure afforded 1.27 g. (81.5%) of 2-ketocyclohexaneacetic acid as white prisms, m.p. 74–76° (lit.[25] 73°), from an ethyl acetate–hexane mixture.

***o*-Tolylacetic Acid.**—A mixture of 10.0 g. (0.0746 mole) of *o*-methylacetophenone,[26] 3.56 g. (0.111 g.-atom) of sulfur and 9.84 g. (0.112 mole) of morpholine was heated to reflux for 16 hr. and then cooled and poured into 40 ml. of ethanol. The product separated as light yellow crystals, m.p. 85–87°, yield 8.81 g. (50.5%). The pure **thiomorpholide of *o*-tolylacetic acid** crystallized as white prisms, m.p. 86–87.5°, with no infrared absorption[14] in the 3 and 6 μ region attributable to an O—H, N—H or C═O function and an ultraviolet maximum[15] at 281 mμ (ϵ 15,900).

Anal. Calcd. for $C_{13}H_{17}NOS$: C, 66.36; H, 7.28; N, 5.95; S, 13.60. Found: C, 66.33; H, 7.25; N, 5.96; S, 13.90.

A solution of 2.08 g. (8.85 mmoles) of the thiomorpholide in 90 ml. of constant-boiling hydrobromic acid was refluxed for 23 hr. and then cooled, diluted with water and extracted with ether. The acidic product, separated from the ether solution by extraction with aqueous sodium bicarbonate, was isolated in the usual way. Recrystallization of the crude acid from water afforded 0.90 g. (67%) of the *o*-tolylacetic acid as white needles, m.p. 88–89° (lit.[27] 88–89°). The same acid was obtained from α-bromo-*o*-xylene in an over-all yield of 63% by way of the intermediate *o*-tolyl[28] acetonitrile, b.p. 67–69° (0.36 mm.), n^{25}_{D} 1.5259 [lit.[28] b.p. 125° (14 mm.)].

1-Methylfluoren-9-one.—After chromatography of samples of the crude tetrahydrofluorenones **4**, the disproportionation product, 1-methylfluoren-9-one, was isolated as yellow needles, m.p. 97.5–99° (lit.[29] 97.5–98.5°), from methanol. The product has infrared absorption[14] at 1705 cm.$^{-1}$ (conj. C═O in a 5-membered ring), with ultraviolet maxima[15] at 251 mμ (ϵ 59,600), 258 mμ (ϵ 93,200) 288 mμ (shoulder, ϵ 2,530), 297 mμ (ϵ 3,140), 317 mμ (ϵ 2,440), 322 mμ (ϵ 2,410) and 329 mμ (ϵ 2,270).

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[25] W. Cocker and S. Hornsby, *J. Chem. Soc.*, 1157 (1947).

[26] This ketone, b.p. 104–106°, n^{26}_{D} 1.5290, was prepared in 71% yield by the procedure of M. S. Newman and W. T. Booth, *J. Am. Chem. Soc.*, **67**, 154 (1945).

[27] P. Schorigin, *Ber.*, **43**, 1938 (1910).

[28] M. S. Newman, *J. Am. Chem. Soc.*, **62**, 2295 (1940).

[29] T. P. C. Mulholland and G. Ward, *J. Chem. Soc.*, 4676 (1954).

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF KENTUCKY, LEXINGTON, KY.]

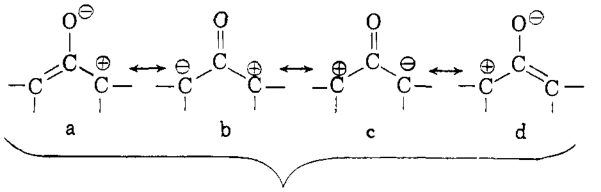
Evidence for a Delocalized Intermediate in the Favorskii Rearrangement. 2,6-Lutidine-promoted Methanolysis of α-Chlorodibenzyl Ketone[1]

BY ARTHUR W. FORT

RECEIVED JULY 28, 1961

α-Chlorodibenzyl ketone undergoes rapid methanolysis in the presence of 2,6-lutidine to give α-methoxydibenzyl ketone. The reaction is first order in chloroketone, first order in lutidine, and almost independent of the lutidinium ion produced. Chloroacetone and desyl chloride are unreactive in methanolysis reactions in the presence of 2,6-lutidine. An elimination–addition mechanism, involving a delocalized intermediate, is proposed for the methanolysis of α-chlorodibenzyl ketone. This interpretation receives strong support from the finding that α,α'-dibromodibenzyl ketone is dehalogenated by sodium iodide in methanol to give α-methoxydibenzyl ketone. The possible significance of these results for the Favorskii rearrangement is discussed.

Several aspects of the Favorskii rearrangement of α-haloketones[2] have led to proposals that the reaction sometimes proceeds through a delocalized intermediate[3] (Ia–d). The present work examines the possibility that the proposed delocalized intermediate may be stabilized by conjugation of the delocalized system with aryl groups. Such stabilization, if it occurs, might be reflected in increased ease of dehydrohalogenation of the parent α-haloketone.



