

Reactivity–Selectivity Relationships. Part 5.¹ Effect of Solvent Ionizing Power on the Selectivity of Diphenylmethyl Derivatives

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The effect of solvent polarity on the selectivity of a series of substituted diphenylmethyl derivatives is investigated. The key result is that all substrates studied exhibit higher selectivity in solvents of higher polarity. Three possible explanations for this effect are proposed. (a) Greater stabilization of solvolytic intermediates in more polar solvents results in these species showing greater selectivity. (b) Increased solvent ionizing power results in greater dissociation to free ions which are intrinsically more selective. (c) The effect of an increase in solvent polarity on the nucleophilicity of ethanol and water may result in enhanced ethanol nucleophilicity. No clear differentiation between these three alternatives appears possible at the present time.

THE existence of reactivity–selectivity relationships in solvolytic reactions are now well established.^{2–5} Substrates which yield relatively stable solvolytic intermediates were found to exhibit correspondingly high selectivity when reacted with competing nucleophiles. This inverse relationship between the reactivity of a species and its ability to discriminate between a number of competing reagents is predicted by the Reactivity–Selectivity Principle (RSP).⁶ The principle states that within a restricted family of substrates any increase in the reactivity of a particular substrate due to some perturbation (a substituent or medium change, for example) will induce a corresponding decrease in the selectivity of that substrate; conversely, any decrease in reactivity will bring about a corresponding increase in selectivity.

A number of examples of such relationships are known. Sneen² and Schleyer³ showed that the selectivity of alkyl derivatives toward the competing nucleophiles, azide ion and water, was related to the solvolytic reactivity of the substrates. Harris⁴ noted the existence of such relationships using the competing nucleophiles, ethanol and water, while Okamoto⁵ also observed the interdependence of reactivity and selectivity for solvolyses in phenol, an ambident nucleophile.

In all these studies the variation in reactivity was brought about by structural changes in the substrates undergoing solvolysis. From earlier work on benzyl and octyl derivatives performed in this laboratory we proposed that the observation of increased selectivity in solvents of increasing polarity constituted possible evidence for ion pair intermediates.¹ However, other explanations are also possible.⁷

In this work, the selectivity of a series of substituted diphenylmethyl derivatives is examined in media of variable ionizing power and an attempt made to understand the factors responsible for the observed variation.

RESULTS

The selectivities of a series of substituted diphenylmethyl chlorides and diphenylmethyl bromide toward competitive attack by ethanol and water in the binary medium, aqueous ethanol (70–95% v/v) were determined by product analysis using g.l.c. The selectivity values, k_E/k_W , were calculated

¹ Part 4, A. Pross and H. Aronovitch, *J.C.S. Chem. Comm.*, 1976, 817.

² R. A. Sneen, J. V. Carter, and P. S. Kay, *J. Amer. Chem. Soc.*, 1966, **88**, 2594.

³ D. J. Raber, J. M. Harris, R. E. Hall, and P. v. R. Schleyer, *J. Amer. Chem. Soc.*, 1971, **93**, 4821.

according to equation (1).⁴ k_E and k_W are the specific rate constants for nucleophilic attack by ethanol and water

$$S = k_E/k_W = \frac{[\text{diphenylmethyl ethyl ether}][\text{water}]}{[\text{diphenylmethanol}][\text{ethanol}]} \quad (1)$$

respectively in the product-determining step. The data for solvolyses at 25° are listed in Table 1. Data for bis-

TABLE 1
Selectivity^a of substituted diphenylmethyl chlorides in aqueous ethanol at 25°

Substituent	Ethanol (% v/v)			
	70 ^b	80	90	95
<i>p</i> -H	3.25	2.78	2.54	2.32
<i>p</i> -H ^c	4.13	3.69	3.34	3.09
<i>p</i> -Cl	2.84	2.49	2.14	2.03
<i>p</i> -Me	4.66	3.93	3.54	3.32
<i>p,p'</i> -Cl ₂	2.75	2.41	2.03	1.93
<i>p,p'</i> -Cl ₂ (75°)	2.94	2.63	2.02	2.07

^a Selectivity defined as k_E/k_W and determined from equation (1). Product ratios determined by g.l.c. in the presence of excess lutidine. Data based on at least three determinations on 2–4 samples. Error is estimated to be $\pm 5\%$. ^b Our data in 70% ethanol differ substantially from values previously reported by Harris.^{4a} This is true in particular for bis-*p*-chlorophenylmethyl chloride which was reported as exhibiting inverse selectivity. ^c Data are for diphenylmethyl bromide.

p-chlorophenylmethyl chloride at 75° are included as well.

