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A Comparison of Carbon-Carbon Double Bond and Cyclopropane as Neighboring Groups. Solvolysis Rates of 1-Aryl-4--cyclopropylbutyl Chlorides

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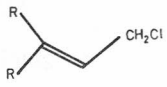
1-Phenyl-4-cyclopropylbutyl chloride *13*a and 1-*m*-bromophenyl-4-cyclopropylbutyl chloride *13*b were prepared and their solvolysis rates measured. As with corresponding 1-aryl-5-hexenyl chlorides *9*, no reaction rate increases were observed. In contrast, 1-aryl-5-methyl-5-hexenyl chlorides *10* and *1*-aryl-5-heptenyl chlorides *11* which are isomeric to *13* solvolyze with significant anchimeric assistance of the methyl-substituted aliphatic double bond. This failure of the cyclopropane ring to act as a neighboring group is rationalized in terms of possible charge delocalization in the reaction transition state arising from *13* and from *10* or *11*.

INTRODUCTION

It is a well known fact that the cyclopropane ring in many reactions behaves similarly to a carbon-carbon double bond. Thus both are known to be able to donate electrons and stabilize a neighboring positive charge through delocalisation. In a solvolysis reaction the presence of either of these structural features in the substrate often produces large rate accelerations and extensive skeletal rearrangements[2,3]. In S_N1 reactions the reactivity of allyl chloride *1*a, a primary substrate, is between those of isopropyl and tert-butyl chloride[2]. In several solvolyses a neighboring cyclopropane ring was shown to be even more efficient than the double bond in accelerating the reaction rate. Thus cyclopropylcarbinyl sulfonate esters *2*a solvolyze about ten times faster than the corresponding allyl derivatives[3,4]. It is however not clear if the reactivity of cyclopropylcarbinyl derivatives should be compared to that of allyl or of homoallyl derivatives *3*. There are indications that the large solvolytic reactivity of cyclopropylcarbinyl derivatives might be due to conjugative electron release (vertical stabilization)[5] as happens with allyl derivatives. On the other hand, S_N1 reactions of both homoallyl and cyclopropylcarbinyl compounds yield very similar product mixtures indicating that both reactions proceed by way of structurally closely related carbocations[3,6]. In the former case it seems necessary to invoke bridging in the rate determining step in order to account for both the observed rate increase (about 4 times relative to the saturated analogue) and the skeletal rearrangement[6a]. In the latter case it is not clear if bridging occurs in the reaction transition state or subsequent

to it[5b]. If anchimeric assistance is responsible for the observed rate increases in reactions of both cyclopropylcarbinyl and homoallyl systems then it can be estimated that a cyclopropyl group is about 10^5—10^6 times more efficient than a vinyl group in accelerating solvolyses rates by that mechanism[6a,7].



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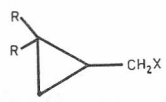

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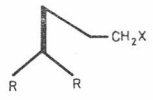

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a, R = H
b, R = CH_3

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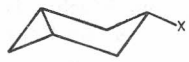

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Another indication that cyclopropyl is a better neighboring group than vinyl is obtained by comparing the solvolytic behaviour od 3-cyclopentenyl and *cis*-bicyclo(3,1,0)hexyl derivatives, *4* and *5* respectively. In the latter case small rate increases and skeletal rearrangements have been observed[8] while there is no indication of anchimeric assistance with *4*[9]. In this respect, a further example is the solvolysis of *anti*-7-norbornyl derivatives *6*, *7* and *8*. Here, the double bond[10] as well as cyclopropane[11] produce tremendous rate increases but the latter is more efficient than the former by a factor of 10^3—10^4.

6

7

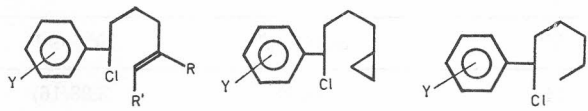
8

Rel. rate 1 10^{11} $10^{14}-10^{15}$

Finally it should be mentioned that there are strict geometric requirements for participation by either of the two groups. If those requirements are not met in the substrate, rate accelerations are much less pronounced or even nil[10-12].

