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Stereochemical Studies on the Nuclear Alkylation of Phenols with 1-Phenylethyl Chloride and the Acidic Rearrangement of the 1-Phenylethyl Ethers of Phenols in the Phenolic Solvents

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Phenolyses of optically active 1-phenylethyl chloride were carried out in phenol (50 °C), *p*-cresol (100 °C), *p*-chlorophenol (100 °C), and 2,6-xylenol (100 °C) in the presence of variable concentrations of the sodium salts of the respective phenols or triethylamine; the distributions (%) for the O- and C-alkylation products and the net steric courses (α%) for each product were examined. The distribution and the steric course which were graphically extrapolated to the zero base concentration indicated that, if the influence of the liberated hydrogen chloride was excluded, in the phenolyses without an added base the major products are the 1-phenylethyl ethers of the respective phenols with net *retained* configurations and the minor products are the *o*- and *p*-1-phenylethylated phenols with net *inverted* configurations. The hydrogen chloride rearrangement of the optically active 1-phenylethyl ethers of the respective phenols proceeded rapidly to give *o*-1-phenylethylated phenols with predominantly *retained* configurations (for phenol, *p*-cresol, and *p*-chlorophenol) and *p*-1-phenylethylated phenols with net *inverted* configurations (for phenol and 2,6-xylenol) in the respective phenol–benzene (1 : 1 by wt) solvents. The *p*-toluenesulfonic acid rearrangement of 1-phenylethyl phenyl ether-^{18}O proceeded to give *o*- and *p*-1-phenylethylphenols with partial loss of the oxygen-18 atom in the phenol–benzene (1 : 1 by wt) solvent, indicating the coexistence of the *intermolecular* course for the acidic rearrangement in the phenolic solvents. From these findings, it is concluded that the formation of the *ortho*-alkylates with retention of configuration, experimentally observed in the respective phenolyses without an added base, is attributed not to the direct retentive alkylation of the phenols, but to the rapid rearrangement of the 1-phenylethyl ethers with net retention of configuration, caused by the hydrogen chloride liberated in the S_N1-phenolysis of 1-phenylethyl chloride in the respective phenolic solvents.

When the S_N1 phenolysis of optically active 1-phenylethyl chloride was conducted in the presence of a base, partially (20—50%) retained 1-phenylethyl phenyl ether and partially (25—87%) inverted *o*- and *p*-1-phenylethylphenols were obtained in phenol, *p*-cresol, *p*-chlorophenol, and *p*-nitrophenol solvents.[1)]

On the other hand, when the phenolysis was carried out without an added base, no phenolic ether was obtained. Instead, 1-phenylethylphenols alone were isolated; the *ortho* alkylated phenol possessed partially retained configuration, whereas the *para* isomer configuration was partially inverted.[2)] These are illustrated in the following scheme.

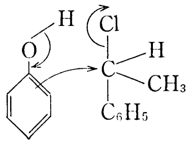
In the presence of a base:

$$(R)\text{-RCl} + \text{PhOH} \longrightarrow (R)\text{-ROPh}$$
$$+ (S)\text{-}o\text{-RC}_6\text{H}_4\text{OH} + (S)\text{-}p\text{-RC}_6\text{H}_4\text{OH}$$

Without an added base:

$$(R)\text{-RCl} + \text{PhOH} \longrightarrow$$
$$(R)\text{-}o\text{-RC}_6\text{H}_4\text{OH} + (S)\text{-}p\text{-RC}_6\text{H}_4\text{OH}$$

Prior to these investigations,[1,2)] Hart and his collaborators[3)] had already reported that *ortho*-alkylations of *p*-cresol and *p*-chlorophenol with optically active 1-phenylethyl chloride proceeded with retention of configuration, but the *para*-alkylation of 2,6-xylenol involved inversion; they suggested that the *ortho*-alkylation with retention of configuration would be a direct retentive C-alkylation with a cyclic transition state as follows.