I

In the absence of strong, nucleophilic base, the reaction course taken by the key intermediate of the Favorskii rearrangement might furnish additional evidence as to the structure of this intermediate (see below). The possibility that a change in the character of the base employed would lead to changes in the structures of the products provided another motive for undertaking the present work.[4]

A serious objection to the proposed intermediate (Ia–d)[3] arises from the fact that the only forms shown contributing to the hybrid molecule are forms involving separation of charges. Resonance stabilization for such a molecule could not be very large, and the proposed delocalized intermediate could not be expected to be stable relative to a classical cyclopropanone structure with all bonds essentially localized. This objection to a delocalized

[1] Presented at the Organic Division, A.C.S. Meeting, New York, N. Y., September, 1960; abstracts, p. 45-P.

[2] Reviewed by A. S. Kende, *Org. Reactions*, **11**, 261 (1960).

[3] (a) J. G. Aston and J. D. Newkirk, *J. Am. Chem. Soc.*, **73**, 3900 (1951); (b) J. G. Burr, Jr., and M. J. S. Dewar, *J. Chem. Soc.*, 1201 (1954); (c) H. O. House and W. F. Gilmore, *J. Am. Chem. Soc.*, **83**, 3972, 3980 (1961).

[4] Another possible way of preventing the Favorskii intermediate from reacting with strong, nucleophilic base is simply to keep the concentration of base very low. The effect of low base concentration, achieved by slow addition of alkoxide, is described in another paper, *ibid.*, **84**, 2625 (1962).

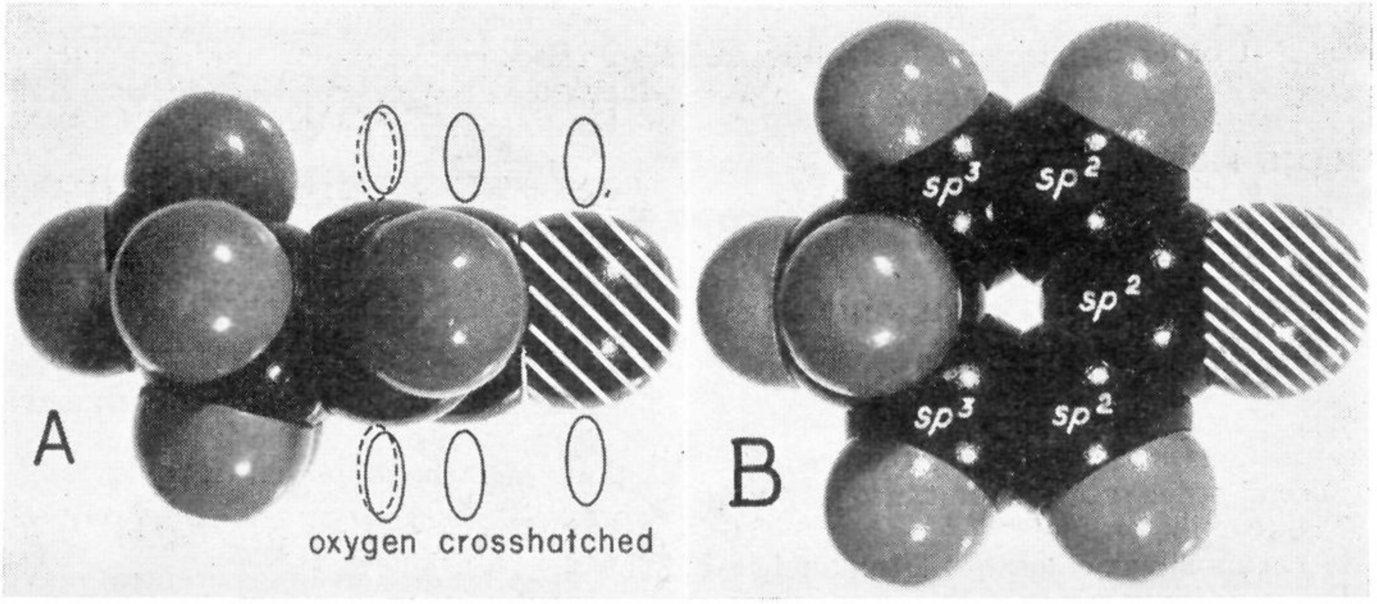
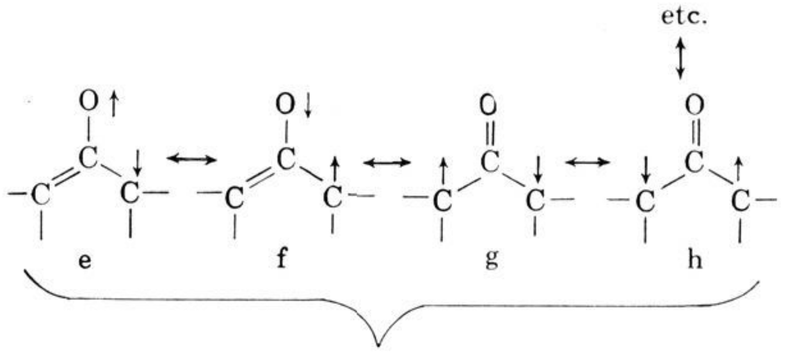


Fig. 1.—Model of the proposed delocalized intermediate from α-halocyclohexanone: (A) side view, showing the atomic p-orbitals that can be involved in mutual overlap; (B) top view.

intermediate can be overcome, at least in part, by noting that forms such as Ie–h, which do not involve separation of changes, would also make important contributions to the hybrid molecules. A convenient notation for the proposed delocalized system, which summarizes all of the above resonance forms, is provided by the three forms Ii–k[5].



