OXIDATION OF ACETALS BY DIMETHYLDIOXIRANE

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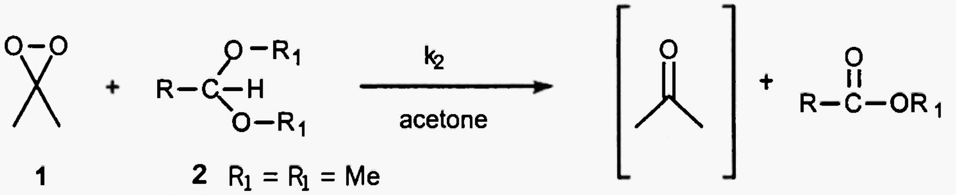
Abstract. Kinetic data (k_2's, LFER and activation parameters) for the oxidation of a series of acetals by dimethyldioxirane to the corresponding esters in dried acetone are reported; the results are consistent with either a H-atom abstraction or direct insertion mechanism.

Introduction

Dioxiranes are powerful, versatile oxidants for the mild oxidation of a great variety of organic substrates.[1] Dimethyldioxirane is often the reagent of choice rather than the more reactive methyl(trifluoromethyl)dioxirane[2] because of its inexpensive, facile preparation.[3] Dimethyldioxirane has been shown to be useful in epoxidation, heteroatom oxidation and C-H oxidation.[1] Specifically, extensive CH bond oxidation studies have been carried out[4] on saturated hydrocarbons, phenyl-substituted hydrocarbons, aldehydes, alcohols and ethers. Several reports have appeared[5] on the reactions of acetals with either dimethyldioxirane or methyl(trifluoromethyl)dioxirane. We report here a kinetic study of the oxidation of a series of acetals by dimethyldioxirane in dried acetone.

Results

The reaction of dimethyldioxirane **1** [isolated; ~0.1 M in dried acetone] with substituted benzaldehyde dimethyl acetals (**2a-c**), 2-aryl-1,3-dioxolanes (**3a-g**), 2-methyl-1,3-dioxolane (**4**) and 2-phenyl-1,3-dioxane (**5**) produced the corresponding esters in good to excellent yields (reaction 1). A threefold excess of **1** was employed to achieve efficient conversion. Product studies in the dark under inert (N$_2$) atmosphere, yielded results essentially identical to those obtained when carried out under normal conditions (Table 1). The yields for oxidation of **2a** and **3c** are essentially identical to those previously



(1)

1

2 $R_1 = R_1 = Me$
3, **4** $R_1, R_1 = \cdot CH_2CH_2\cdot$
5 $R_1, R_1 = \cdot CH_2CH_2CH_2\cdot$

reported.[5a,c] The yield of **4** from reaction with **1** is similar to those found for other 2-alkyl-1,3-dioxolanes. [5c] The products (methyl benzoates from **2a-c**, 2-hydroxyethyl benzoates[6] for **3a-g**, 2-hydroxyethyl acetate[7] from **4**, and **3**-hydroxypropyl benzoate[8] from **5**) were isolated and the structures proven by comparison of physical and spectral properties with literature values.

Kinetic studies were carried out in acetone at 25° employing UV techniques. The reactions were shown to be of the first order in both dioxirane and substrate. The second order rate constants (k_2) were determined under pseudo-first order conditions with **1** in at least 10-fold excess. The results are summarized in Table 1. Interestingly, for reaction with **1** arylaldehyde dimethyl acetals **2a-c** were found to be the least reactive. On the other hand, 2-phenyl-1,3-dioxolane (**3c**) was found to be slightly more reactive than the corresponding 2-phenyl-1,3-dioxane (**5**), both of which were much more reactive than acyclic acetal 2a. A k_2 value (4.5×10^{-2} $M^{-1}s^{-1}$) at 22 °C has been reported[5c] for **3c** in (wet?) acetone which is in fair agreement with the results in dried solvent. The larger k_2 value observed for oxidation of **4** relative to that for **3c** is consistent with results[5c] for other 2-alkyl-1,3-dioxolanes. Phenyl groups with electron-donating substituents increased the k_2 values for the reaction while those with electron withdrawing groups produced

Table 1. Second Order Rate Constants for the Oxidation of Acetals **2-5** by Dimethyldioxirane in Dried Acetone.