However, as we pointed out in the previous paper,[2)] in view of the fact that in the phenol–acetonitrile solvent optically active 1-phenylethyl phenyl ether undergoes a rapid rearrangement to give the predominantly retained *o*-(1-phenylethyl)phenol in the presence of hydrogen chloride, it is probable that the product distribution and the steric course observed in the experiments[2,3)] without an added base do not reflect the true reaction result between 1-phenylethyl chloride and phenol, but they are perturbed by the facile acidic rearrangement of 1-phenylethyl phenyl ether formed as a precursor of *o*- and *p*-alkylated phenols.

In order to confirm this anticipation, we intended to know the true product distribution and the true steric course avoided from the perturbation by the hydrogen chloride rearrangement. For this purpose we adopted an extrapolation method which we had applied to several phenolyses without an added base.[4)] Namely, we carried out the phenolyses of optically active 1-phenylethyl chloride in phenol, *p*-cresol, *p*-chlorophenol, and 2,6-xylenol solvents, and examined the product distribution and the steric course for each product in the respective phenolyses with variable concentrations of sodium salts of the phenoxides or triethylamine; then extrapolated the results graphically to the zero base concentration. We considered the extrapolated values as the intrinsic results which are not affected by the liberated hydrogen chloride.

In this paper we will report that, contrary to the results of the experiments carried out without an added base,[2,3)] the extrapolated results indicate that the direct *ortho*-alkylation with optically active 1-phenylethyl chloride proceeds with predominant *inversion* of configuration in phenol, *p*-cresol, and *p*-chlorophenol solvents, and that the *retained* *ortho*-1-phenylethylated phenols which were obtained in the experiments without an added base are mostly produced by the retentive and rapid hydrogen chloride rearrangement of 1-phenylethyl phenyl ethers, initially-formed from the respective phenols and with net retained configurations, and consequently that a direct retentive C-alkylation[3)] is not a major mechanism for the formation of the retained *ortho*-alkylates in the nuclear alkylations of phenol, *p*-cresol, and *p*-chlorophenol.

The S_N1 Phenolysis Rates and the Product Distribvtions in the Absence of a Base. In the presence of a base the phenolysis of 1-phenylethyl chloride obeys a good first-order kinetics, showing a good S_N1 characteristics, and gives the phenyl ethyl eher and *o*- and *p*-alkylated phenols.[1)] However, as mentioned above, in the experiments without an added base the liberated hydrogen chloride seems to perturb the S_N1 phenolysis by the acidic rearrangement of the phenyl ether[2)] and also by the cleavage reaction[5)] of the phenyl ether with hydrogen chloride (*vide infra*).

In order to confirm such perturbation, we carried out the rate measurements without an added base. As anticipated, the first-order titrimetric rate constants of the phenolysis of 1-phenylethyl chloride tended to decrease after 19—26% completion in the mixtures of benzene and the respective phenols (1: 1 by weight). This is most probably ascribed to the occurrence of the cleavage reaction[5)] of the respective phenyl ether by hydrogen chloride to give the starting 1-phenylethyl chloride. The initial first-order rate constants are summarized in Table 1.

TABLE 1. FIRST-ORDER RATE CONSTANTS FOR PHENOLYSES OF 1-PHENYLETHYL CHLORIDE IN PHENOL (ArOH)–BENZENE (1: 1 by wt) SOLVENT IN THE ABSENCE OF A BASE

Solvent ArOH–C_6H_6	Temp. °C	RCl M	k_1 s^{-1}	Conversion %
C_6H_5OH–C_6H_6	50	0.100	3.95×10^{-4}	25
p-MeC_6H_4OH–C_6H_6	50	0.103	3.85×10^{-4}	19
p-ClC_6H_4OH–C_6H_6	50	0.101	3.66×10^{-4}	20
2,6-Xylenol–C_6H_6	50	0.100	6.86×10^{-7} a)	26

a) Extrapolated value from data at 75 and 100 °C.