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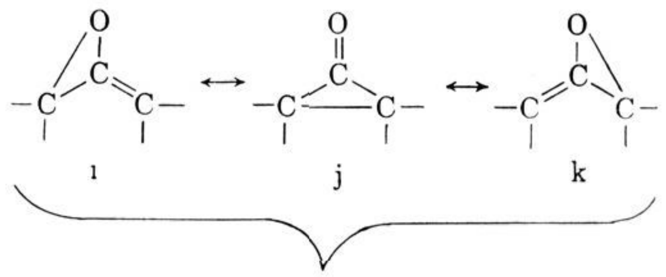
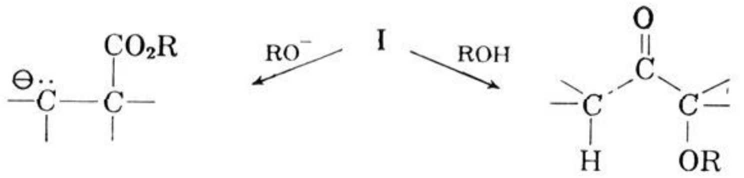


I

In order that the resonance indicated in the proposed structure I can occur, it is necessary that the four explicit atoms of I be coplanar. The required geometry can usually be attained, even when the proposed delocalized system is part of a six-membered ring, as illustrated in Fig. 1 by a model of the delocalized intermediate that would be obtained by elimination of hydrogen halide from α-halocyclohexanone. Inspection of Fig. 1 reveals that the four atomic p-orbitals in question are correctly aligned for mutual overlap. When aryl groups are attached to the radial carbon atoms of I, further possibilities for p-orbital overlap exist, and structure I should be stabilized by conjugation with aryl groups.

Chloroacetone (II) and α-chlorodibenzyl ketone (III) were chosen for study in the present work. Enhanced reactivity in the dehydrochlorination of III could be overlooked easily under conditions that favor good yields of Favorskii rearrangement products.[6] However, if III were to show unusual reactivity, a weak base should accomplish the dehydrohalogenation. By employing a hindered (non-nucleophilic) base it should be possible to avoid side reactions such as direct nucleophilic displacement of chloride ion[2,7] and nucleophilic attack at the carbonyl carbon atom.[2] For these reasons the weak hindered base, 2,6-lutidine, was chosen for the attempted dehydrochlorinations of II and III.

Both chloroacetone[2] (II) and α-chlorodibenzyl ketone[2,8] (III) have been reported to undergo Favorskii rearrangement in the presence of strong base.[9] In the absence of strong base the delocalized intermediates, if formed, might be expected to give α-substituted ketone products instead of Favorskii rearrangement products. The possibility of such a reaction path was mentioned by Aston and Newkirk in connection with their suggestion for a delocalized intermediate in the Favorskii rearrangement,[3a] but no conclusive experimental evidence for such a reaction has appeared.



Results and Discussion

α-Chlorodibenzyl ketone (III) underwent smooth methanolysis in the presence of 2,6-lutidine to give

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[5] The distances between the radial atoms of I are too large to permit extensive p-orbital overlap, and the suggested notation (Ii–k) for the proposed intermediate overemphasizes p-orbital overlap between radial atoms.

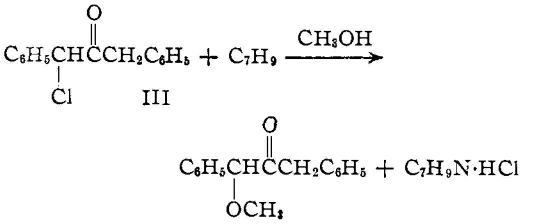
[6] It has been observed (ref. 2) that use of excess alkoxide and high base concentration leads to higher yields of Favorskii rearrangement products at the expense of other possible products; see also ref. 4.

[7] See, for example, E. L. Eliel in M. S. Newman, "Steric Effects in Organic Chemistry," J. Wiley and Sons, Inc., New York, N. Y., 1956, p. 103.

[8] J. Jullien and P. Fauche, *Bull. soc. chim. France*, [5] **20**, 374 (1953).

[9] Chloroacetone and sodium alkoxides give resins predominantly. For examples, see (a) R. P. Mariella and J. L. Leech, *J. Am. Chem. Soc.*, **71**, 3558 (1949); (b) Y. Yamamoto, *J. Pharm. Soc. Japan*, **73**, 938 (1953); *C. A.*, **48**, 10739 (1954).

α-methoxydibenzyl ketone in excellent yield. The reaction was first order in base and first order in



$$\underset{\text{III}}{C_6H_5\underset{\displaystyle Cl}{CH}\overset{\displaystyle O}{\overset{\|}{C}}CH_2C_6H_5} + C_7H_9 \xrightarrow{CH_3OH} C_6H_5\underset{\displaystyle OCH_3}{CH}\overset{\displaystyle O}{\overset{\|}{C}}CH_2C_6H_5 + C_7H_9N\cdot HCl \quad (1)$$

chloroketone. Data for several runs at various initial concentrations of reactants, together with the calculated second-order rate constant, are given in Table I. The reaction was followed by precipitating chloride ion as silver chloride. Methanolysis was quenched by adding, along with silver nitrate, an excess of nitric acid to convert free 2,6-lutidine into lutidinium ion.