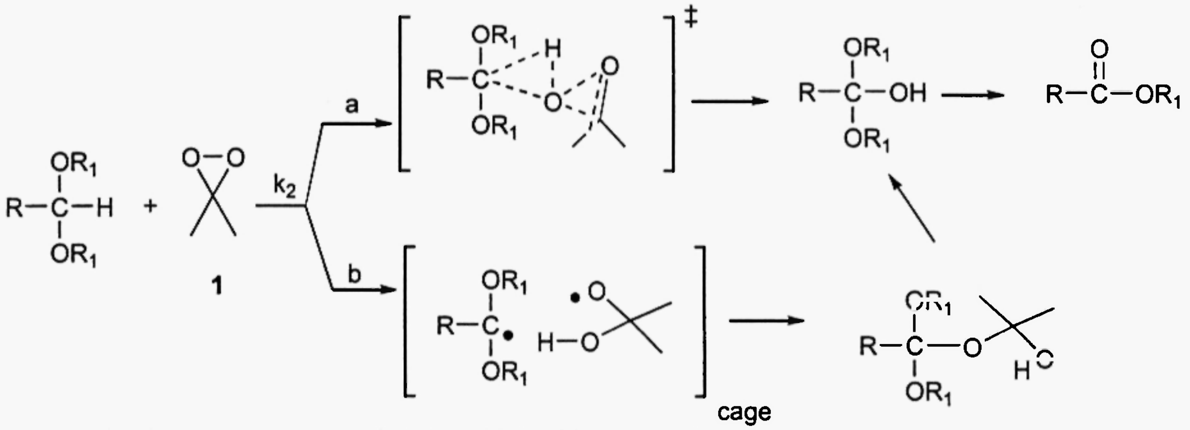
Entry	R	R_1, R_1	k_2 $M^{-1}s^{-1}$ [a]	Ester % yield (lit. value)
2a	Ph	Me, Me	2.7×10^{-4}	92 (95%)[b]
2b	$pMeC_6H_4$-	Me, Me	$6.8 \pm 0.3 \times 10^{-4}$	95
2c	$pMeOC_6H_4$-	Me, Me	$1.08 \pm 0.02 \times 10^{-3}$	97
3a	$pMeOC_6H_4$-	$-CH_2CH_2-$	$3.9 \pm 0.1 \times 10^{-2}$	98
3b	$pMeC_6H_4$-	$-CH_2CH_2-$	$3.14 \pm 0.08 \times 10^{-2}$	95
3c	Ph	$-CH_2CH_2-$	$2.08 \pm 0.05 \times 10^{-2}$	96 (95%)[c]
			$1.39 \pm 0.04 \times 10^{-2}$ (15°C)	
			$1.73 \pm 0.03 \times 10^{-2}$ (20°C)	
			$2.35 \pm 0.04 \times 10^{-2}$ (30°C)	
			$3.16 \pm 0.04 \times 10^{-2}$ (35°C)	
			$3.74 \pm 0.04 \times 10^{-2}$ (40°C)	
3d	pFC_6H_4-	$-CH_2CH_2-$	$1.68 \pm 0.03 \times 10^{-2}$	92
3e	$pClC_6H_4$-	$-CH_2CH_2-$	$1.55 \pm 0.03 \times 10^{-2}$	93
3f	$pBrC_6H_4$-	$-CH_2CH_2-$	$1.52 \pm 0.03 \times 10^{-2}$	90
3g	$pNCC_6H_4$-	$-CH_2CH_2-$	$0.91 \pm 0.03 \times 10^{-2}$	82
4	Me	$-CH_2CH_2-$	$1.86 \pm 0.04 \times 10^{-2}$	91
5	Ph	$-CH_2CH_2CH_2-$	$9.1 \pm 0.1 \times 10^{-3}$	90

a) at 25°C unless specified; b) Ref. 5a; **c)** Ref. 5c the opposite effect. A Hammett plot for the dioxolane series **3a-c** yielded a very good LFER with a rho of −0.72 ± 0.06 (r = 0.98). This result is in excellent agreement with our earlier study of the oxidation of ethers by **1** which yielded a rho value of −0.74.[4j]

The k_2 values for oxidation of **3c** were determined at 5° intervals from 15° to 40°C. The activation, parameters determined by the Arrhenius method, were found to be $\Delta H^{\ddagger} = 6.4 \pm 0.2$; $\Delta S^{\ddagger} = -45$ eu.; $\Delta G^{\ddagger} = 19.8$ ($k_2 = 2.1 \times 10^{-2}\ M^{-1}\ s^{-1}$, 25°C). The results were in agreement with those found[5c] for the reaction of **1** with 1,3-dioxolane ($\Delta H^{\ddagger} \approx 9.5$ kcal/mol; $\Delta S^{\ddagger} > -37$ eu; $k_{22} = 4.83 \times 10^{-3}\ M^{-1}s^{-1}$) in (wet?) acetone. The activation parameters for acetal oxidation are considerably different from those[4j] for ether oxidation by **1**. In particular, the $\Delta S^{\ddagger}$ value is larger, more negative, and similar to those found[4h] for secondary alcohol oxidation by **1**.

The mechanism for this type of dioxirane oxidation is controversial and subject to debate. Two mechanistic extremes for this reaction—a) concerted (direct) insertion and b) hydrogen-atom abstraction (caged radical pair)—are shown in Scheme 1. Both routes ultimately yield hemiacetal intermediates which would fragment to esters. Recent work[9] on the related benzyl alcohol oxidation by **1** has been interpreted in favor of the concerted process. Our earlier mechanistic studies have suggested[4h] a caged radical pair process, but cannot rule out the concerted process. Recent calculations[10] have located genuine TS's, diradicaloid in nature, which can lead to final products via radical pair intermediates for alkane CH insertion by dimethyldioxirane. This is in contrast to the results of previous calculations.[11] The data for acetal oxidation are consistent with a caged radical pair mechanism but do not distinguish between the two mechanistic possibilities. As pointed out for analogous reactions,[4j] the trajectory of approach of **1** to the C-H bond remains to be elucidated.

Scheme 1



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