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Oxidation of Alcohols with Peracetic Acid in Ethyl Acetate in the Presence of Sodium Bromide

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Aliphatic primary alcohols and 1,ω-diols were oxidized to the dimeric esters and lactones, respectively, by peracetic acid in ethyl acetate in the presence of sodium bromide under mild conditions. Aliphatic secondary and benzylic alcohols were converted smoothly to the corresponding carbonyl compounds by the same system.

Peroxy acids are soluble in organic solvents and have been conveniently used for the oxidation of various organic substrates, since almost all organic compounds are soluble in organic solvents. In addition, only carboxylic acids, which are much less poisonous and easily removable from a reaction mixture, remained after completion of the reaction and, hence, peroxy acid oxidations are favorable from both environmental and operational points of view. Although recent developments in peroxy acid oxidations have focused on the epoxidation of olefins[1] and the Baeyer–Villiger reaction,[2] little is known about the oxidation of alcohols.[3]

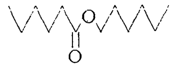
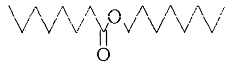
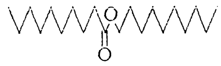
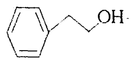
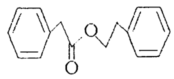
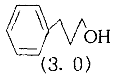
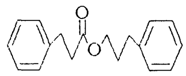
We have recently reported the facile oxidation of benzylic and aliphatic secondary alcohols to the corresponding carbonyl compounds by peracetic acid catalyzed by bromide ion in acetic acid, where the aliphatic primary alcohols were not oxidized, but acetylated.[4] In this report, we wish to describe the oxidation of various alcohols by means of a combination of peracetic acid and an inorganic bromide in nonpolar solvents, especially in ethyl acetate, since under these conditions primary and secondary alcohols, and 1,ω-diols can be converted to the corresponding dimeric esters, ketones, and lactones, respectively, in good to excellent yields.

Results and Discussion

When benzyl alcohol (**1**) was treated with an equimolar peracetic acid in acetic acid in the presence of sodium bromide ($[NaBr]/[PhCH_2OH]=0.1$; mole ratio) at 333 K for 2 h under an argon atmosphere, benzaldehyde (**2**) and benzyl acetate (**3**) were formed in 60 and 39% yield, respectively. The use of nonpolar solvents such as benzene, carbon tetrachloride, and ethyl acetate instead of acetic acid resulted in an increased yield of **2** and a decreased yield of **3**. For example, when peracetic acid in acetic acid (1.53 mol dm^{-3}, 3 ml; 4.59 mmol) was added dropwise to **1** (4.20 mmol) in benzene (3 ml) in the presence of sodium bromide (0.42 mmol), **2** was formed in 94% yield, along with 4% of **3**. Similar results were obtained by using carbon tetrachloride, acetonitrile, or ethyl acetate as a solvent. The same solvent effect was also observed in the oxidation of 1-octanol. These results clearly suggest that the exclusive oxidation of an alcohol occurs under suitable conditions, eliminating the acetylation of the alcohol. On the basis of these results, subsequent oxidations of various alcohols were carried out in ethyl acetate, since peracetic acid in ethyl acetate is readily available. It is worth noting that although other inorganic bromides (lithium, potassium, and ammonium salts) are also effective for the oxidation of alcohols with peracetic acid in ethyl acetate, the use of hydrogen bromide resulted only in an increased yield of the corresponding acetates.

Oxidation of Aliphatic Primary Alcohols. Upon treatment of 1-octanol with peracetic acid in the presence of NaBr in ethyl acetate, the dimeric ester, octyl octanoate, was obtained in good yield, and no octanal was detected by GLC analysis under various conditions. A smooth reaction can be attained by using a relatively

Table 1. Oxidation of Aliphatic Primary Alcohols with Peracetic Acid in Ethyl Acetate in the Presence of Sodium Bromide[a)]

Entry No.	Alcohol mmol	Product	Isolated yield mol%
1	 (3. 0)		92
2	 (3. 8)		88
3	 (3. 2)		74
4	 (3. 0)		86
5	 (3. 0)		88

a) $[AcOOH]/[Alcohol]=2.2$, $[NaBr]/[Alcohol]=1.0$ (mole ratio); 313 K, 2 h. Peracetic acid in ethyl acetate was added to a neat alcohol.