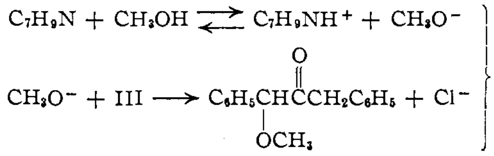
TABLE I

METHANOLYSIS OF α-CHLORODIBENZYL KETONE (III) AT 25.2 ± 0.1°

Initial concn., M^a	Time, min.	Wt. of AgCl, mg.	f^b	k, l. mole^{-1} min.$^{-1}$
III, 0.0396	0.0	0.4	(0.000)	
	14.5	25.2	.175	0.139
C_7H_9N, 0.0999	45.0	62.9	.440	.143
	89.0	94.1	.660	.144
	106.5	102.7	.720	.146
	∞	142.4		
				0.144^c
III, 0.0420	0.0	23.9	(0.000)	
	27.9	69.3	.302	0.148
C_7H_9N, 0.0943	60.1	100.6	.501	.145
	118.0	133.5	.728	.148
	537.0	173.3	.993	.154
	∞	174.4		
				0.147^c
III, 0.0794	0.0	1.2	(0.000)	
	22.5	72.5	.203	0.145
C_7H_9N, 0.0997	37.5	104.9	.364	.145
	85.0	169.1	.589	.148
	139.5	208.7	.728	.154
	∞	285.7		
				0.148^c
III, 0.0840	0.0	47.9	(0.000)	
	10.0	112.1	.213	0.135
C_7H_9N, 0.1866	30.0	196.1	.493	.139
	95.0	304.0	.851	.146
	∞	348.8		
				0.144^c
III, 0.0985	0.0^d	3.3		
	0.0^e	358.7	(0.000)	
C_7H_9N, zero	225	375.5	.048	$(0.0022)^f$
	1200	397.9	.111	$(0.0010)^f$
HCl, 0.0992	∞	710.9		

[a] Corrected for autocatalyzed methanolysis of III that occurred prior to addition of lutidine. [b] Fraction of III reacted. [c] Obtained from the slope of a plot of log $([C_7H_9N]_0 - f[\text{III}]_0) - \log([C_7H_9N]_0(1-f))$ *vs.* time. [d] Immediately before addition of HCl to reaction flask. [e] Immediately after addition of HCl to reaction flask. [f] Fictitious second-order rate constant, calculated on the assumption that $v = k[\text{III}][\text{HCl}]$.

The function of lutidine in the rapid methanolysis of III cannot be that of producing methoxide ion which then displaces chloride ion from III by direct nucleophilic attack on C-α.

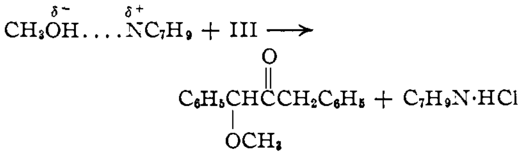


$$\left.\begin{array}{l} C_7H_9N + CH_3OH \rightleftarrows C_7H_9NH^+ + CH_3O^- \\ CH_3O^- + \text{III} \longrightarrow C_6H_5\underset{\displaystyle OCH_3}{CH}\overset{\displaystyle O}{\overset{\|}{C}}CH_2C_6H_5 + Cl^- \end{array}\right\} \quad (2)$$

The rate of reaction, v, by this path would be inversely proportional to the lutidinium ion concentration, but the observed rate is almost inde-

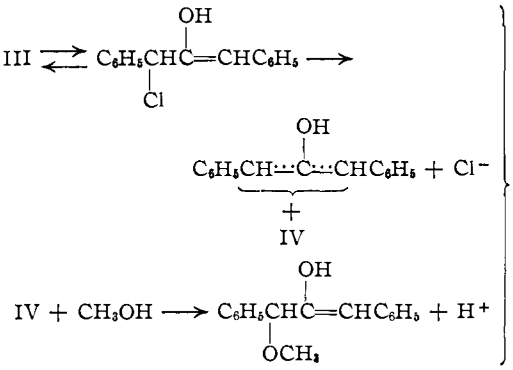
$$v \propto [\text{III}][CH_3O^-] \propto [\text{III}][C_7H_9N][C_7H_9NH^+]^{-1}$$

pendent of lutidinium ion concentration (Table I). The finding that chloroacetone (II) and desyl chloride are unreactive in methanolysis in the presence of lutidine (see below) provides additional evidence against this reaction path and, also, against a modification of this reaction path in which methanol, hydrogen bonded to lutidine, acts as the nucleophilic species.



$$CH_3\overset{\delta-}{O}H\ldots.\overset{\delta+}{N}C_7H_9 + \text{III} \longrightarrow C_6H_5\underset{\displaystyle OCH_3}{CH}\overset{\displaystyle O}{\overset{\|}{C}}CH_2C_6H_5 + C_7H_9N\cdot HCl \quad (3)$$

An enolization–ionization mechanism is a reasonable reaction path for methanolysis of α-chloroketones.[10]



$$\left.\begin{array}{l} \text{III} \rightleftarrows C_6H_5\underset{\displaystyle Cl}{CH}\overset{\displaystyle OH}{\overset{|}{C}}{=}CHC_6H_5 \longrightarrow \\ \qquad \underset{\displaystyle \text{IV}}{\underset{+}{\underbrace{C_6H_5CH{\cdots}\overset{\displaystyle OH}{\overset{|}{C}}{\cdots}CHC_6H_5}}} + Cl^- \\ \text{IV} + CH_3OH \longrightarrow C_6H_5\underset{\displaystyle OCH_3}{CH}\overset{\displaystyle OH}{\overset{|}{C}}{=}CHC_6H_5 + H^+ \end{array}\right\} \quad (4)$$

