New Ring Opening Reactions of Oxiranes with Aryl Carboxylates

Kazutoshi FUNAHASHI

Central Research Institute, Teijin Ltd., Asahigaoka, Hino, Tokyo 191

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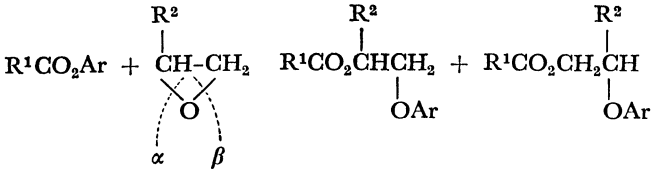
Oxiranes reacted with aryl esters in the presence of base. The reactions of aryl carboxylates with alkyloxiranes afforded almost exclusively 1-alkyl-2-(aryloxy)ethyl carboxylates, whereas the reactions with aryloxiranes gave a mixture of 1-aryl-2-(aryloxy)ethyl carboxylates and 2-aryl-2-(aryloxy)ethyl carboxylates. Similar results were also obtained in the reaction with *S*-aryl thiocarboxylates and diaryl carbonates. The rate of reaction between phenyl acetate and phenoxymethyloxirane (PMO) in the presence of tributylamine (n-Bu_3N) as a catalyst has been determined in the temperature range 110 to 130 °C and may be expressed by $-d[PMO]/dt=k_2[n\text{-}Bu_3N]\cdot[PMO]$. The apparent activation energy calculated from the Arrhenius plots is 85.8 kJ/mol. The reaction catalyzed by tributylamine is assumed to proceed through zwitter ions, n-$Bu_3\overset{+}{N}CH_2CH(R)O^-$ and n-$Bu_3\overset{+}{N}CH(R)CH_2O^-$, which attack aryl carboxylate.

Oxiranes have drawn much attention recently as starting compounds in chemical syntheses. Reports[1] have been published on the addition reactions of oxiranes, but not on the addition reactions of aryl carboxylates to oxiranes. In this paper it will be reported that an aryl carboxylate adds to an oxirane to give addition products, **1** and **2**, as shown in Scheme 1. The reaction is catalyzed by bases such as pyridine, 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU), tributylamine, and potassium *t*-butoxide. When the substituent R^2 on the oxirane is an electron donating group, *e.g.* methyl or phenoxymethyl, cleavage of the oxirane occurs almost exclusively at the β-position, yielding **1** as the product. When R^2 is an aryl group, a mixture of **1** and **2** is obtained. When aryl carbonates or *S*-aryl thiocarboxylates are employed as aryl esters, similar results are observed.

The reaction rate has been determined in the reaction of phenoxymethyloxirane (abbreviated to PMO hereafter) with phenyl acetate in the presence of tributylamine as the catalyst. A probable reaction mechanism has been proposed.

Results and Discussion

The reaction between an aryl carboxylate and alkyloxirane in the presence of a base produced almost exclusive β-cleavage of the oxirane to form aryl carboxylate adducts **1a—g**, as shown in Scheme 1.



1a—i **2a—i**

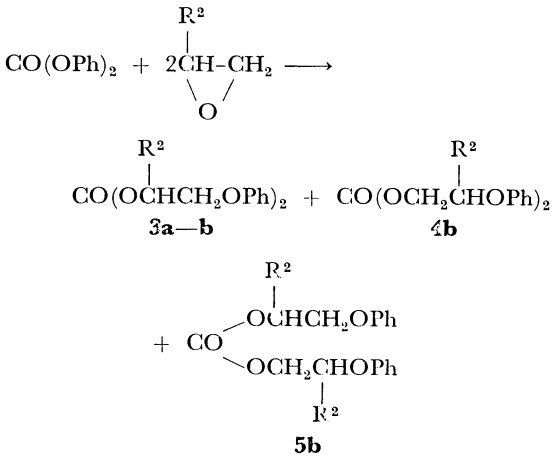
a:	R^1=Me	R^2=H	Ar=Ph
b:	Me	Me	Ph
c:	Me	CH_2OPh	Ph
d:	Ph	H	Ph
e:	Ph	H	*p*-$MeOC_6H_4$
f:	Ph	H	*p*-PhC_6H_4
g:	Ph	Me	Ph
h:	Me	Ph	Ph
i:	Ph	Ph	Ph

Scheme 1.

