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INTRINSIC MIGRATION APTITUDES OF ALKYL GROUPS IN A PINACOL REARRANGEMENT

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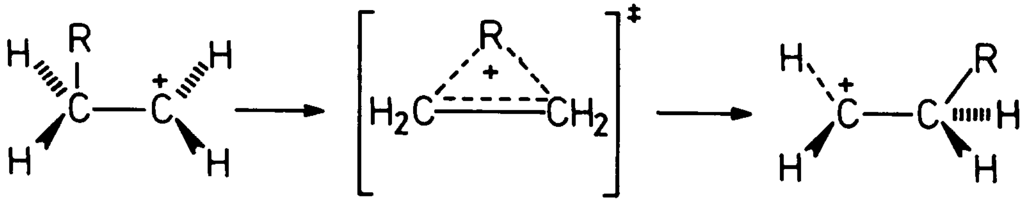
Summary: From rates of solvolysis of substituted cis-2-tosyloxy-cyclopentanols 3 in sodium acetate buffered acetic acid the following relative migration aptitudes were deduced: H(171); CH_3(6.7); C_2H_5(9.7); 2-C_3H_7(5.2); t-C_4H_9(2.5); C_6H_5(62).

In the course of a systematic investigation[1-3] of intrinsic migration aptitudes[4] we became interested in the relative migration rates of a sextet rearrangement in which alkyl groups migrate from carbon to carbon. For the simple model reaction (1)

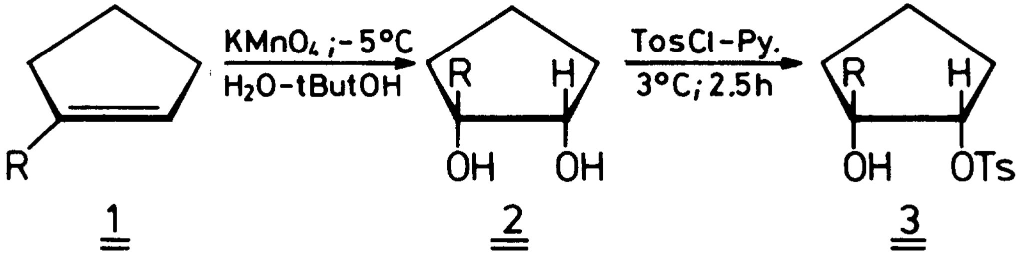


(1)

the order methyl > ethyl > i-propyl > t.butyl was suggested by MINDO/3 or ab initio calculations using the STO-3G basis set[5]. The principal difficulties in determining meaningful intrinsic migration aptitudes in carbenium ion rearrangements in general[5] and in the pinacol rearrangement in particular[6] have been discussed recently. In order to obtain migration aptitudes free from complications by preequilibria or conformational equilibria we decided to measure the kinetics of the solvolysis of a series of 1-alkyl-cis-2-tosyloxy-cyclopentanols 3 in NaOAc buffered acetic acid[7]. For comparison 3a and

3f were also studied.

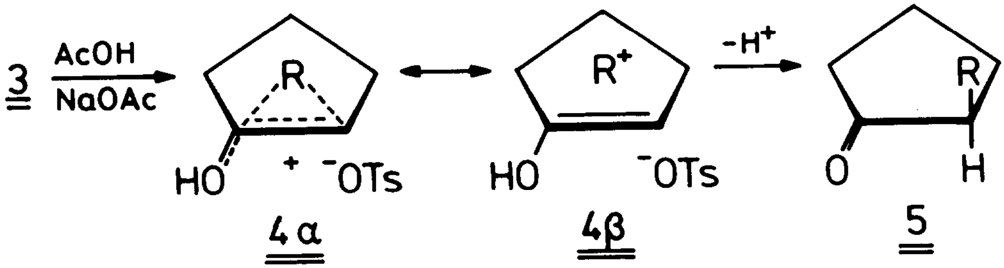
The model compounds 3a-f were prepared by cis-hydroxylation of the cyclopentenes 1[8)] and selective tosylation of the more reactive secondary hydroxy group in 2[8)] (see eq.2).



(2)

R = a) H b) CH_3 c) C_2H_5 d) $2\text{-}C_3H_7$ e) $t\text{-}C_4H_9$ f) C_6H_5

In these compounds the groups R are placed in an anti position to the leaving tosyloxy group, ideal for neighbouring group participation as shown in eq. 3).