The effect on selectivity of changes in solvent polarity is also examined by the addition of variable amounts of acetone to a fixed ethanol–water mixture. The data for diphenylmethyl chloride in 50% aqueous ethanol with variable amounts of acetone are listed in Table 2.

TABLE 2
Effect of acetone on selectivity^a of diphenylmethyl chloride in 50% aqueous ethanol at 25°

Selectivity	Acetone (%) ^{b,c}			
	20	40	60	80
	3.56	3.24	2.78	2.44

^a From equation (1). ^b Volume %. ^c Solution composed of $x\%$ of 50% ethanol and $(100 - x)\%$ acetone.

In order to ensure that product formation is irreversible and that ether and alcohol products do not interconvert under the reaction conditions, *p*-methyl-diphenyl- and bis-*p*-chlorophenyl-methanol were treated with aqueous ethanol

⁴ (a) J. M. Harris, D. C. Clark, A. Becker, and J. F. Fagan, *J. Amer. Chem. Soc.*, 1974, **96**, 4478; (b) J. M. Harris, A. Becker, J. F. Fagan, and F. A. Walden, *ibid.*, p. 4484.

⁵ K. Okamoto and T. Kinoshita, *Chem. Letters*, 1974, 1037.

⁶ A. Pross, *Adv. Phys. Org. Chem.*, 1977, **14**, 69.

⁷ A. Pross, H. Aronovitch, and R. Koren, *J.C.S. Perkin II*, in the press.

in the presence of lutidine for a period corresponding to 10 half-lives. G.l.c. analysis of the two mixtures indicated the presence of ether to the extent of *ca.* 2% for the more labile *p*-methyl-derivative and none at all for the *p,p'*-dichloro-derivative. This result suggests that our data, reported to within 5% accuracy, are not significantly modified by any equilibration that may take place.

DISCUSSION

It is readily apparent that in more aqueous solutions all substrates exhibit greater selectivity. The trend is consistent with the behaviour exhibited by diphenylmethyl *p*-nitro- and *p*-methoxy-benzoates as found by Harris.^{4b} This result, however, is in contrast to the behaviour of 1- and 2-adamantyl⁸ as well as norbornyl derivatives.^{4b} The data are presented as a plot of log *S* against solvent ionizing power as measured by *Y* values. Series of approximately linear correlations were obtained

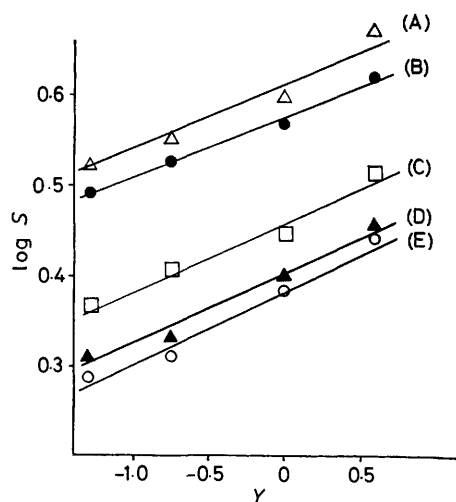


FIGURE 1 Plot of log *S* against *Y* values for (A) *p*-methyl-diphenylmethyl chloride, (B) diphenylmethyl bromide, (C) diphenylmethyl chloride, (D) *p*-chlorodiphenylmethyl chloride, (E) bis-*p*-chlorophenylmethyl chloride in aqueous ethanol at 25°

for all five compounds studied and are presented in Figure 1. The fact that this change in selectivity may be attributed to the corresponding change in solvent polarity is confirmed by examination of the selectivity of diphenylmethyl chloride in 50% aqueous ethanol mixed with varying amounts of acetone. The data listed in Table 2 indicate that at high acetone concentration low selectivity values are obtained. Since acetone is a medium of relatively low polarity compared with aqueous alcohol, the addition of acetone brings about a reduction in solvent polarity.

A priori, the effect of changes in solvent polarity is likely to influence the selectivity of diphenylmethyl derivatives in a number of different ways. We discuss the likelihood of these being responsible for the selectivity variation.

⁸ Y. Karton and A. Pross, *J.C.S. Perkin II*, in the press.

