

## THEORETICAL STUDY ON THE MIGRATORY APTITUDE IN PINACOL REARRANGEMENT

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**Summary:** Reactivity of some migrating groups in pinacol rearrangement is studied by means of *ab initio* molecular orbital method. Transition-state structures are obtained for 1,2-shift of hydrogen, methyl, vinyl and cyclopropyl groups substituting in ethandiol concerted with dehydration. The result shows relatively high migratory aptitude for vinyl and cyclopropyl group.

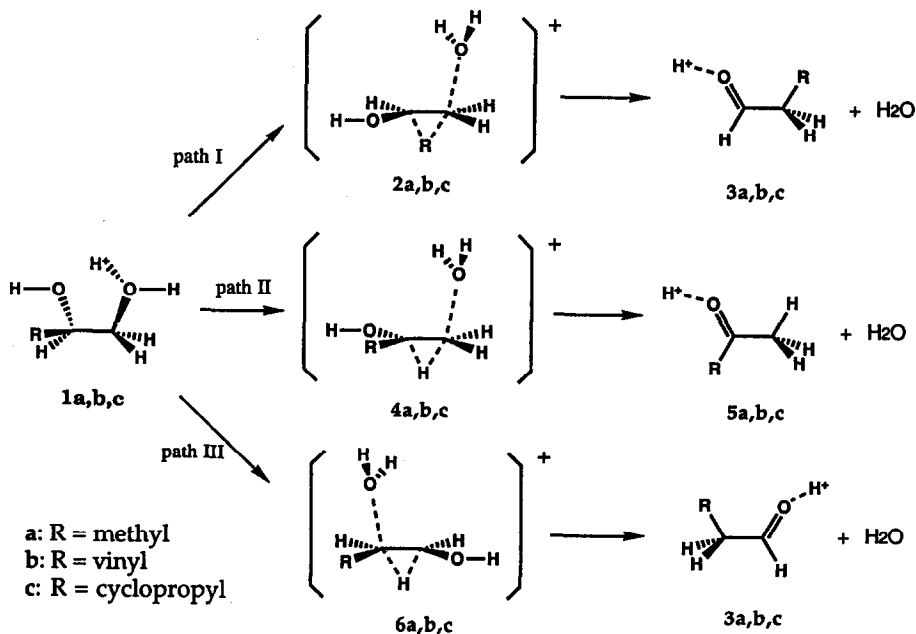
In the previous paper,<sup>1)</sup> we have proposed that the pinacol rearrangement reaction is not likely to be a stepwise reaction *via* carbocation intermediates, because the  $\beta$ -hydroxy carbocation was found to be unstable in most cases.

The recent experiments report the stereospecific 1,2-rearrangements for pinacol-type reaction,<sup>2)</sup> under carefully controlled condition using Lewis acid catalyst. The experimental results support the concerted mechanism, because the simultaneous elimination of leaving group with 1,2-shift leads to the full inversion of configuration. Alkenyl or cyclopropyl groups are used in these studies because of their high reactivity.

Many studies were reported during the period 1950~1970 on the migratory aptitude in pinacol rearrangement,<sup>3)</sup> in which the relative tendency of aryl>alkenyl>alkyl is generally accepted. Reaction rates are well examined for various alkyl groups<sup>3)</sup> and aryl groups substituted with electron-donating or electron-withdrawing groups.<sup>4)</sup> It is, however, hard to define the general migratory aptitude of a specific group, because the ability of rearrangement depends not only on the intrinsic nature of migrating group but also on the electronic and/or steric factors of the non-migrating substituents.

In this communication, we report the migratory aptitude of hydride, methyl, vinyl and cyclopropyl groups from the theoretical point of view. The molecular structures and their energies are calculated by means of *ab initio* SCF molecular orbital method. We used the GAUSSIAN 82 program package.<sup>5)</sup> Geometry optimization was carried out using STO-3G and 6-31G basis sets. Since small basis sets are not appropriate to evaluate the energies of the cationic system, we performed single point calculations by using 6-31G\*\* basis set at the geometries optimized with 6-31G basis set in order to obtain the reliable relative energies. Table 1 summarizes the energies obtained with this procedure.

The reaction mechanisms considered in this paper are as follows;



We consider the protonated monosubstituted 1,2-diols (1) as the starting materials. There are three possible pathways for the 1,2-shift reactions of these substrates, *i.e.* the migration of R (path I), the migration of hydrogen from the substituted carbon atom (path II), and the migration of hydrogen from the unsubstituted carbon atom (path III).

In the case of methyl substituted 1,2-diol (1a), dehydration occurs from the substituted carbon atom because positive charge is stabilized by the alkyl substitution. This situation means migration of hydrogen from the unsubstituted carbon atom (path III). The activation energy of hydrogen migration is calculated to be 19.6 kcal/mol. It is also interesting to examine the difference of the activation energies for two pathways of migration from the substituted carbon atom. The energy barriers of methyl migration (path I) and hydrogen migration (path II) are found to be 27.1 kcal/mol and 23.1 kcal/mol, respectively. From these results, hydrogen migration seems to predominate over the methyl migration, which may be due to the difference of the stability of products; *i.e.* the methyl migration gives the aldehyde, while the hydrogen migration leads to the ketone. Although such difference is not necessary to present the net activities of hydrogen and methyl group, the migratory aptitude of

hydride is likely to be higher than that of alkyl groups. The details are discussed in the forthcoming paper.<sup>7)</sup>