Hart and his collaborators[3)] found that mixtures of various phenols and 1-phenylethyl chloride evolved hydrogen chloride to give 1-phenylethylated phenols, but they neither carried out the kinetic measurement, nor interpreted the reaction in terms of the typical S_N1 phenolysis.

In order to know the true product distribution which is not perturbed by the liberated hydrogen chloride, the distribution values in the phenolyses with variable concentrations of triethylamine or the sodium salt of the respective phenols were examined and extrapolated to the zero base concentration. The results obtained for the phenolyses in *p*-cresol (100 °C), *p*-chlorophenol (100 °C), 2,6-xylenol (100 °C), and phenol (50 °C) are summarized in Table 2, and illustrated in Figs. 1, 2, 3, and 4.

As it is shown in Figs. 1—4, the extrapolated values for the yield of the phenyl ether clearly indicate that, if the influence of hydrogen chloride is excluded from the reaction medium, the phenyl ether would be the major product for each phenolysis. The results, which were obtained by Hart and his collaborators[3)] and confirmed in our duplicate runs, are clearly different from our extrapolated results (see Table 2).

The Steric Course of the S_N1 Phenolysis in the Absence of a Base. Hart and his collaborators[3)] found that 1-phenylethyl chloride gives partially *retained ortho* 1-phenylethylated phenol in *p*-cresol and in *p*-chlorophenol. We confirmed their results under similar reaction conditions (see Table 2).

However, in the previous experiments[1b)] carried out with added triethylamine in the mixtures of *p*-substituted phenols (phenol, *p*-cresol, and *p*-chlorophenol) and organic solvents (benzene and acetonitrile), we found that *ortho* 1-phenylethylated phenols exhibited partially *inverted* configurations.

In order to make the situation clearer, we examine

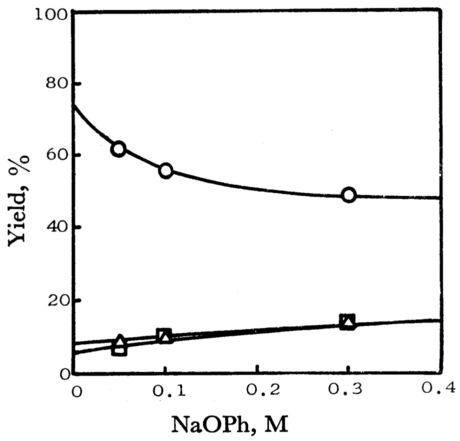
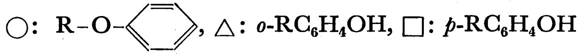


Fig. 1. The product composition for 1-phenylethyl chloride phenolysis in phenol in the presence of sodium phenoxide at 50 °C.


○: R-O-, △: o-RC_6H_4OH, □: p-RC_6H_4OH

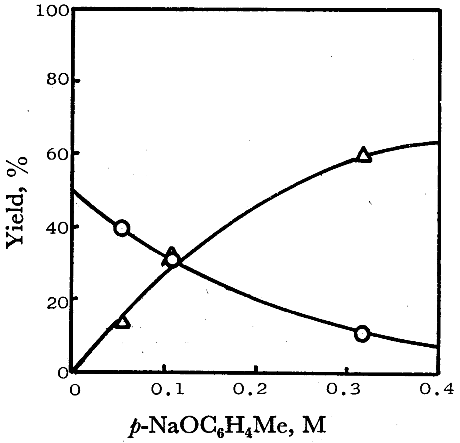
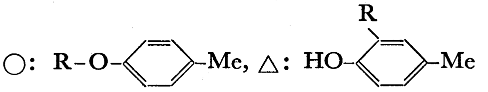


Fig. 2. The product composition for 1-phenylethyl chloride phenolysis in *p*-cresol in the presence of sodium *p*-cresoxide at 100 °C.


