

KINETICS OF EPOXIDATION OF ALIPHATIC ALKENES BY DIMETHYLDIOXIRANE: STERIC EFFECTS

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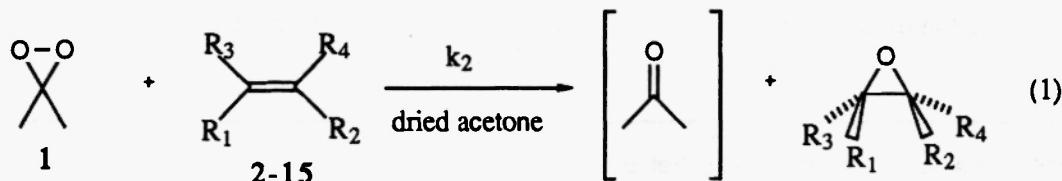
Abstract. Kinetic data for epoxidation of three series of aliphatic alkenes by dimethyldioxirane in dried acetone showed the reaction to be sensitive to steric effects; consistent with the current spiro transition state model.

Introduction

Dioxiranes, either *in situ*¹ or in isolated solution,² are powerful oxidants which efficiently transfer an oxygen atom to a wide variety of organic compounds.³ Numerous synthetically useful transformations have been carried out employing dioxiranes. Dimethyldioxirane 1 has been found to be a versatile epoxidizing reagent for a wide variety of alkenes. Epoxidation by 1 has been shown to be stereospecific, quantitative and to occur via a concerted electrophilic process with a "spiro" transition state.⁴ The reaction of alkenes with 1 has been shown to be sensitive to steric factors. In general, *cis*-alkenes have been found⁴ to be of greater reactivity than the corresponding *trans* compounds. Recently, we have shown⁵ that within a series of *cis*-alkenes, reactivity was relatively insensitive to steric influences except for the case of the bulkiest groups. We report here the results of a kinetics study of the epoxidation of several series of aliphatic alkenes with substituents of varying steric bulk by dimethyldioxirane in dried acetone.

Results and Discussion

The reaction of dimethyldioxirane (1) with a series of *trans*-alkenes (2-6), a series of trisubstituted alkenes (7-10) and a series of tetrasubstituted aliphatic alkenes (11-15) produced the corresponding epoxides (stereospecific) in essentially quantitative yields (reaction 1). The products were isolated and characterized by comparison of spectral data



with literature values. Kinetic studies were carried out in dried acetone at 23 °C via UV techniques. As expected, the epoxidations were found to be of the first order with respect to both dioxirane and alkene. The k_2 values determined under pseudo first order conditions with 1:10 and 10:1 ratios of alkene to dioxirane were essentially identical. The kinetic results are listed in Table 1.

Table 1. Second Order Rate Constants for Epoxidation of Alkenes 2-15 by Dimethyldioxirane 1 in Dried Acetone at 23°C.

Entry	Alkene	Structure	$k_2 \text{ M}^{-1}\text{s}^{-1}$	$k_{(\text{Rel})}$	$k_{(\text{Calc})}^a$
2	trans-2-Butene		0.084 ± 0.003	≈ 1.00	1.00
3	trans-2-Pentene		0.070 ± 0.003	0.83	0.88
4	trans-3-Hexene		0.057 ± 0.004	0.68	0.50
5	trans-2-Methyl-3-Hexene		0.026 ± 0.002	0.31	0.25
6	trans-2,2-Dimethyl-3-Hexene		0.012 ± 0.001	0.14	0.18
7	2-Methyl-2-Butene		1.94 ± 0.05	≈ 1.00	1.00
8	2-Methyl-2-Pentene		1.0 ± 0.1	0.52	0.80
9	2,4-Dimethyl-2-Pentene		0.59 ± 0.01	0.30	0.46
10	2,4,4-Trimethyl-2-Pentene		0.33 ± 0.01	0.17	0.22
11	2,3-Dimethyl-2-Butene		6.17 ± 0.66	≈ 1.00	1.00
12	2,3-Dimethyl-2-Pentene		1.01 ± 0.09	0.16	0.16
13	2-Methyl-3-Ethyl-2-Pentene		0.97 ± 0.07	0.15	-
14	2,3,4-Trimethyl-2-Pentene		1.08 ± 0.08	0.18	0.19
15	2,3-Diethyl-3-Hexene		0.32 ± 0.05	0.05	0.03

a) calculated using AM1 approach; see: Ref. 5.