The enolization of ketones is subject to both general acid and general base catalysis,[11] and, if lutidine-catalyzed methanolysis of III proceeded by an enolization–ionization mechanism, the lutidinium ion produced in the reaction should catalyze the reaction efficiently, contrary to the observed kinetics (Table I). As mentioned above, in kinetic runs lutidine-catalyzed methanolysis was quenched by converting lutidine into lutidinium ion with nitric acid. These observations, together with a brief examination of the hydrochloric acid-catalyzed methanolysis of III (Table I) serve to show that acid-catalyzed methanolysis (probably by an enolization-ionization mechanism) is a much slower reaction than lutidine-catalyzed methanolysis.[12,13]

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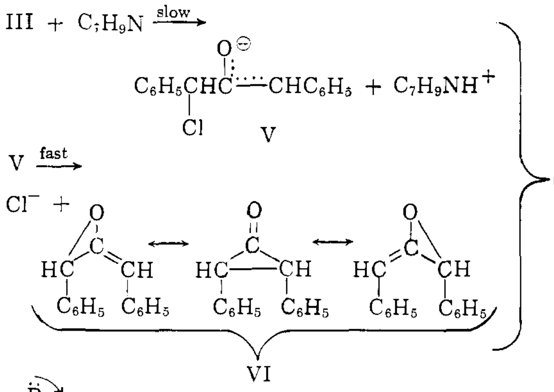
(10) See, for example, A. W. Fort, *J. Org. Chem.*, **26**, 332 (1961).

(11) See, for example, P. D. Bartlett in H. Gilman, "Organic Chemistry," Vol. III, J. Wiley and Sons, Inc., New York, N. Y., 1953, p. 87.

The relatively rapid base-catalyzed methanolysis can be understood readily on the basis that the loss of a chloride ion from a negatively charged enolate ion (V) should be faster than from the corresponding uncharged enol. In the base-catalyzed methanolysis of III, the loss of a chloride ion apparently occurs very soon after, or simultaneously with, the removal of a proton.



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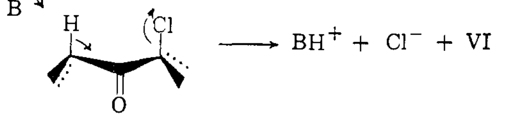

(6)

Both the two-step elimination 5 and the concerted process 6 are consistent with the observed kinetics and with the enhanced reactivity of α-chlorodibenzyl ketone (III) relative to chloroacetone (II) in lutidine-promoted methanolysis. Both stages of 5 would be favored by the presence of the phenyl groups. The expected conjugation of the phenyl groups with a developing delocalized system (VI) in the transition state for loss of the chloride ion, 5, could account for the rapid loss of chloride ion from V relative to protonation of V that is indicated by the failure of lutidinium ion to inhibit methanolysis. An alternative possibility, a concerted loss of a proton and a chloride ion, 6, is attractive because of its close analogy to the preferred reaction path for bimolecular dehydrohalogenation of alkyl halides.[14] A concerted elimination of hydrogen and chlorine from III to give a conjugated delocalized intermediate (VI) would be expected to be similar to facile dehydrohalogenations of alkyl halides to give conjugated olefins.[15,16] The corresponding reaction of chloroacetone would be expected to take place much less rapidly on the basis of this mechanism.

Chloroacetone (II) undergoes methanolysis very slowly in the presence of 2,6-lutidine. A solution of II (1 *M*) and 2,6-lutidine (1 *M*) in methanol produced approximately 1% of the theoretical amount of chloride ion in the course of seven days at room temperature. This result confirms the finding, above, that the function of lutidine in the methanolysis of α-chlorodibenzyl ketone (III) cannot be that of producing methoxide ion which then displaces chloride ion by direct nucleophilic attack, reaction 2. If III were to have undergone methanolysis by direct nucleophilic displacement of chloride ion under these conditions, then the unhindered structure II should have undergone lutidine-catalyzed methanolysis faster, rather than very much slower, than III.[17]

Desyl chloride yielded only a trace of chloride ion under conditions that resulted in complete methanolysis of α-chlorodibenzyl ketone (III). This result shows that there is no special feature of an α-chlorobenzyl ketone *per se* that could account for the enhanced reactivity of III in base-catalyzed methanolysis.

The function of the base, the almost negligible effect of lutidinium ion on the reaction rate, the structure of the product, and the enhanced reactivity of α-chlorodibenzyl ketone (III) in lutidine-catalyzed methanolysis are easily accommodated by an elimination–addition mechanism. In this interpretation, the enhanced reactivity of III relative to chloroacetone (II) can be attributed to conjugation of the phenyl groups of III with a developing delocalized system as described above.

The apparently successful dehydrochlorination of III by means of a weak base suggested the possibility of an iodide ion-promoted dehalogenation of an α,α'-dihaloketone, analogous to olefin-forming dehalogenation of vicinal dihalides,[14,18] and such a reaction was attempted with α,α'-dibromodibenzyl ketone (VII).

α,α'-Dibromodibenzyl ketone (VII) reacted with sodium iodide to produce iodine. In methanol solution, the major organic product was α-methoxydibenzyl ketone; in acetone–water, α-hydroxydibenzyl ketone was produced in excellent yield. The facile elimination of halogen from VII is comparable to the halogen elimination that takes place when stilbene bromide is treated with iodide ion.[19] This similarity is easily understood if electron over-

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[12] The slight upward drift of the calculated second-order rate constant (Table I) may be caused, in part, by a relatively slow lutidinium ion-catalyzed reaction. Another possible factor is the increase in ionic strength of the medium that occurred as the reaction progressed.