In several reactions, a very small amount of compound resulting from α-cleavage was found in the products. The structure of the products has been confirmed by a comparison of the isolated reaction products with authentic samples prepared by other routes, the results of which are shown in Table 1. For example, the compound isolated from the reaction product of phenyl acetate with methyloxirane has been identified as 1-methyl-2-phenoxyethyl acetate by comparison with an authentic sample of **1b**, synthesized through other routes.[2] In the case of $R^2=CH_2OC_6H_5$ in Scheme 1, the reaction product was similarly compared with an authentic sample of **1c** synthesized separately[5] and found to be pure **1c**.

The reaction between a phenyl carboxylate and phenyloxirane however caused both α- and β-cleavage of the oxirane to form a mixture of the phenyl carboxylate adducts **1** and **2**. For example, the reaction of phenyloxirane with phenyl acetate produced 2-phenoxy-1-phenylethyl acetate **1h** and β-phenoxyphenethyl acetate **2h**, which were identified by comparison with authentic samples derived from 2-phenoxy-1-phenylethanol and 2-phenoxy-2-phenylethanol, each synthesized by Guss's procedure.[3] The ratio of **1** to **2** formed in the reaction has been determined by gas chromatography, the results of which are shown in Table 2.

A similar reaction occurred when diphenyl carbonate was used as an aryl ester.



3a—b **4b**

5b

a: R^2=H, **b**: $R^2=CH_3$

Table 1. Reaction of aryl esters with oxiranes[a)]

Initial reagents R¹	R²	Ar	Catalyst	Reaction temp (°C)	time (h)	Product	**1** in the mixture (%)[c)]	Yield[d)] (%)	Mp(Bp/kPa) (°C)	Calcd (Found) (%) C	H
Me	H	Ph	DBU	140	4	**1a**	100	77	131/20 [97.5—98.5/0.27][7)e)]		
Ph	H	Ph	*n*-Bu_3N	140	7	**1d**	100	84	60	74.63 (74.49	5.82 5.68)
Ph	Me	Ph	Pyridine	150	4	**1g**, **2g**	95	82	239—241/4	74.98 (75.14	6.29 6.14)
Ph	H	*p*-$MeOC_6H_4$	*t*-BuOK	170	5	**1e**	100	88	71	70.57 (70.72	5.92 5.88)
Ph	H	*p*-PhC_6H_4	DBU	160	5	**1f**	100	78	95	79.22 (79.35	5.70 5.90)
Me	$PhOCH_2$	Ph	*t*-BuOK	170	4	**1c**	100	92	185/0.67 [33][5)e)]		
Me	Me	Ph	Pyridine	150	4	**1b**, **2b**	97	84	141/3.1		
OPh	H	Ph[b)]	*t*-BuOK	190	5	**4a**	100	79	91.5—92.5 [92—93][8)e)]		

a) The molar ratio of substrates: aryl esters/oxiranes/catalyst=1/1.2/0.03 except in (b). b) The molar ratio of substrates: diphenyl carbonate/oxirane/catalyst=1/2.4/0.06. c) The ratio was determined by integration of the NMR absorption area. d) Total isolated yield based on the aryl ester used. e) Value described in the literature.