The reaction was found to be more sensitive to steric effects than expected. Values of k_{rel} were determined for each series; they were normalized in relation to the most reactive alkenes (see Table 1). For the *trans*-series (2-6), a systematic decrease in k_{rel} is found upon formal substitution on the methyl groups in *trans*-2-butene (increased branching). Formal addition of one methyl group yielded roughly a 20% decrease in k_{rel} . The magnitude of the effect was significantly larger than that reported⁵ for *cis*-alkenes. The results for the corresponding *cis*-alkenes had been shown⁵ to be relatively insensitive to increasing steric bulk; only the bulkiest groups showed measurable decreases in k_2 values. The trisubstituted series (7-10) yielded results consistent with the *trans* series but showed even greater sensitivity to branching. Surprisingly, the tetrasubstituted series (11-15) showed the greatest sensitivity to steric effects. Formal addition of even a methyl group to tetramethylethylene (11) yielded roughly a six-fold decrease in relative reactivity. Compound 15 was found to be ~20-fold less reactive than expected for a tetrasubstituted compound. Clearly, the steric influence of the bulky groups was negating the effect of increased substitution such that several of the tetrasubstituted alkenes were less reactive than some of the trisubstituted compounds. In addition, under these conditions, a sterically hindered tetrasubstituted alkene, tetra-isopropylethylene (16), was found to be inert to 1. The dioxirane underwent decomposition and the hindered starting material, 16, was recovered unreacted.

Our initial kinetic study of the epoxidation of simple *cis/trans* alkenes by 1 resulted^{4a} in the postulation of a concerted "spiro" transition state mechanism. *Ab initio* calculations⁵ strongly support the "spiro" transition state model. Recently, we have shown⁵ that semiempirical calculations (AM1) provide a quick, convenient approach for the calculation of relative reactivity (k_{cal}) within a series. Transition state calculations were performed for the spiro geometry (two unique directions of approach if demanded by alkene geometry). In all cases, a viable "spiro" transition state was located. The determination was judged successful when the calculated structure possessed a single imaginary frequency that, when animated, proved to be on the reaction coordinate. Interestingly, using the AM1 approach, tetra-isopropylethylene is calculated to show a k_{cal} of 10^{-5} in agreement with the observed lack of epoxidation under the reaction conditions. The values of k_{calc} shown in Table 1 were determined by this method.⁵ Plotting the experimental relative reactivities, k_{rel} vs "predicted" relative reactivities k_{calc} for all the series, yields a fair correlation ($r=0.96$) with a slope of 0.96. This shows that the AM1 approach is of general value in the estimation of relative reactivities for epoxidation of aliphatic alkenes by dimethyldioxirane.

Recently, *in situ* generated dioxiranes have been shown⁷ to be effective at asymmetric epoxidation of *trans*-stilbene and similar disubstituted alkenes. The results have been interpreted⁷ to be consistent with predictions based on the spiro transition⁴ state model. The observed sensitivity to steric influences of the *trans* alkenes to reaction with 1 in the present study is consistent with the asymmetric induction results. The greater sensitivity to steric effects for trisubstituted and tetrasubstituted alkenes to those for *trans* disubstituted compounds suggests that asymmetric epoxidation by dioxiranes for these systems should be evaluated.

In conclusion, steric influences on the rate constants for epoxidation are much greater than anticipated. Between series, the relative order of sensitivity to steric effects is: tetrasubstituted > trisubstituted > *trans*-disubstituted > *cis*-disubstituted compounds. Semiempirical modeling studies (AM1) employing a spiro transition state show a reasonable correlation with the experimental data.

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