In the course of our work on π-participation we have examined the solvolytic behaviour of the series of chlorides *9*—*12* in some detail[13]. It was found that most compounds of the series *10*—*12* solvolyze with assistance of the aliphatic double bond while there is no indication of neighboring group participation in reactions of chlorides of series *9*. In view of these results it seemed of interest to investigate the solvolysis rates of chlorides *13* in which the aliphatic double bond of *9* has been replaced by a cyclopropane ring. Since in series *9*—*12* as well as in *13* the aliphatic chain is rather flexible, there should be no difficulty for the substrates to assume a conformation favorable to participation by the neighboring group. Geometrical factors being thus minimized, solvolysis rates could then possibly provide a better measure

for relative efficiencies of the two neighboring groups. Herewith, we report the results of this investigation.



13 14

9, R = R′ = H
10, R = CH_3 R′ = H
11, R = H R′ = CH_3
12, R = R′ = CH_3
For all series: a, Y = H; b, Y = *m*—Br

RESULTS

1-Phenyl-4-cyclopropylbutyl chloride *13*a and 1-*m*-bromophenyl-4-cyclopropylbutyl chloride *13*b were prepared according to the Scheme and their solvolysis rates measured. For comparison, the reaction rates of 1-phenylhexyl chloride *14*a and 1-*m*-bromophenylhexyl chloride *14*b were also measured in the same solvents and temperature. First order rate constants were calculated and the results are shown in Table I.

Scheme

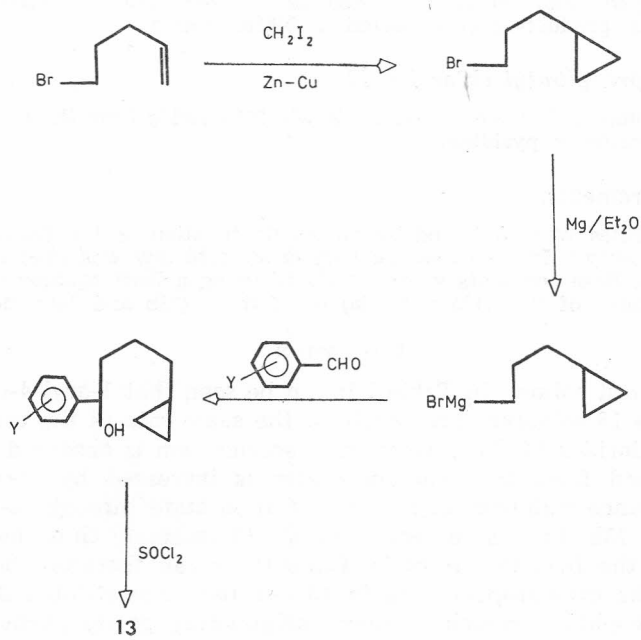


TABLE I

Solvolysis Rates of 1-Aryl-4-cyclopropylbutyl Chlorides 13 *and 1-Arylhexyl Chlorides* 14 *at* 50.9 °C

Chloride	Y[a]	Solvent[b]	$10^5\ k/s^{-1}$[c]	k_{13}/k_{14}
*13*a	H	80 E	3.98(16)	0.78
*14*a	H	80 E	5.13(14)	
*13*b	*m*-Br	97 T	4.38 (7)	1.00
*14*b	*m*-Br	97 T	4.39(39)	

[a] Substituent on the phenyl ring. [b] 80 E and 97 T are 80 vol. % aqueous ethanol and 97 wt. % aqueous 2,2,2-trifluoroethanol respectively. [c] Numbers in parentheses are standard deviations of the mean, e. g. 3.98 (16) = 3.98 ± 0.16.

EXPERIMENTAL

1-Bromo-3-cyclopropylpropane[14]

A mixture of zinc powder (4.6 g, 0.07 mol), cuprous chloride (7 g, 0.07 mol) and 20 mL of anh. ether was refluxed for 30 min under stirring and nitrogen atmosphere. Methylene iodide (7 g, 0.026 mol) in 10 mL of anh. ether was then added, followed after 30 min of refluxing by addition of 1-bromo-4-pentene (3 g, 0.02 mol) in 10 mL of anh. ether. Refluxing and stirring was continued for 48 hrs. After the usual work up, the reaction product was purified by column chromatography on silica gel with petroleum ether as eluent. The yield of the pure product, which gave the expected ^{1}H NMR spectrum, was 2.52 g (77%).