○: R-O-⟨⟩-Me, △: HO-⟨⟩-Me

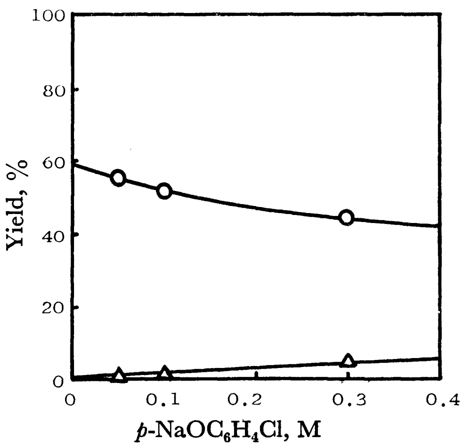
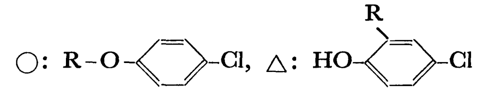


Fig. 3. The product composition for 1-phenylethyl chloride phenolysis in p-chlorophenol in the presence of sodium p-chlorophenoxide at 100 °C.



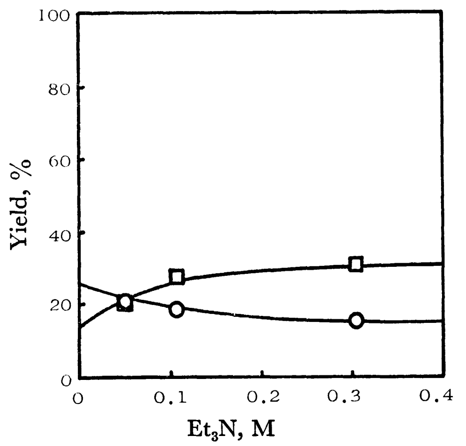


Fig. 4. The product composition for 1-phenylethyl chloride phenolysis in 2,6-xylenol in the presence of triethylamine at 100 °C.

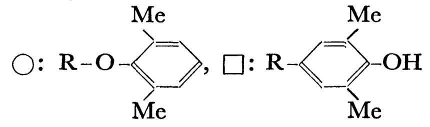


Table 2. Effect of added sodium phenoxides upon the product compositions and the steric courses for the phenolyses of 1-phenylethyl chloride in phenolic solvents

Solvent	Base[a] M	Product					
		Phenolic ether		o-Alkylated phenol		p-Alkylated phenol	
		Yield %	Net steric course, α%[b]	Yield %	Net steric course, α%[b]	Yield %	Net steric course, α%[b]
Phenol[c]	0.000	0.00	—	34.5	15.1 Ret.	63.8	35.1 Ret.
	0.051	61.8	30.3 Ret.	9.19	10.9 Inv.	6.78	29.7 Inv.
	0.109	56.3	29.7 Ret.	9.79	14.4 Inv.	10.3	31.2 Inv.
	0.309	49.3	33.5 Ret.	14.2	33.5 Inv.	14.4	32.3 Inv.
p-Cresol[d]	0.000	0.00[e]	—	60[e]	4.15 Ret.[e]	—	
	0.000	2.25	8.66 Ret.	87.3	2.50 Ret.	—	
	0.054	39.8	6.16 Ret.	13.9	7.34 Inv.	—	
	0.124	31.6	4.93 Ret.	31.4	9.13 Inv.	—	
	0.333	11.5	2.20 Ret.	60.0	19.1 Inv.	—	
p-Chlorophenol[d]	0.000	0.00[e]	—	62[e]	2.26 Ret.[e]	—	
	0.000	1.05	—	56.2	0.97 Ret.	—	
	0.051	55.9	22.1 Ret.	0.976	24.7 Inv.	—	
	0.101	53.0	20.7 Ret.	1.25	28.5 Inv.	—	
	0.302	44.3	16.3 Ret.	4.56	54.0 Inv.	—	
2,6-Xylenol[f]	0.000	0.00[e]	—	—		50[e]	5.46 Inv.[e]
	0.000	4.20	27.6 Ret.	—		41.5	7.06 Inv.
	0.051[g]	20.8	38.4 Ret.	—		20.1	18.8 Inv.
	0.115[g]	19.1	29.3 Ret.	—		27.2	30.0 Inv.
	0.310[g]	15.7	19.1 Ret.	—		32.1	77.9 Inv.