Next, we tried to reveal the reason of high migratory aptitude of alkenyl<sup>2b)</sup> and cyclopropyl<sup>6)</sup> groups. The  $\pi$ -orbital of alkenyl groups and pseudo  $\pi$ -orbital of cyclopropyl groups may play a major role in nucleophilic 1,2-shift reactions. In the case of the reaction of vinyl substituted 1,2-diol (**1b**), we would expect that the hydrogen migration results large stabilization by forming the conjugated ketone (**5b**). Nevertheless, the calculated activation energies show the predominance of the vinyl migration (10.5kcal/mol) over the hydrogen migration (17.8kcal/mol). Fig.1 illustrates the transition-state structures of vinyl migration (**2b**) and cyclopropyl migration (**2c**) optimized with 6-31G basis set.

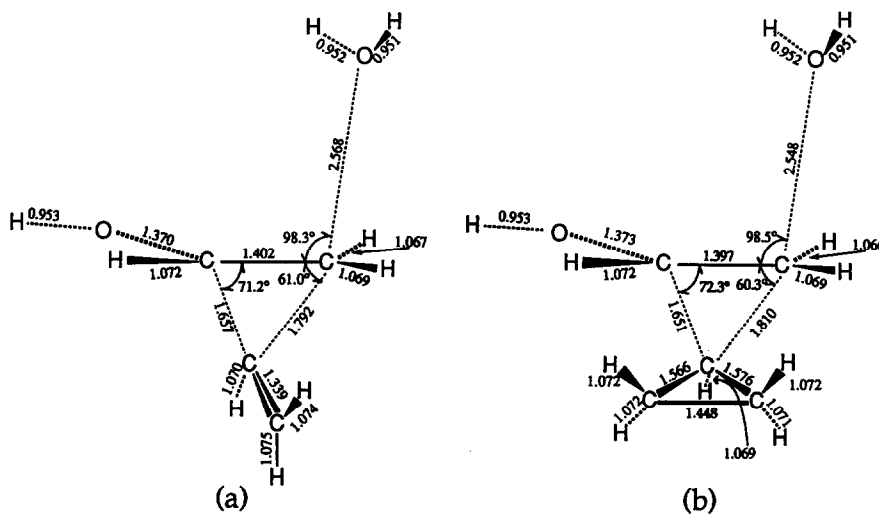


Figure 1 Transition-state structures of (a)vinyl and (b)cyclopropyl migrations optimized by using 6-31G basis set

Table 1. Energies(hartree) of reactants, transition states, products of 1,2-shift reactions of substituted 1,2-diols calculated with (6-31G\*\*//6-31G). Relative energies(kcal/mol) are in parenthesis.

R	Path	Reactant	T.S.	Product
methyl	I	-268.31590 (0.0)	-268.27256 (27.1)	-268.34401 (-17.6)
	II	-268.31590 (0.0)	-268.27904 (23.1)	-268.36305 (-29.6)
	III	-268.31590 (0.0)	-268.28463 (19.6)	-268.34401 (-17.6)
vinyl	I	-306.14876 (0.0)	-306.13198 (10.5)	-306.18493 (-22.7)
	II	-306.14876 (0.0)	-306.12034 (17.8)	-306.21419 (-41.0)
cyclopropyl	I	-345.18779 (0.0)	-345.15620 (19.8)	-345.20963 (-13.7)

It is noticeable that the geometry shown in Fig.1(a) is quite similar to the structure proposed for the 1,2-shift of aryl group (Fig.2 (a)).<sup>8)</sup> The transition-state structure (Fig.1(a)) clearly shows the contribution of the  $\pi$ -orbital of vinyl group to stabilize the transition state of the migration(Fig.2(b)). We may find the similar orbital interaction in the case of 1,2-shift of cyclopropyl group (2c) illustrated in Fig.1(b). Relatively low activation energy of this reaction (19.8 kcal/mol) is due to the contribution of pseudo  $\pi$ -orbital as depicted in Fig.2(c).

In summary, the reason of high ability of vinyl and cyclopropyl group as migrating group is confirmed from the energetics and the transition-state structures obtained by *ab initio* calculation. Further investigation on the mechanism of pinacol rearrangement reaction is currently in progress.

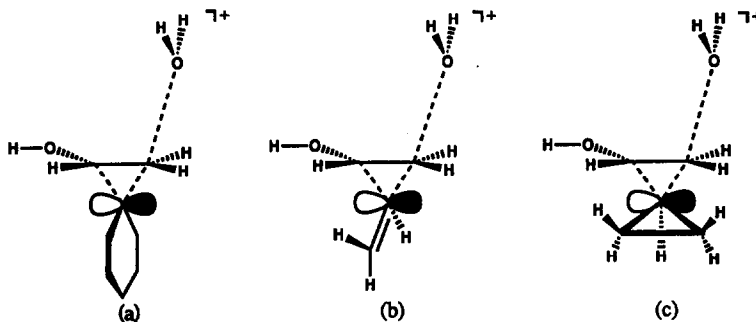


Figure 2  $\pi$ - and pseudo  $\pi$ -orbital participation in the transition states of (a) aryl, (b) vinyl and (c) cyclopropyl migration

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