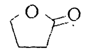
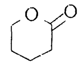
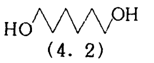
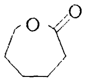
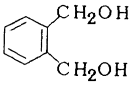
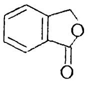
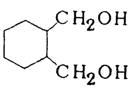
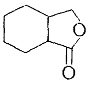
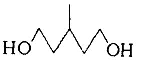
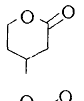
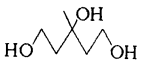
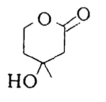
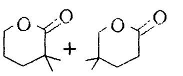
large amount of NaBr in a nonpolar solvent at 303—313 K. Several primary alcohols were oxidized with peracetic acid in ethyl acetate under comparable conditions. In all cases, the corresponding dimeric esters were formed in good yields; the results are given in Table 1. On the other hand, the oxidation of these alcohols in acetic acid led only to an exclusive formation of the corresponding acetates; none of the dimeric esters were formed, even in the presence of a larger amount of NaBr.

Oxidation of 1,ω-Diols. Treatment of 1,5-pentanediol with peracetic acid in the presence of NaBr in ethyl acetate gave an excellent yield of 5-pentanolide (Entry 7). Lactonization occurred under milder conditions than those for the dimeric esterification of the primary alcohols. The results are summarized in Table 2. Although five- and six-membered ring formations (Entries 6, 7, and 9—13) were smooth, lactonization to a seven-membered ring (Entry 8) was rather difficult. Regrettably, such functional groups as the olefinic double bond, sulfide etc. were found to be more labile than were the hydroxyl groups under the conditions employed, failing in the chemoselective oxidation of the hydroxyl group in a multifunctional substrate.

Oxidation of Aliphatic Secondary and Benzylic Alcohols. Various aliphatic secondary and benzylic alcohols were oxidized by the above-mentioned system, and the results were compared with those given by the reactions in acetic acid. The tabulated alcohols underwent smooth oxidation to the corresponding carbonyl compounds in ethyl acetate under mild conditions. Although oxidation in acetic acid gave good yields of the products as previously reported,[4] the reaction in ethyl acetate can be carried out under milder conditions than those in acetic acid. Moreover, the products, so formed, can be readily isolated in the present cases, owing to the very small concentration of the resultant acetic acid; on the contrary, the previous method using acetic acid as the solvent required a tedious work-up procedure in order to remove a large amount of acetic acid.

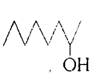
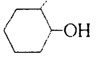
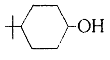
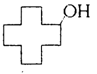
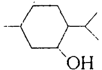
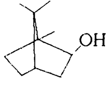
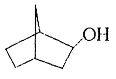
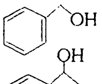
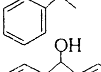
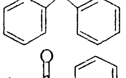
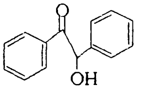
A peracetic acid–bromide ion system is a useful oxidant for both alcohols and diols, whereas peracetic acid merely catalyzes the acetylation of alcohols with acetic acid in the absence of the bromide ion. These results suggest that for the effective oxidation of an alcohol, the reaction conditions should be chosen so that the concentration of "free" peracetic acid in the reaction mixture is restrained so as to be as low as possible, and the alcohol is prevented from contact with acetic acid.