a) Sodium salts of the respective phenols. RCl=0.050 M. b) Calculated taking into account lack of optical purity of the starting substrate; the rotations of optically pure materials are taken to be 125° for R-(+)-1-phenylethyl chloride(H.M.R. Hoffmann and E.D. Hughes, *J. Chem. Soc.*, **1964**, 1244), 46.6° for S-(+)-1-phenylethyl phenyl ether (Ref. 1b), 20.4° for S-(+)-1-phenylethyl p-cresyl ether (Ref. 1b), −22.40° for R-(−)-1-phenylethyl p-chlorophenyl ether (Ref. 1b), −57.9° for R-(−)-1-phenylethyl 2,6-xylyl ether, 27.85° for R-(+)-o-(1-phenylethyl)phenol (Ref. 1b), 10.26° for S-(+)-p-(1-phenylethyl)phenol (Ref. 1b), 17.1° for S-(+)-o-(1-phenylethyl)p-cresol (Ref. 9), 44.7°for S-(+)-o-(1-phenylethyl)-p-chlorophenol (Ref. 9), and 8.6° for S-(+)-4-(1-phenylethyl)-2,6-xylenol (Ref. 9). Reported value for the 2,6-xylyl ether, −51° (Ref. 5a), was recalculated on the basis of the new value for the maximum rotation of the chloride (H. and H., *loc. cit.*). c) At 50 °C for 2 hr. d) At 100 °C for 5 hr. e) Hart *et al.* (Ref. 3). f) At 100 °C for 20 hr. g) Triethylamine.

TABLE 3. PRODUCT COMPOSITION AND STERIC COURSES FOR PHENOLYSES OF 1-PHENYLETHYL CHLORIDE IN VARIOUS PHENOLS.

Extrapolated values to the zero base concentration

Solvent	Temp. °C	Product Phenolic ether Yield %	 Phenolic ether Net steric course, α%	 *o*-Alkylated phenol Yield %	 *o*-Alkylated phenol Net steric course, α%	 *p*-Alkylated phenol Yield %	 *p*-Alkylated phenol Net steric course, α%
Phenol	100	75	29 Ret.	9.0	7.0 Inv.	7.0	29 Inv.
p-Cresol	100	49	8.7 Ret.	0—1	6.0 Inv.		—
p-Chlorophenol	100	59	59 Ret.	0—1	17 Inv.		—
2,6-Xylenol	100	25	50 Ret.		—	15	10 Inv.

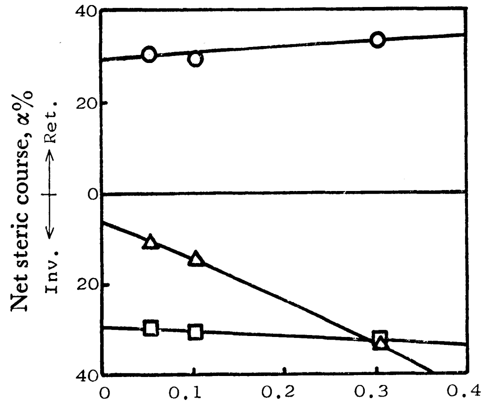
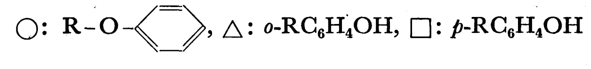


Fig. 5. The steric course for 1-phenylethyl chloride phenolysis in phenol in the presence of sodium phenoxide at 50 °C.



