The Acetolysis of 2,2-Dimethyl-1-(*p*-methoxyphenyl)propyl Chloride.—The First Example of S_N2C^+-Type Solvolysis under Typical Solvolysis Conditions in the Absence of Additives

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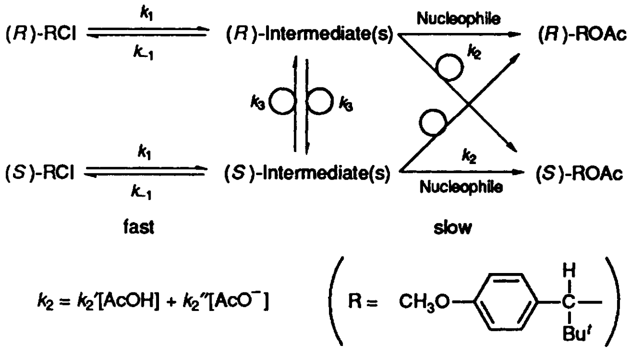
The acetolysis of 2,2-dimethyl-1-(*p*-methoxyphenyl)propyl chloride has been found to be the first example of the S_N2C^+-type solvolysis under typical S_N1 solvolysis reaction conditions, on the basis of its kinetic, stereochemical, and isotopic features.

The extreme case of the S_N1 solvolysis involving a very stable, easily formed, and somewhat slowly reacting solvolysis intermediate has been designated the 'S_N2C^+-type' solvolysis.[1] The S_N2C^+-type solvolysis is suitable for the investigation of the mechanism of nucleophilic attack on the stable dissociated carbocation, for which a few reports can be found.[†][2] Although only some examples were known of the S_N2C^+-type solvolysis, they were all reactions of substrates with nucleophiles in highly polar solvents,[1,5] or under common ion effects.[6] Recently, we have found the first example of this type of solvolysis under typical solvolysis conditions, where the solvolysis solvent itself acts both as an ionizing agent and as a nucleophile.

Optically active 2,2-dimethyl-1-(*p*-methoxyphenyl)propyl chloride (RCl)[7] was solvolysed in acetic acid at 25.0 °C and 50.0 °C. In the presence of sodium acetate (or 2,6-lutidine), the solvolysis was run to 100% conversion and apparently obeyed good second-order kinetics, k_2: 2.49×10^{-4} dm^3 mol^{-1} s^{-1} at 25.0 °C. In the absence of any buffer, the solvolysis was reversible and attained equilibrium (23% conversion at the initial concentration, 0.0503 mol dm^{-3}, of RCl) to afford a first-order titrimetric rate constant (k_t), $1.084(\pm 0.001) \times 10^{-5}$ s^{-1} at 25.0 °C,[‡] by means of the theoretical equilibrium treatment. Good first-order behaviour was observed for the polarimetric rate constant [k_p: $5.62(\pm 0.02) \times 10^{-4}$ s^{-1} at 25.0 °C] which was estimated to be rather close to the ionization rate constant. The very large k_p/k_t ratio, 51.8,[§] indicates the large return rate and the large racemization rate of the solvolysis intermediate, and corresponds to the complete racemization of the produced acetate in the presence and the absence of an added base. These experimental facts exhibit the intermediacy of the solvolysis intermediate in this reaction system and demonstrate unequivocally the features of S_N2C^+-type mechanism, *i.e.* the slow bimolecular reaction of the substituting agent with a solvolysis intermediate, rapidly formed from the substrate in a pre-equilibrium.



Scheme 1

Such experimental results can be expressed by the following reaction scheme, although the dissociation stage of intermediate(s)[4] has not been examined.

According to Scheme 1, the total rate expression for k_t and k_p [eqns. (1) and (2)] can be derived by application of the stationary-state treatment. The kinetic features ($k_2 \ll k_{-1}, k_3$) lead to eqn. (3). Since the difference between the zero-point energies of the isotopic case at the intermediate stage, which is presumably closer to the transition state, is most probably smaller than that at the substrate,[¶] the α-deuterium isotope effect on k_{-1} and k_3 should be relatively negligible resulting in eqn. (4). Kinetic α-deuterium isotope effect was found to be 1.05 on k_t and 1.15 on k_p for the acetolysis of RCl.[‖] Consequently, the isotope effect on the nucleophilic attack step (k_2) could be estimated to be 0.91_3. This is the first value for the nucleophilic attack step on the solvolysis intermediate, and corresponds to the structural change from sp^2 to sp^3.[8]

$$k_t = k_1{\cdot}k_2/(k_{-1} + k_2) \simeq k_1{\cdot}k_2/k_{-1} \qquad (1)$$

$$k_p = k_1(k_2 + 2k_3)/(k_{-1} + k_2 + 2k_3) \simeq 2k_1{\cdot}k_3/(k_{-1} + 2k_3) \qquad (2)$$

[†] It has been accepted by most researchers in the field that the S_N1 solvolysis proceeds *via* two kinds of ion pair intermediate (contact and solvent-separated) and a dissociated (free) carbocation intermediate.[3] However, we can find no example of a solvolysis system which has been ascertained to contain all three intermediates in the medium (*vide infra*).[4]

[‡] The initial first-order rate constant was estimated to be 1.17×10^{-5} s^{-1} by the graphical method. The activation parameters were $E_a = 71.0$ kJ mol^{-1}, $\Delta H^\ddagger = 68.4$ kJ mol^{-1}, $\Delta S^\ddagger = -110$ J mol^{-1} K^{-1}, and $\Delta G^\ddagger = 101$ kJ mol^{-1} (at 25.0 °C). The theoretical equilibrium treatment gave rise to the reverse reaction rate constant, 3.00×10^{-3} dm^3 mol^{-1} s^{-1}, which was in fair agreement with the observed value, 3.25×10^{-3} dm^3 mol^{-1} s^{-1}, for the reaction of ROAc with HCl in AcOH at 25.0 °C.

[§] The k_p/k_t ratio is 1.43 in 90% aq. ethanol, 2.53 in 80% aq. ethanol, and 2.47 in 80% aq. acetone at 25.0 °C.

[¶] The energy difference at R$^+$ is 0.094 kcal mol^{-1} smaller than that at the substrate by MINDO/3 calculation for the system.

[‖] Kinetic α-deuterium isotope effect is 1.14 and 1.15, on k_t and k_p, respectively, for the solvolysis of RCl in 90% aqueous ethanol.

$$k_2 \simeq \{2k_3 \cdot k_{-1}/(k_{-1} + 2k_3)\}(k_t/k_p) \tag{3}$$

$$k_{2H}/k_{2D} \simeq (k_{tH}/k_{tD})/(k_{pH}/k_{pD}) \tag{4}$$

Common ion rate depression (mass law effect),[9] which is observed in this acetolysis system in the presence of LiCl, indicates the high degree of dissociation of the solvolysis intermediate.* However, the acetolysis of RCl produces only the non-rearranged ROAc with complete racemization and no product with a rearranged carbon atom skeleton.[2a] Further examination is in progress of the structure of the solvolysis intermediate(s) for this system.

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* Although the observation of 'the common ion rate depression' has been considered to give strong evidence for the intermediacy of the dissociated carbocation in the S_N1 solvolysis reaction,[10] we have recently found a novel example of the common ion rate depression which arises at the stage of the ion pair intermediate, not the dissociated (free) carbocation intermediate.[11]

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