⁹ G. A. Russell, (a) *J. Amer. Chem. Soc.*, 1958, **80**, 4987; (b) *Tetrahedron*, 1960, **8**, 101.

¹⁰ H. L. Goering and H. Hopf, *J. Amer. Chem. Soc.*, 1971, **93**, 1224.

(a) A change in solvent polarity is likely to change the selectivity of the solvolytic species which undergo product-determining attack. Since changes in solvent polarity are expected to change the reactivity of the species involved, a corresponding change in selectivity would be anticipated. This effect has been noted previously for chlorine radicals.⁹ In aromatic solvents in which chlorine radicals are stabilized through complexation greater selectivity is observed. The increase in selectivity was found to be dependent on the basicity of the aromatic solvent. More basic solvents induced greater radical selectivity.⁹ The effect of an increase in solvent polarity on solvolytic intermediates possessing significant charge concentrations is likely to operate in the same way. In more polar mixtures greater selectivity is anticipated. This explanation is therefore consistent with the observed increase in selectivity at high solvent polarity.

(b) A change in solvent polarity is likely to change not only the selectivity of each solvolytic species but also the proportion of nucleophilic attack on the various species. This possibility has been pointed out by Harris^{4a} who considered changes in selectivity to be diagnostic of product formation from more than one solvolytic species. This may be expressed by equation (2).^{4a} Thus the observed selectivity, *S*_{obs} is dependent

$$S_{\text{obs}} = \sum_i a_i S_i \quad (2)$$

not only on *S*_{*i*}, the intrinsic selectivity of each species, but on *a*_{*i*} the proportion of product formation from each species, which is itself solvent dependent. For diphenylmethyl derivatives, it is now established that during solvolysis, product formation takes place by nucleophilic attack on both solvent separated ion pairs and free carbocations.¹⁰ On the basis of trapping experiments with azide ion it was shown that product formation, directly from an intimate ion pair, does not take place. This suggests, therefore, that a change in solvent ionizing power is likely to change the proportion of nucleophilic attack on solvent separated ion pair and free carbocation. The increase in selectivity observed at higher solvent polarity would be consistent with a shift in the quasi-equilibrium toward greater dissociation if free carbocations were intrinsically more selective toward ethanol and water than solvent separated ion pairs. This point is not clear at present; however one factor which supports this supposition is that solvent separated ion pairs exhibit inverse selectivity, *i.e.* *k*_E/*k*_W < 1, when product formation occurs predominantly *via* front side attack.^{4a,11} This is because, by this pathway, water is more nucleophilic than ethanol (contrary to the normal order¹²) due to leaving group stabilization. Therefore, solvent separated ion pairs, capable of both back side and front side attack, are likely to exhibit lower selectivity, due to the

¹¹ A. Pross, *Tetrahedron Letters*, 1975, 637.

¹² (a) T. W. Bentley, F. L. Schadt, and P. v. R. Schleyer, *J. Amer. Chem. Soc.*, 1972, **94**, 993; (b) F. L. Schadt, T. W. Bentley, and P. v. R. Schleyer, *ibid.*, 1976, **98**, 7667.

inverse k_E/k_W value contributed to the overall selectivity by the latter pathway.

This interpretation is further supported by the observation that a plot of $\log S$ against σ^+ for all solvents gives a significant correlation (Figure 2). A least

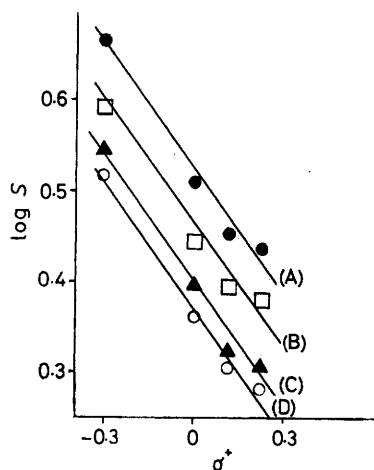


FIGURE 2 Plot of $\log S$ against σ^+ for substituted diphenylmethyl chlorides in (A) 70%, (B) 80%, (C) 90%, (D) 95% aqueous ethanol at 25°

squares analysis gave ρ values as follows: -0.45 in 70% ethanol, -0.42 in 80% ethanol, -0.47 in 90% ethanol, and -0.46 in 95% ethanol. These values are equivalent within experimental error and indicate an average ρ value of -0.45 ± 0.05 . Substituents capable of stabilizing the carbocationic species formed during solvolysis bring about greater selectivity in these species in accord with the RSP. The correlation is also attributed to the effect of substituents on the quasi-equilibrium: electron-releasing substituents enhance dissociation to free ions. The fact that diphenylmethyl bromide (see Table 1) is more selective than the chloride is consistent with this interpretation. Br^- , being a better leaving group than Cl^- , also brings about greater dissociation to free carbocations.