1-Aryl-4-cyclopropylbutanols

The title compounds were prepared[13] from the Grignard reagent of 1-bromo-3-cyclopropylpropane and either benzaldehyde or *m*-bromobenzaldehyde in yields of 27—30%. Both products gave expected ^{1}H NMR spectra.

1-Aryl-4-cyclopropylbutyl chlorides 13

The title compounds were prepared[13] in 80—90% yields from the parent carbinol and thionyl chloride in pyridine.

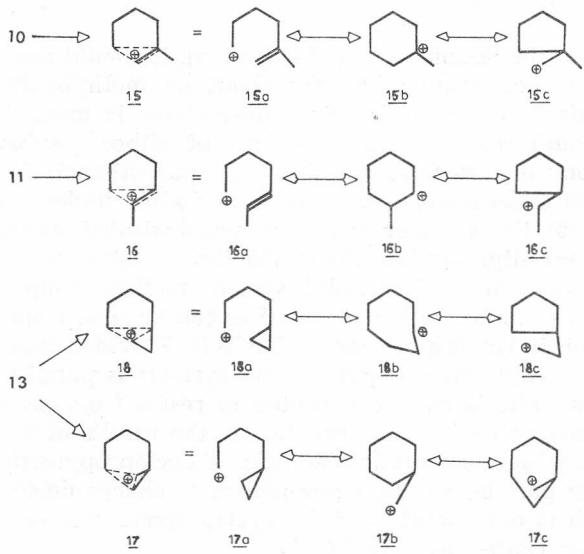
Kinetic measurements.

Solvolysis rates were followed by automatic titration of the liberated acid as described previously[13]. In all cases the first order rate law was obeyed to at least 85% completion. Rate constants were calculated using a least squares program and represent the mean of five (*13*a and *14*a) or of three (*13*b and *14*b) measurements.

DISCUSSION

From the last column in Table I it can be seen that 1-aryl-4-cyclopropylbutyl chlorides *13* solvolyze practically at the same rate as the corresponding 1-arylhexyl chlorides *14*. No relative rate acceleration is observed even if the electron demand from the reaction center is increased by decreasing the benzylic resonance stabilization of the transition state through *m*-bromo substitution as in *13*b. In this respect chlorides *13* resemble chlorides *9*[13] as can be seen from the first two rows in Table II. It can therefore be concluded that neither the cyclopropane ring in *13* nor the unsubstituted double bond in *9* are nucleophylic enough to make neighboring group participation (k_Δ)

efficiently competitive with unassisted solvolysis (k_c). However, it might be more appropriate to compare the behaviour of chlorides *13* with that of chlorides *10* and *11* to which they are isomeric. The two latter compounds, which contain a methyl-substituted double bond solvolyze faster than the analogues with a saturated aliphatic chain (Table II)[13]. The observed rate accelerations are not large but are significant, i. e. due to double bond participation as ascertained by other means ($\varrho\,\sigma$ correlations, activation parameters, isotope effects). Here, rate constants k_Δ and k_c are of comparable magnitudes. Smaller k_Δ/k_c ratios in reactions of *13* relative to those of *10* and *14* can be explained in terms of the structure of carbocation-like transition states. It has been shown[13] that in the reactions of *10* and *11* transition states of the k_Δ process resemble carbonium ions cognate to *15* and *16*, respectively rather than charge localized carbenium ions. The former can be depicted as resonance hybrids of valence bond forms *15* A—C and *16* A—C. The analogous stabilization in reactions of *13* would possibly involve species like *17* and/or *18* depending upon which edge of the cyclopropane ring is involved in participation.