[13] A referee suggests the possibility that III undergoes methanolysis *via* an enolization–displacement mechanism, involving attack of a lutidine–methanol complex, $\overset{\delta-}{CH_3OH}\ldots\overset{\delta+}{NC_7H_9}$, upon the enol, $C_6H_5CHCl\overset{OH}{C}=CHC_6H_5$. This suggestion is open to the same objection raised against an enolization–ionization mechanism (above), namely, reaction through the enol form should be catalyzed by lutidinium ion, contrary to the observed kinetics. The proposed enolization–displacement mechanism is open to the additional objection that it should involve catalysis by lutidine at both stages of reaction, and the over-all reaction could not be expected to be first order in lutidine as required by the data of Table I.

[14] D. J. Cram in M. S. Newman, "Steric Effects in Organic Chemistry," J. Wiley and Sons, Inc., New York, N. Y., 1956, Chap. 6.

[15] C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, N. Y., 1953, p. 436.

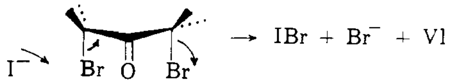
[16] Elimination of hydrogen bromide to give α-bromostilbene is reported to take place merely on warming the low-melting form of stilbene bromide with pyridine. Under the same conditions the high-melting form of stilbene bromide is said to lose bromine and regenerate stilbene: P. Pfeiffer, *Ber.*, **45**, 1810 (1912).

[17] The steric effect of an α-phenyl group on the direct nucleophilic displacement of chloride ion from an α-haloketone is illustrated by the reactions of II, III and desyl chloride with sodium iodide in acetone. Under conditions that produced very nearly the theoretical amount of sodium chloride from II, only 51 and 55% of the calculated amount of sodium chloride was obtained from III and desyl chloride respectively. A. W. Fort, unpublished observations.

[18] S. Winstein, D. Pressman and W. G. Young, *J. Am. Chem. Soc.*, **61**, 1645 (1939).

[19] C. F. van Duin, *Rec. trav. chim.*, **45**, 345 (1926). Experimental details were not reported, but it is to be expected that both forms of stilbene bromide (ref. 16) would undergo this reaction readily.

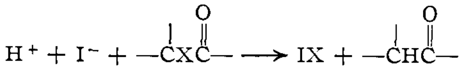
lap develops in a forming delocalized system, as in the related olefinic molecule,[18] during the departure of the halogen atoms, 7. Alternatively, the dehalogenation of VII could occur in discrete steps, in a manner analogous to reaction 5. By either process, dehalogenation results in the formation of a reactive intermediate, for which the delocalized structure VI



(7)

seems reasonable in view of its ease of formation and its reaction with solvent to give an α-substituted ketone product.

Clearly, in these reductive–displacement reactions of VII, reduction and displacement are intimately related, not independent reactions. Solvolysis of α-haloketones is very slow in the absence of catalysts,[7] and the α-halogenated dibenzyl ketones are not exceptional in this respect (see Experimental). Solvolytic displacement would produce hydrogen ion; consequently, reduction of α-haloketone by iodide ion could accompany solvolytic displacement, but reduction should be indiscrim-



$$H^+ + I^- + -\overset{|}{C}X\overset{\overset{O}{\|}}{C}- \longrightarrow IX + -\overset{|}{C}H\overset{\overset{O}{\|}}{C}-$$

inate. Accordingly, if the reaction of VII with iodide ion involved independent reduction and displacement steps, the reaction should be slow and should lead to mixtures containing appreciable amounts of dibenzyl ketone and disubstituted dibenzyl ketone as well as monosubstituted dibenzyl ketone.

It is generally accepted that the initial steps of the Favorskii rearrangement involve the elimination of the elements of hydrogen halide from the parent α-haloketone to give a reactive intermediate.[2] The present work furnishes evidence that the initial step or steps of the lutidine-promoted methanolysis of α-chlorodibenzyl ketone (III) involves the dehydrochlorination of III to give a delocalized intermediate, and it is reasonable to assume that the Favorskii rearrangement of III proceeds through the same intermediate.

Experimental

Melting points are corrected. Microanalyses are by Drs. Weiler and Strauss, Oxford, England.

α-Chlorodibenzyl ketone (III) was prepared by the procedure of Prévost and Sommière,[20] slightly modified. Sulfuryl chloride (86 g., 0.64 mole) was added to a stirred solution of 122 g. (0.58 mole) of dibenzyl ketone in 150 ml. of carbon tetrachloride at 45–50° over a period of 1.5 hours, and stirring at 45–50° was continued for 1.5 hours after the addition was completed. The reaction mixture was cooled in an ice-bath and the product was collected by filtration. Recrystallization from methanol then from benzene–hexane gave 90 g. (63%) of III, m.p. 65.5–66° (lit.[20] m.p. 68.5°). Further recrystallization from these solvents did not result in elevation of the melting point.