Table 2. Reaction of phenyl ester with phenyloxirane

Phenyl ester[a)]	Catalyst	Reaction temp (°C)	time (h)	Product	Yield[b)] (%)	**1** in the mixture (%)	Bp/kPa (°C)	Calcd (Found) (%) C	H
AcOPh	DBU	140	4	**1h**, **2h**	86	75.1	154—157/0.53	75.00 (75.25	6.29 6.37)
AcOPh	Pyridine	180	6	**1h**, **2h**	34	59.0			
BzOPh	*t*-BuOK	200	5	**1i**, **2i**	79	79.4	202—205/0.4	79.22 (79.49	5.70 5.58)
BzOPh	DBU	150	6	**1i**, **2i**	88	72.9			

a) The molar ratio of substrates: phenyl ester/phenyloxirane/catalyst=1/1/0.015. b) Total isolated yield.

For example, diphenyl carbonate reacted with methyloxirane to give a mixture of **3b**, **4b**, and **5b**, the proportion of **3b** being more than 91% in the product, which was determined by integration of the NMR peak. Product **3b** was identified by comparison with an authentic sample prepared by the reaction of phosgene with 1-phenoxy-2-propanol.

The reaction of *S*-phenyl thiobenzoate with oxirane was conducted in order to determine the reaction mechanism and was found to proceed as follows.

$$PhCOSPh + \overset{\diagdown\!\diagup}{O} \longrightarrow \underset{\mathbf{6}}{PhCO_2CH_2CH_2SPh}$$

Product **6** was identified by comparison with an authentic sample prepared by the benzoylation of 2-(phenylthio)ethanol. No other products, for example, *S*-(2-phenoxyethyl) thiobenzoate, were detected. The reaction proved therefore that the aryl ether oxygen of the product came from the aryloxyl group in the aryl carboxylate.

Reaction Rates. The reaction rate was investigated as follows. PMO was chosen as the oxirane and allowed to react with phenyl acetate in nitrobenzene in the presence of tributylamine. The reaction rate was determined by measurement of the unchanged PMO.

Reaction Rate and Catalyst Concentration and Reaction Temperature. The rate of reaction was found to be in linearly related to the PMO concentration as shown in Figs. 1 and 2, *i.e.*,

$$-d[PMO]/dt = k_1[PMO] \quad (1)$$

where k_1 is the first order rate constant and [PMO] is the concentration of PMO.

The reaction rate was also determined at various [PMO]/[Phenyl acetate] ratios and was found to be first order with respect to [PMO] and zero order with respect to [Phenyl acetate] as may be seen in Fig. 1.

The relation between k_1 and catalyst concentration was determined by changing the concentration of *n*-Bu_3N. A linear relationship passing through the origin was established as shown in Fig. 3.

Eq. 1 may be rewritten:

$$-d[PMO]/dt = k_2[cat][PMO] \quad (2)$$

where k_2 is the second order rate constant and [cat] is the concentration of catalyst. k_2 is equal to $k_1/[cat]$.

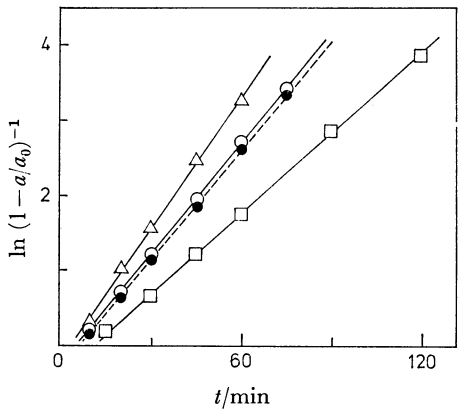


Fig. 1. First-order decrease of [PMO] in the reaction of AcOPh with PMO. The reactions were carried out at various temperatures, △; 130 °C, ○; 120 °C, □; 110 °C, in the reaction system containing AcOPh (1.6 mol), PMO (1.6 mol), *n*-Bu_3N (0.08 mol), and $PhNO_2$ with which the total weight of the system was adjusted to 1 kg. ●; Instead of using 1.6 mol of AcOPh in the system, 3.2 mol was used at 120 °C. a_0; $[PMO]_{initial}$, a; $[PMO]_{decreased}$.