(3)

Equation 3) is qualitatively supported by product analyses[7,10,11)]. The results of the kinetic experiments are shown in the table.

The large influence of R in β-position to the leaving group in 3 on the solvolysis rate is a strong indication for neighbouring group participation. It is concluded therefore from these solvolysis rates that the migration aptitude strongly decreases in the series H > phenyl > alkyl. The migration aptitudes of the alkyl groups $CH_3 < C_2H_5 > C_3H_7 > t\text{-}C_4H_9$ are very similar to those found in the isonitrile rearrangement[1)] and close to those of the Curtius rearrangement[1)], but opposite to those of the Beckmann and Criegee rearrangements[1)]. They are in qualitative agreement with the prediction of theory[5)].

Table Rates of solvolysis of cis-2-tosyloxy-cyclopentanols 3 (0.035 m) in acetic acid containing 0.035 m NaOAc12)

No.	R	$10^5 k_1 (s^{-1})$ a)	range b)	TosOH c)
3a	H	171.4 ± 2.47	87%	85%
3b	CH_3	6.74 ± 0.69	80%	91%
3c	C_2H_5	9.68 ± 0.26	90%	98%
3d	2-C_3H_7	5.16 ± 0.02	83%	97%
3e	t-C_4H_9	2.52 ± 0.02	87%	95%
3f	C_6H_5	61.8 ± 0.05	93%	96%

a) ± experimental error of double determinations
b) range of linear first order plot
c) final titer of TosOH

We conclude from these results:

1) The difference in the order of alkyl group migration aptitudes between the Beckmann and Criegee rearrangements on the one hand and the Curtius and isonitrile rearrangements on the other1), is not due to the fact that in the former reactions charged species are rearranging and in the latter uncharged ones.
2) The pinacol rearrangement passes a tight transition state in which the migrating alkyl groups are more closely resembling a pentacoordinated carbonium center like in 4α than a trivalent carbenium center as in 4β1-3).

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4) cf. G.W.Wheland, Advanced Organic Chemistry, 3rd ed. p.573, John Wiley Inc. New York 1960.

5) M.Saunders, J.Chandrasekhar and P.v.R.Schleyer in Rearrangements in Ground and Excited States, Vol.1, p.1 and p.35, Academic Press, New York 1980.

6) a) J.March, Advanced Organic Chemistry, 1.ed. p.787, McGraw Hill Book Co. New York 1968.
   b) T.H.Lowry and K.Schueller Richardson, Mechanismen und Theorien der Organischen Chemie, 1.ed., p.264, Verlag Chemie, Weinheim 1980.
   c) F.A.Carey and R.J.Sundberg, Advanced Organic Chemistry, 1.ed. Part B, p.336, Plenum Press, New York 1977.

7) For examples of this type of pinacol rearrangement in natural products synthesis see: G.Büchi, W.Hofheinz and J.v.Paukstelis, J.Am.Chem.Soc. 88, 4113 (1966); D.M.Mac Sweeney and R.Ramage, Tetrahedron 27, 1481 (1971).

8) cis-hydroxylation: K.B.Wiberg and K.A.Saegebarth, J.Am.Chem.Soc. 79, 2822 (1957);
tosylation: To a stirred solution of 25 mmol 2 in 10 ml anhydrous pyridine 25 mmol TosCl were added slowly at 3-5°C. After 3h stirring the solution was diluted with 50 ml ether. 2n HCl was added with shaking till pH 4 was reached. Then the ether solution was washed neutral at 0°C with soda and water and dried over Na_2SO_4. The ether was evaporated and the residue purified by chromatography over silicagel in CH_2Cl_2-pentane (60:40). After elution of TosCl the compounds 3 were eluted with ether. The crude products were recrystallized from pentane at -20°C.
All compounds were characterised by spectral means and by elemental analysis$^{9)}$.

9) Dissertation E.Wistuba, Univ. Freiburg, 1976.

10) No quantitative product analyses were performed because of strong discoloration of the reaction solutions. In a preparative experiment 35% 5c were isolated from 3c, however.

11) See P.D.Bartlett and A.Barley, J.Am.Chem.Soc. 60, 2416 (1938) for complications by competing elimination in the pinacol rearrangement of trans-1.2-dimethyl-cyclopentane-diol.

12) The kinetics were followed by titration of the NaOAc concentration with standard $HClO_4$ cf. S.Winstein, E.Grunwald and L.I.Ingraham, J.Am.Chem.Soc. 70, 821 (1948).

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