The Methanolysis of α-Chlorodibenzyl Ketone (III).—A solution of 12.2 g. (0.050 mole) of III and 10.7 g. (0.100 mole) of 2,6-lutidine in 100 ml. of anhydrous methanol was boiled under reflux for 1 hour. The reaction mixture was cooled and diluted with water. The oily product was separated and the methanol–water layer was extracted with four 50-ml. portions of pentane. The pentane extracts were combined with the oily layer and the combined solution was washed with dilute sulfuric acid, with dilute sodium carbonate solution, and with water, then dried, concentrated to a volume of about 100 ml. by evaporation of part of the solvent, and diluted with a little ether. Refrigeration of the pentane–ether solution, first at 0°, than at −20°, gave 10.8 g. (90%) of crude, yellow α-methoxydibenzyl ketone, m.p. 28–32°. Recrystallization of the crude product from hexane–ether (freezer) gave 9.7 g., almost colorless, m.p. 30–32°. Recrystallization of a portion of the product from ether gave a colorless sample, m.p. 31–32°.

Anal. Calcd. for $C_{16}H_{16}O_2$: C, 79.97; H, 6.71. Found: C, 80.12; H, 6.59.

The oxime of α-methoxydibenzyl ketone was recrystallized from methanol, m.p. 82–83°.

Anal. Calcd. for $C_{16}H_{17}NO_2$: C, 75.27; H, 6.71; N, 5.49. Found: C, 75.12; H, 6.74; N, 5.35.

The 2,4-dinitrophenylhydrazone of α-methoxydibenzyl ketone was recrystallized two times from ethanol; m.p. 147.5–148.5°.

Anal. Calcd. for $C_{22}H_{20}N_4O_5$: C, 62.85; H, 4.80; N, 13.33. Found: C, 62.65; H, 4.80; N, 13.50.

Kinetics of Methanolysis.—At zero time 5.00 ml. of a solution of 2,6-lutidine in methanol was added by means of a hypodermic syringe to 20.0 ml. of a methanol solution of α-chlorodibenzyl ketone (III). At time *t* silver nitrate and nitric acid in methanol–water were added in excess to the reaction flask. The flask was removed from the thermostat, and the silver chloride was collected in a filtering crucible, washed with methanol and with water, and dried at 100°. No lutidine was added to the reaction flask for a used zero time determination of chloride ion. For the determination of chloride ion at "infinite" time the reaction was allowed to proceed for 3 or 4 days. The hydrochloric acid-catalyzed methanolysis of III was followed similarly, except that excess 2,6-lutidine was added to the reaction mixture used for the determination of chloride ion at "infinite" time.

Each run reported in Table I was corrected for autocatalyzed methanolysis of III that occurred prior to the addition of lutidine. At room temperature, a methanol solution of III (0.125 *M*) gave, on treatment with silver nitrate solution, 0.9, 1.7, 5.6, 12.1, 15.3 and 22.0% of the theoretical amount of silver chloride after 22, 43, 92, 139, 168 and 213 hours, respectively.

The methanolysis reactions of chloroacetone and desyl chloride were not examined in detail, and no effort was made to find conditions under which reaction would occur at a reasonable rate.

A solution of desyl chloride[21] (0.4 *M*) and 2,6-lutidine (0.4 *M*) in methanol was allowed to stand at room temperature for 7 days. The amount of silver chloride (less than 1%) that precipitated immediately upon addition of excess silver nitrate and nitric acid in methanol–water was not significantly greater than the amount produced when a fresh solution of reactants was treated similarly.

The Reaction of α,α′-Dibromodibenzyl Ketone (VII) **with Sodium Iodide.**—A solution of VII[22] (m.p. 114–116°, 14.7 g., 0.040 mole) and sodium iodide (30 g., 0.20 mole) in 350 ml. of anhydrous methanol was boiled under reflux for 1 hour. The reaction mixture was treated with excess dilute sodium thiosulfate solution, and extracted with four 100-ml. portions of pentane. The combined extracts were washed with water, dried, and the solvent was removed by distillation. Distillation of the residue at reduced pressure gave a small forerun, which was discarded; 5.5 g. (57%) of α-methoxydibenzyl ketone, b.p. 142° (*ca.* 0.5 mm.); and 2.6 g. of dark, viscous pot residue. The pale yellow product crystallized under refrigeration, and it gave an oxime, m.p. 81–82°, after one recrystallization from methanol. Recrystallization of the crude methoxydibenzyl ketone product from methanol (freezer) gave a colorless product with about 50% loss of material, m.p. *ca.* 29°, infrared spectrum like that of the reaction product of III with lutidine in methanol.

A solution of 7.36 g. (0.020 mole) of VII in 50 ml. of acetone was added dropwise to a boiling solution of 7.50 g. (0.050 mole) of sodium iodide in 40 ml. of water and 20 ml. of acetone (30 min.). The mixture was heated under reflux

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(20) C. Prévost and A. Sommière, *Bull. soc. chim. France*, [5] **2**, 1151 (1935).

(21) A. M. Ward, "Organic Synthesis," Coll. Vol. II, John Wiley and Sons, Inc., New York, N. Y., (1943), p. 159.

(22) (a) P. Ruggli, H. Dahn and J. Wegmann, *Helv. Chim. Acta*, **29**, 113 (1946); (b) E. Bourcart, *Ber.*, **22**, 1368 (1889).

for 20 min. more, then was allowed to cool gradually over a period of 1 hour. The reaction mixture was diluted with water and the crude, tan α-hydroxydibenzyl ketone product was collected by filtration, washed with water, and air-dried; 4.22 g. (93%), m.p. 111–115°. Recrystallization from methanol then from cyclohexane gave 3.51 g. of almost colorless product, m.p. 114.5–116.5° (lit.[23] m.p. 115–116°).