The specific effect of the substituents on the selectivity of the solvent separated ion pair and free ion should not, however, be overlooked, since this may also affect the observed substituent dependence of selectivity. With regard to free cations, Ritchie's work on the N_+ relationship¹³ has provided strong experimental evidence that cation selectivity is substituent independent. This surprising observation has been attributed to compensating solvation effects.¹⁴ The effect of substituents on the selectivity of solvent separated ion pairs is less certain. However, such an effect may well be slight. This is because stabilization of the solvent separated ion pair is likely to enhance the selectivity of both back side and front side attack. However, these contributions are opposed to each other, because for back side attack $k_E/k_W > 1$, while for front side attack $k_E/k_W < 1$. In

other words, enhanced water nucleophilicity during front side attack and enhanced ethanol nucleophilicity during back side attack may result in the observation of a small overall selectivity change for different substituents in the solvent separated ion pair.

(c) The possibility exists that changes in selectivity of the diphenylmethyl derivatives is due to a variation in the relative reactivity of ethanol and water and is not due to the substrates at all. As a result of changes in solvent polarity the nucleophilicities of both ethanol and water are expected to vary. If this variation is different for each nucleophile then a change in selectivity will occur. It is difficult to assess the validity of this explanation since there is no information available regarding the relative nucleophilicity of ethanol and water as a function of solvent composition. However, if the effect is exclusively a solvent effect and independent of the substrate studied then comparison with other substrates could confirm this possibility. In point of fact, octyl and certain benzyl derivatives^{1,7} show a similar response to solvent ionizing power as do the diphenylmethyl derivatives. Since these systems are solvolytically all quite different, the above interpretation receives some support. However, norbornyl,^{4a} adamantyl,⁸ and other benzyl¹⁵ derivatives behave quite differently, suggesting that changes in selectivity due to changes in solvent polarity are not entirely due to solvent effects on nucleophilicity.

The possibility that the observed selectivity values are due to changes in microscopic solvation structure as the solvent composition is changed appears unlikely. Previous work in this laboratory has indicated that selectivity in octyl derivatives is leaving group independent.¹ This suggests that solvent sorting about the molecule, which would be expected to be structure dependent, does not play a significant role.⁷

At the present time the overall picture is somewhat clouded. Of the three likely explanations of the observed solvent dependence of diphenylmethyl selectivity none can be eliminated and some experimental support exists for each of them. Further study on other systems and competing nucleophiles to clarify this problem is now in progress.

EXPERIMENTAL

Materials.—Alkyl halides were commercially available and were distilled prior to use. Bis-*p*-chlorophenylmethyl chloride was prepared by reduction of *p,p'*-dichlorobenzophenone followed by reaction with hydrogen chloride, m.p. 60° (lit.,¹⁶ 63°). Lutidine was distilled and stored over potassium hydroxide pellets or molecular sieves. Analytical grade absolute ethanol and acetone (Merck) were stored over molecular sieves and used directly.

Product Determination.—Reactions were performed in pressure tubes containing substrate (0.01M), lutidine as base (0.013M), and solvent (5 ml). Reactions were conducted in thermostatted oil-baths (± 0.05 °C) for 10–20

¹⁵ A. Pross and H. Aronovitch, unpublished data.

¹⁶ J. F. Norris and C. Banta, *J. Amer. Chem. Soc.*, 1928, **50**, 1804.

¹³ C. D. Ritchie, *Accounts Chem. Res.*, 1972, **5**, 348.

¹⁴ A. Pross, *J. Amer. Chem. Soc.*, 1976, **98**, 776.

half lives. For all materials, product ratios were established as stable under the reaction conditions. Product ratios were determined by response calibrated g.l.c. on a $1.5 \text{ m} \times 1/4$ in glass column packed with a mixture of 3% OV 17 and 0.3% Carbowax 20M on 80—100 mesh Chromosorb WAW DMCS. Results are the average of at least

three determinations on at least duplicate runs. An error of 5% is estimated for product ratios.

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