Table 2. Oxidation of Diols with Peracetic Acid in Ethyl Acetate in the Presence of Sodium Bromide[a)]

Entry No.	Diols / mmol	Products	[AcOOH] / [Sub]	[NaBr] / [Sub]	Time / h	Isolated yield / mol%
6	 (5. 5)		2.2	0.5	2	86
7	 (4. 8)		2.2	0.5	2	97
8	 (4. 2)		3.0	1.0	2	70[b)]
9	 (2. 5)		2.2	0.1	1	87
10	 (2. 5)		2.2	0.5	1	94
11	 (3. 0)		2.2	0.5	1	89
12	 (3. 3)		2.0	0.5	2	83
13	 (3. 0)		2.2	0.5	1	71 (4:6)[c)]

a) Peracetic acid in ethyl acetate (2.0—3.4 mol dm^{-3}) was added to the solution of a diol in ethyl acetate (4 ml) at 313 K. b) At 323 K. c) Product ratio was determined by NMR spectrum.

Table 3. Oxidation of Aliphatic Secondary and Benzylic Alcohols with Peracetic Acid in Ethyl Acetate in the Presence of Sodium Bromide[a)]

Entry No.	Alcohols	[AcOOH]/[Sub]	[NaBr]/[Sub]	Time/h	Temp/K	Carbonyl compounds isolated yield/mol%
14		1.2	0.1	1	303	92
15		1.1	0.5	1	303	84
16		1.1	0.3	1	303	91
17		1.1	0.3	1	303	97
18		1.5	1.0	2	303	92
19		1.5	0.5	1	303	99
20		1.5	1.0	2	303	44
21		1.1	0.3	1	313	93[b)]
22		1.1	0.1	2	313	96
23		1.1	0.3	1	313	92
24		1.1	0.5	1	303	64[c)]

a) Peracetic acid in ethyl acetate (2.59—3.85 mol dm^{-3}) was added to the solution of an alcohol in ethyl acetate (4 ml). b) GLC yield (mol%). c) The product is benzaldehyde (GLC yield; mol%).

The former conditions are attainable by increasing the concentration of NaBr, since we have observed that in the presence of a relatively large amount of NaBr, aliphatic secondary and benzylic alcohols were smoothly converted to the corresponding carbonyl compounds in good yields by peracetic acid, even in acetic acid.[4)] No occurrence of the Baeyer–Villiger reaction of the resultant carbonyl compounds in these cases is also indicative of the absence of "free" peracetic acid in the reaction mixture. However, the previous method[4)] failed to provide an effective conversion of aliphatic primary alcohols, which resist oxidation.

The present reaction uses ethyl acetate as a solvent instead of acetic acid. By this method, the concentration of acetic acid, which is considered to be an acetylation reagent of an alcohol, can be suppressed to be minimum. Thus, an alcohol may be consumed exclusively for the oxidation. In fact, primary alcohols, which are not oxidized in acetic acid, and secondary alcohols were effectively converted to the corresponding dimeric esters and ketones, respectively, under milder conditions than those in acetic acid. There have been ample methods for the oxidation of primary alcohols to the dimeric esters and of 1,ω-diols to the corresponding lactones.[5–15)] Among these, the present oxidation is much superior to the conventional procedures in economical, manipulative, and environmental terms, since the reagents are inexpensive and easy to handle, the procedures are facile, and no poisonous materials are formed.

Based on the previous observations[4)] as well as on the present results, the active species of a AcOOH–NaBr system is considered to be acetyl hypobromite (**4**) stemmed from an interaction of peracetic acid with sodium bromide; **4** has also been proposed as an active species in the bromination of aromatic compounds by a peracetic acid–bromine or –bromide ion system[16)] and in the oxidative bromination of alkenes by mercury[17)] and silver[18)] acetates in the presence of bromine. The positive bromine atom attacks the α-position of an alcohol to give a carbocation, which then liberates a proton to form a carbonyl compound (Eqs. 1—3). Upon oxidation of an aliphatic primary alcohol, a primarily formed aldehyde may give a hemiacetal with

$$\mathrm{AcOOH} + \mathrm{NaBr} \longrightarrow \mathrm{AcOBr} + \mathrm{NaOH} \qquad \text{(Eq. 1)}$$