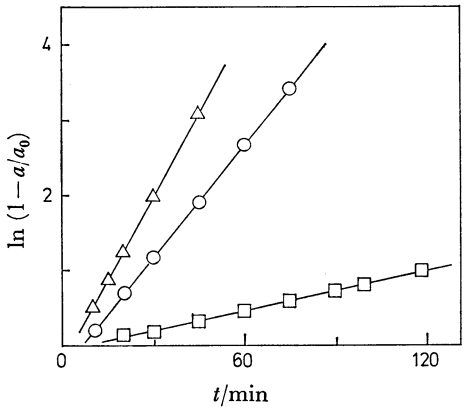


Fig. 2. First-order decrease of [PMO] in the reaction of AcOPh with PMO at 120 °C. The reactions were carried out in the reaction system containing AcOPh (1.6 mol) and PMO (1.6 mol) and various amounts of *n*-Bu_3N, △; 0.12 mol, ○; 0.08 mol, □; 0.016 mol.

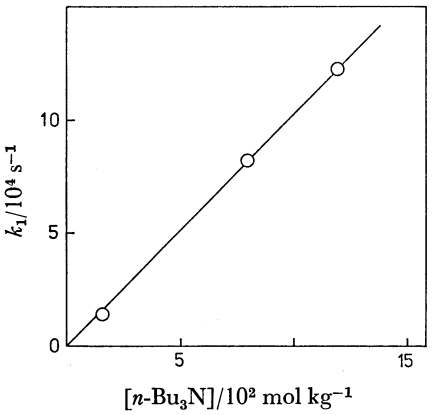


Fig. 3. The relation between the first order rate constant (k_1) and the concentration of *n*-Bu_3N at 120 °C. The reactions were carried out in the reaction system containing AcOPh (1.6 mol), PMO (1.6 mol), and various amounts of *n*-Bu_3N.

TABLE 3. RELATION OF REACTION TEMPERATURES TO k_1 AND k_2 IN THE REACTION SYSTEM CONTAINING AcOPh (1.60 mol), PMO (1.60 mol), *n*-Bu_3N (0.08 mol), AND $PhNO_2$ (TOTAL WEIGHT OF 1 kg)

	110 °C	120 °C	130 °C
10^4k_1 (s^{-1})	6.048	8.222	10.60
10^2k_2 ($l\,mol^{-1}\,s^{-1}$)[a]	0.713	0.979	1.274

a) Converted by the density of the reaction system.

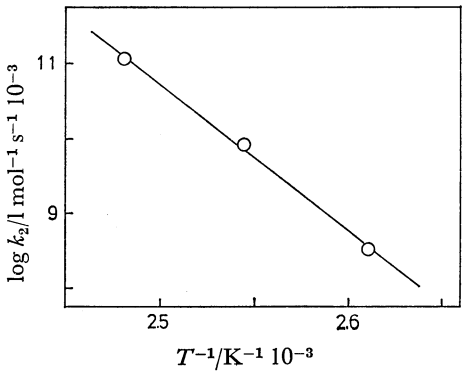


Fig. 4. Arrhenius plots of the second order rate constants.

Values of k_1 and k_2 are given in Table 3.

The Apparent Activation Energy. The Arrhenius plots based on k_2 are shown in Fig. 4 and the apparent activation energy has been estimated as 85.8 kJ/mol in the temperature range 110—130 °C.

The Reaction Mechanism. 1) In the presence of tributylamine and nitrobenzene as catalyst and solvent respectively, the rate of the reaction shown in Scheme 1, may be expressed as follows:

$$-d[PMO]/dt = k_2[n\text{-}Bu_3N][PMO]$$

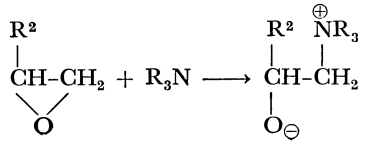
and is of zero order with respect to the concentration of aryl ester.