In valence bond formulations these are hybrids of forms *17* A—C and *18* A—C, respectively. In all three cases *10*, *11* and *13*, the importance of the k_Δ route relative to k_c will be determined by the stability of forms B and/or C relative to form A. In this respect, the degree of alkyl substitution at the site of positive charge location is of prime importance. Participation in reactions of *13* displaces the charge to a secondary and a primary center (*18* B and *18* C resp.) or to two primary centers (*17* B and *17* C). The analogous process with *10* involves charge delocalization to a tertiary and a primary center (*15* B and *15* C resp.) and in those of *11* to two secondary centers (*16* B and *16* C). By this criterion participation should therefore be favored in reactions of *10* and *11* relative to *13*.

From this discussion it might be inferred that participation in reactions of *13* could be enforced by alkyl substitution on the cyclopropane ring in the

TABLE II[a]

Solvolyses of 1-Aryl-5-alkenyl Chlorides 9—12. Relative Rates[d] at 50.0 °C

Chloride	Y[b]	Solvent[c]	Relative rate[d]
*9*a	H	80 E	0.92
*9*b	*m*-Br	97 T	1.37
*10*a	H	80 E	1.50(1.81)
*10*b	*m*-Br	97 T	4.41(2.49)
*11*a	H	80 E	1.43(4.49)
*11*b	*m*-Br	97 T	6.64(3.89)
*12*a	H	80 E	5.68(7.93)
*12*b	*m*-Br	97 T	58.2[e]

[a] Compiled from data in ref. 13. [b] Substituent on the phenyl ring. [c] 80 E and 97 T are 80 vol. % aqueous ethanol and 97 wt. % aqueous 2,2,2-trifluoroethanol respectively. [d] Rates relative to the analogue with the saturated aliphatic chain. In parentheses are rates relative to analogous chlorides of series *9*. [e] At 25.0 °C.

same way as with the double bond (*10*—*12* vs. *9*). It should however be pointed out that the rate acceleration brought about by methyl-substitution on the ring in solvolysis of cycloproylcarbinyl derivatives is much less pronounced (per methyl group) than it is in reactions of either γ-substituted allyl or δ-substituted homoallyl derivatives. Thus aqueous ethanolysis of *2*b (X = Cl) is only about 400 times faster than that of *2*a[15] while under similar conditions *1*b reacts 10^7—10^8 times faster than the unsubstituted analogue *1*a[16]. Also, formolysis of homoallyl tosylate *3*b is 450 times faster than that of *3*a[6b]. In comparison to allyl or to homoallyl system methyl-group rate effects on solvolysis of *9* (*10*—*12*) are rather modest[13] as can be seen from the numbers in parentheses given in the last column of Table II. Provided that the comparison with allyl or homoalyl / cyclopropylcarbinyl systems is permissible, even more parsimonious rate effects can be expected to result from methyl substitution on the cyclopropane ring in *13*. In conclusion, the results of this work indicate that the relatively large solvolytic reactivity of cyclopropylcarbinyl derivatives might at least in part be due to a mechanism of charge delocalization (conjugation)[17,18] which is not operative if the cyclopropane ring is further removed from the reaction center, as with *13*.

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SAŽETAK

Usporedba dvostruke veze ugljik-ugljik sa ciklopropanom kao susjednim skupinama. Brzine solvolize 1-aril-4-ciklopropilbutil klorida

D. Ostović, O. Kronja i S. Borčić

Priređeni su 1-fenil-4-ciklopropilbutil klorid *13*a i 1-*m*-bromfenil-4-ciklopropilbutil klorid *13*b te su izmjerene njihove brzine solvolize. Pronađeno je da reakcije ovih spojeva nisu ubrzane, analogno reakcijama 1-aril-5-heksenil klorida. Suprotno takovom ponašanju, kloridi *10* i *11*, koji su izomerni sa *13*, solvoliziraju uz značajno sudjelovanje alifatske metil-supstituirane dvostruke veze. Činjenica da u ovom slučaju ciklopropan ne djeluje kao susjedna skupina tumačena je različitom delokalizacijom naboja u prelaznom stanju reakcije supstrata *13* u usporedbi sa *10*, odnosno *11*.

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