$$\mathrm{AcOBr} + {>}\mathrm{CHOH} \longrightarrow \mathrm{AcOH} + \mathrm{HBr} + {>}\mathrm{C{=}O} \qquad \text{(Eq. 2)}$$

$$\mathrm{HBr} + \mathrm{NaOH} \longrightarrow \mathrm{NaBr} + \mathrm{H_2O} \qquad \text{(Eq. 3)}$$

$$\mathrm{RCHO} + \mathrm{RCH_2OH} \longrightarrow \mathrm{RCH(OH)\text{-}O\text{-}CH_2R} \qquad \text{(Eq. 4)}$$

$$\mathrm{RCH(OH)\text{-}O\text{-}CH_2R} + \mathrm{AcOBr} \longrightarrow \mathrm{RCH(OBr)\text{-}O\text{-}CH_2R} + \mathrm{AcOH} \qquad \text{(Eq. 5)}$$

$$\mathrm{RCH(OBr)\text{-}O\text{-}CH_2R} \longrightarrow \mathrm{RC({=}O)\text{-}OCH_2R} + \mathrm{HBr} \qquad \text{(Eq. 6)}$$

Reaction Scheme.

the parent alcohol. The hemiacetal is further oxidized with **4**, yielding a dimeric ester (Eqs. 4—6). Indeed, the oxidation of a mixture of an aldehyde and the parent alcohol under similar conditions afforded the corresponding dimeric ester in 60—70% yield.

Summing up, the oxidation of alcohols and 1,ω-diols by means of a combination of peracetic acid in ethyl acetate with NaBr afforded the corresponding carbonyl compounds and lactones, respectively, in good to excellent yields in a reasonable period of time under mild conditions. Thus, the present oxidation constitutes a facile and inexpensive synthesis of these compounds.

Experimental

GLC was carried out on a Shimadzu GC-6A or GC-4CM instrument, with a 2 m glass column packed with 5% PEG-20M on Chromosorb GAW-DMCS or with 1.5% Silicone OV-17 on Shimalite W, respectively. For measuring the GLC yield of a product, biphenyl was used as an internal standard. ^{1}H NMR spectra were measured for solutions in $\mathrm{CCl_4}$ or $\mathrm{CDCl_3}$ on a JEOL JNM-C-HL model spectrometer. IR spectra were recorded for liquid films on a JASCO DS-403G spectrophotometer.

Starting Materials. Peracetic acid in ethyl acetate was gifted from Daicel Chemical Industry Co., Ltd., the concentration of which was determined by iodometry. Alcohols and inorganic bromides were commercial materials; the purities of the former were checked by GLC analysis. The solvents were rigorously dried and fractionally distilled before use.

Oxidation Procedure. To a two-necked flask equipped with a condenser and a pressure-equalizing dropping funnel (the top of the latter was connected to a dry argon-filled ballon) was added sodium bromide, an alcohol, and a solvent. Peracetic acid in ethyl acetate was added dropwise to the mixture with magnetic stirring under a gentle argon stream. After completing the addition of the peracetic acid solution, stirring was continued for the same period as that for dropping peracetic acid (total reaction times are indicated in Table 1—3). The reaction mixture was successively washed with water, aqueous sodium carbonate, and water, and then dried ($\mathrm{Na_2SO_4}$). After filtration, the mixture was condensed on a rotary evaporator and the residue was analyzed by GLC. For isolating the product, the residue was chromatographed on silica gel (ethyl acetate–hexane).

The products, except for the following nine compounds, were identified by comparisons of their NMR and IR spectra, and GLC retention times with those of commercial chemicals. The identities of the isolated products in Entries 1, 2, 4, and 9 (e.g. Ref. 7), and in Entries 10, 11, and 13 (e.g. Ref. 13), and the other dimeric esters in Entries 3 and 5 were fully confirmed by spectral analyses.

We thank to Daicel Chemical Industry Co., Ltd. for a gift of peracetic acid in ethyl acetate and also for a partial financial support for this research.

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