2) In the reactions of Scheme 1, with methyloxirane and PMO as oxiranes the reaction products were produced almost exclusively by selective β-cleavage of the oxiranes, *i.e.*, **1b**, and **1c**. This shows that a nucleophile attacks the primary carbon of the oxirane.

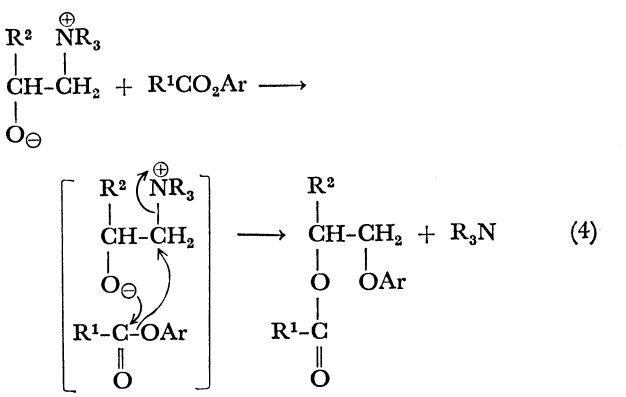
3) The formation of **6** in the reaction between *S*-phenyl thiobenzoate and oxirane suggests that the addition of an aryl ester to an oxirane occurs *via* C–O bond cleavage between the carbonyl carbon and the aryloxyl group of an aryl ester.

4) Laird and Parker[4] assumed that the reaction of oxirane with an alcohol in the presence of triethylamine as catalyst formed a intermediate zwitter ion, $Et_3\overset{+}{N}CH_2CH_2O^-$.

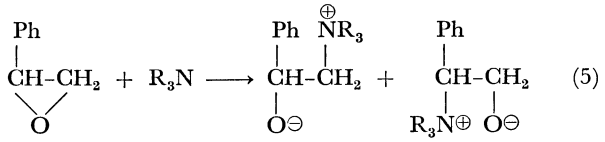
On the basis of the above evidence, the reaction of alkyloxirane, catalyzed by a tertiary amine is assumed to proceed as follows. The rate determining step is Eq. 3.



(3)



In the reaction of phenyloxirane with a phenyl carboxylate, it appears that the tertiary amine attacks competitively on both the primary and secondary carbons in the oxirane. This is due to inductive and steric effects of the phenyl group in the oxirane, as shown in Eq. 5. Thus, a mixture of **1** and **2** was formed.



Experimental

All boiling and melting points are uncorrected. The IR and NMR spectra were recorded on a Hitachi EPI-G and JEOL-PS-100/PET-100A spectrometer respectively. Mass spectra (MS) were obtained on a Shimadzu LKB-9000 mass spectrometer at 70 eV.

Reaction between Phenyl Acetate and Methyloxirane. Phenyl acetate (2.72 g, 20 mmol), methyloxirane (1.28 g, 22 mol) and tributylamine (0.11 g, 0.6 mmol) in THF (15 ml) were placed in an autoclave and stirred at 170 °C for 3 h. The reaction mixture was distilled under reduced pressure giving 3.26 g (84%) of **1b**; bp 141 °C/3.1 kPa; IR(neat) 3040(=C–H), 2970(CH_3), 2920(CH_2), and 1740 (C=O) cm^{-1}; MS (70 eV) *m/e* (rel intensity) 194(2), 134(2), 101(46), 77(13), and 43(100); NMR ($CDCl_3$) δ (ppm from TMS) 1.32 (3H, d, J=7.1 Hz, C–C$\underline{H}_3$), 2.01(3H, s, OCOC$\underline{H}_3$), 3.95(2H, d, J=5.2 Hz, C$\underline{H}_2$–OPh), and 5.22(1H, m, CH_3CO_2–C$\underline{H}$). Found: C, 68.21; H, 7.37%. Calcd for $C_{11}H_{14}O_3$: C, 68.02; H, 7.27%.

The product was identified as **1b** by comparison with an authentic sample of **1b** prepared by another route.