The oxime of α-hydroxydibenzyl ketone was recrystallized twice from methanol–water; m.p. 91–92°.

Anal. Calcd. for $C_{15}H_{15}NO_2$: C, 74.66; H, 6.27; N, 5.81. Found: C, 74.82; H, 6.54; N, 5.51.

The 2,4-dinitrophenylosazone of α-hydroxydibenzyl ketone was recrystallized from ethyl acetate; m.p. 250–251°.

Anal. Calcd. for $C_{27}H_{20}N_8O_8$: C, 55.48; H, 3.45; N, 19.17. Found: C, 55.75; H, 3.65; N, 19.16.

In a control experiment, 4.14 g. of VII in 80 ml. of methanol was boiled under reflux for 1 hour, then the mixture was allowed to stand at room temperature for 24 hours. The mixture was cooled and VII was collected by filtration; 3.19 g. (77% recovery).

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(23) M. Tiffeneau and J. Lévy, *Bull. soc. chim. France,* [4] **37,** 1247 (1925).

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF KENTUCKY, LEXINGTON, KY.]

Evidence for a Delocalized Intermediate in the Favorskii Rearrangement. The Reaction of 6-Tosyloxyisophorone with Sodium Methoxide in Methanol[1]

BY ARTHUR W. FORT

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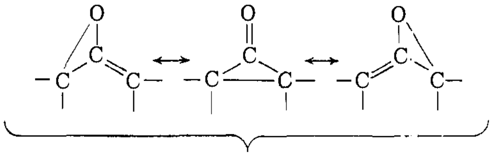
The reaction of 6-tosyloxyisophorone (II) with excess sodium methoxide in methanol gave a mixture of 2- and 6-methoxyisophorones (III and IV) and methyl trimethylcyclopentenecarboxylates (VIII and X). At very low methoxide ion concentration only traces of Favorskii rearrangement products (VIII and X) were produced, and the yield of 6-methoxyisophorone (IV) was increased accordingly. A common delocalized intermediate (VII) is proposed for the four reaction products.

Several reported examples of the Favorskii rearrangement seem to proceed through a delocalized intermediate.[2] Hybrid structure I, involving delocalization of four p-electrons among four parallel p-orbitals, is one possible way of representing the proposed intermediate.[2c] Structure I differs from the zwitterionic representation[2a,b] mainly in that I suggests the likelihood of some π-overlap between the radial atoms of the proposed delocalized system.



I

Previously reported work indicated that, in the absence of strong, nucleophilic base, I reacts with hydroxylic solvent to produce α-substituted ketone products instead of Favorskii rearrangement products.[2c] The present work is devoted to further study of this possible reaction path.

According to the above interpretation of the Favorskii rearrangement, the formation of Favorskii rearrangement products can be suppressed and α-substituted ketones will be produced instead, if alkali is added slowly to a solution of the α-haloketone or related compound at such a rate that the alkali is consumed as rapidly as it is added, and the concentration of alkali in the reaction mixture remains very low throughout the reaction. In order to test this possibility, the reaction of 6-tosyloxyisophorone (II) with sodium methoxide in methanol has been examined.

6-Tosyloxyisophorone (II) possesses several desirable features for present purposes: it is a stable, crystalline compound, prepared from an α-ketol of known structure[3]; it is a derivative of an unsymmetrical ketone, a feature that makes possible easy detection of substitution with rearrangement, if it occurs; and a *gem*-dimethyl group is favorably located to hinder direct nucleophilic displacement of the tosyloxy group by methoxide ion.

Results and Discussion

The addition of a methanol solution of 6-tosyloxyisophorone (II) to a solution of five equivalents of sodium methoxide in methanol gave a 66% yield of a distilled mixture of neutral $C_{10}H_{16}O_2$ products. Gas chromatography revealed the presence of four components in the product mixture. The compounds eluted first in gas chromatography were a pair of methyl trimethylcyclopentenecarboxylates; the last compounds eluted were a pair of methoxyisophorones (see below). The yield of methoxyisophorones was approximately equal to the yield of methyl esters in this reaction (Fig. 1, run A).

The proportion of sodium methoxide was decreased to 1.1 equivalents and the reaction with 6-tosyloxyisophorone was repeated. The yield of methoxyisophorones in this run was approximately twice the yield of methyl esters, but the total yield of the four products remained unchanged (Fig. 1, run B).

In a third reaction, 1.1 equivalents of methanolic sodium methoxide was added dropwise over a period of six hours to a methanol solution of 6-tosyloxyisophorone. Under these conditions, only a trace of esters was produced (Fig. 1, run C), but the total yield of methoxyisophorones and methyl esters in this small-scale reaction was comparable (54%) to those of the reactions above.

The product that was eluted last in gas chromatography was identified as 2-methoxyisophorone

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(1) (a) Presented at the Organic Division, A.C.S. Meeting, Chicago, Ill., September, 1961; abstracts, p. 19Q. (b) Supported in part by the American Academy of Arts and Sciences.

(2) (a) J. G. Burr, Jr., and M. J. S. Dewar, *J. Chem. Soc.,* 1201 (1954); (b) H. O. House and W. F. Gilmore, *J. Am. Chem. Soc.,* **83,** 3972, 3980 (1961); (c) A. W. Fort, *ibid.,* **84,** 2620 (1962).

(3) A. W. Fort, *J. Org. Chem.,* **26,** 332 (1961).