Reaction between Phenyl Acetate and Phenyloxirane. Phenyl acetate (6.8 g, 50 mmol), phenyloxirane (6.0 g, 50 mmol) and potassium *t*-butoxide (0.090 g, 0.8 mmol) were heated at 170 °C for 3 h. The reaction mixture was dissolved in ether and the ethereal solution washed with water, and distilled under reduced pressure, giving 11.6 g (91%) of a mixture of **1h** and **2h**; bp 154—157 °C/0.53 kPa; IR (neat) 1747(C=O) cm^{-1}; Found: C, 75,27; H, 6.37%. Calcd for $C_{16}H_{16}O_3$: C, 75.00; H, 6.29%.

The product was found by means of gas chromatography to be a mixture of **1h** and **2h** (1m column of SE-30 on Celite). The products were identified by comparison with authentic samples prepared separately. The proportion of **1h** in the mixture was 68.2% determined by gas chromatography.

Reaction between S-Phenyl Thiobenzoate and Oxirane. *S*-Phenyl thiobenzoate (4.3 g, 20 mmol), oxirane (1.8 g, 41 mmol) and potassium *t*-butoxide (0.06 g, 0.53 mmol) were heated at 180 °C for 6 h to give 3.7 g (71.6%) of **6**: bp 161—162 °C/0.27 kPa; IR (neat) 3050(=C–H), 2920(CH_2), and 1715(C=O) cm^{-1}; NMR ($CDCl_3$) δ 3.24(2H, t, J=6.8 Hz, PhSC$\underline{H}_2$), and 4.45(2H, t, J=6.8 Hz, $CH_3CO_2C\underline{H}_2$). Found: C, 69.49; H, 5.25%. Calcd for $C_{15}H_{14}O_2S$: C, 69.74; H, 5.46%. The product was identified as **6** by comparison with an authentic sample prepared by another route.

Reaction of Diphenyl Carbonate with Methyloxirane. Diphenyl carbonate (3.2 g, 15 mmol), methyloxirane (2.6 g, 45 mmol) and potassium *t*-butoxide (0.09 g, 0.8 mmol) were heated at 170 °C for 4 h to give 3.7 g(75.0%) of a mixture of **3b**, **4b**, and **5b**: bp 182—186 °C/0.27 kPa; IR (neat) 2960(CH_3) and 1735(C=O) cm^{-1}; NMR ($CDCl_3$) δ 1.39 (d, J=6.8 Hz, C$\underline{H}_3$), 3.98(d, J=4.8 Hz, PhOC$\underline{H}_2$), 4.23(d, J=7.9 Hz, $CO_2C\underline{H}_2$), 4.58(m, PhOC$\underline{H}$), and 5.10(m, CO_2-C$\underline{H}$). Found: C, 69.35; H, 6.89%. Calcd for $C_{19}H_{22}O_5$: C, 69.07; H, 6.71%. The proportion of **3b** in the product was more than 82% determined by integration of the NMR absorption area.

Syntheses of Authentic Samples. ***1b***, ***2b***, ***1g***, *and* ***2g***: 1-Phenoxy-2-propanol and 2-phenoxy-1-propanol were prepared by Sexton's procedure[2] and acetylated or benzoylated by Schotten-Baumann's reaction.

1b: Bp 140—142 °C/3.2 kPa. Found: C, 68.09; H, 7.36%.

2b: Bp 134—136 °C/3.3 kPa; NMR ($CDCl_3$) δ 1.30(3H, d, J=6.0 Hz, CHC$\underline{H}_3$), 2.02(3H, s, C$\underline{H}_3$CO), 4.18(2H, m, C$\underline{H}_2$), and 4.58(1H, m, C$\underline{H}$). Found: C 68.16; H, 7.35%. Calcd for $C_{11}H_{14}O_3$: C, 68.02; H, 7.27%.

1g: Bp 135—137 °C/0.2 kPa; NMR ($CDCl_3$) δ 1.47(3H, d, J=6.8 Hz, C$\underline{H}_3$), 4.10(2H, m, C$\underline{H}_2$), and 5.48(1H, m, C$\underline{H}$). Found: C, 74.88; H, 6.27%.

2g: Bp 131—133 °C/0.2 kPa; NMR ($CDCl_3$) δ 1.40(3H, d, J=6.8 Hz, C$\underline{H}_3$), 4.39(2H, m, C$\underline{H}_2$), and 4.72(1H, m, C$\underline{H}$). Found: C, 74.90; H, 6.21%. Calcd for $C_{16}H_{16}O_3$: C, 74.98; H, 6.29%.

1c. **1c** was prepared by Fairbourne's procedure:[5] bp 143—146 °C/0.27 kPa; MS (70 eV) *m/e* 286(M^+); NMR ($CDCl_3$) δ 2.00(3H, s, C$\underline{H}_3$), 4.10(4H, d, J=4.8 Hz, 2 C$\underline{H}_2$), and 5.35(1H, m, C$\underline{H}$).

3b. **3b** was prepared by the reaction of 1-phenoxy-2-propanol with phosgene in pyridine: bp 185—186 °C/0.27 kPa; NMR($CDCl_3$) δ 1.39(6H, d, J=6.8 Hz, 2C$\underline{H}_3$), 3.98(4H, d, J=4.8 Hz, 2C$\underline{H}_2$OPh), and 5.10(2H, m, $2CO_2$-C$\underline{H}$). Found: C, 69.21; H, 6.77%. Calcd for $C_{19}H_{22}O_5$: C, 69.07; H, 6.71%.

1h, ***1i***, ***2h***, *and* ***2i***. 2-Phenoxy-1-phenylethanol and 2-phenoxy-2-phenylethanol were prepared by Guss's procedure[3] and the products acetylated or benzoylated by Schotten-Baumann's reaction.

1h: Bp 148—151 °C/0.4 kPa; MS(12 eV), *m/e* 256(M^+), and 196. Found: C, 75.15; H, 6.17%.

2h: Bp 141—143 °C/0.4 kPa; MS(12 eV), *m/e* 256(M^+), and 183. Found: C, 75.21; H, 6.21%. Calcd for $C_{16}H_{16}O_3$: C, 75.00; H, 6.29%.

1i: Bp 205—208 °C/0.4 kPa; MS(70 eV), *m/e* 318(M^+), and 196. Found: C, 79.29; H, 5.59%.

2i: Bp 200—205 °C/0.4 kPa; MS(70 eV), *m/e* 225($M^+ - C_6H_5O$), and 183. Found: C, 79.34; H, 5.63%. Calcd for $C_{21}H_{18}O_3$: C, 79.22; H, 5.70%.

6. **6** was prepared by benzoylation of 2-(phenylthio)ethanol by Schotten-Baumann's reaction.

6: Bp 162 °C/0.27 kPa. Found: C, 69.83; H, 5.30%. Calcd for $C_{15}H_{14}O_2S$: C, 69.74; H, 5.46%.

Measurement of Reaction Rates. The rate of the reaction between PMO and phenyl acetate in the presence of tributylamine catalyst was determined.

Samples: PMO was prepared from phenol and epichloro-

hydrin by conventional means. The purity was determined according to Stenmark[6] and was greater than 98.1%. Phenyl acetate, and tributylamine were purified by conventional means. Nitrobenzene solvent was a commercially available product which was further purified.

Determination: PMO, phenyl acetate and tributylamine were mixed in the appropriate amounts and nitrobenzene added until the total amount was 2.5 g. The mixture was charged into a sealed glass tube of 0.8 cm inner diameter and 8 cm length. The sealed glass tube was vigorously agitated in a thermostat bath maintained at a specific temperature. After a specified reaction period the sealed tube was taken out of the bath and quenched. Unchanged PMO in the reaction mixture was determined by Stenmark's procedure.[6]

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