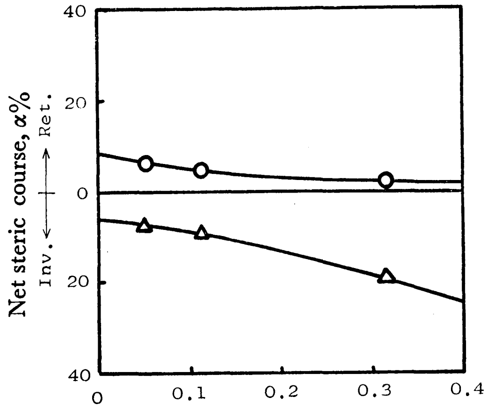
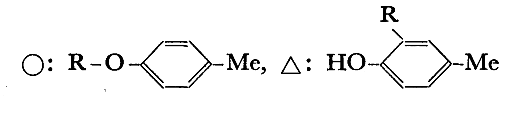


Fig. 6. The steric course for 1-phenylethyl chloride phenolysis in *p*-cresol in the presence of sodium *p*-cresoxide at 100 °C.



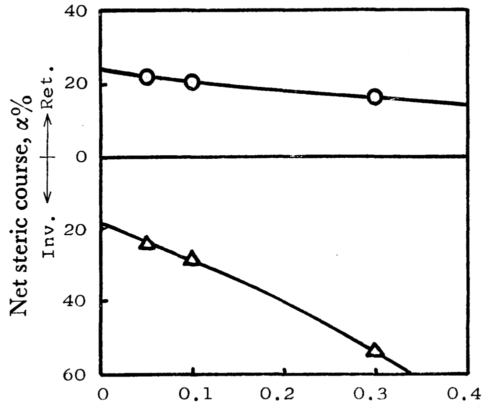
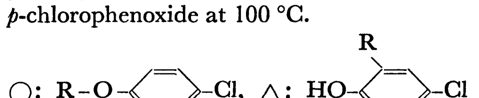


Fig. 7. The steric course for 1-phenylethyl chloride phenolysis in *p*-chlorophenol in the presence of sodium *p*-chlorophenoxide at 100 °C.



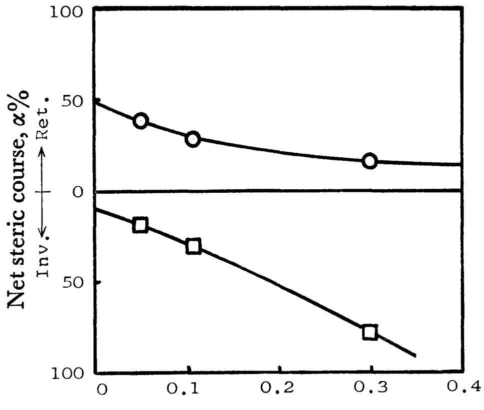
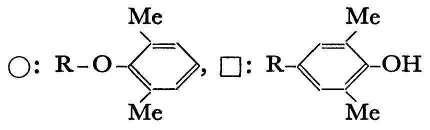


Fig. 8. The steric course for 1-phenylethyl chloride phenolysis in 2,6-xylenol in the presence of triethylamine at 100 °C.



the effect of the base concentration on the steric course of the *ortho* 1-phenylethylated phenol formation by carrying out the phenolyses of optically active 1-phenylethyl chloride in the presence of variable concentrations of the sodium salts of phenol, *p*-cresol, and *p*-chlorophenol. The results are graphically extrapolated to the zero concentration of the respective phenoxides. These are illustrated in Table 3 and Figs. 5, 6, and 7 along with the steric courses for the formation of 1-phenylethyl ether of the respective phenols. In Fig. 8 the steric course for the formation of *para* 1-phenylethylated 2,6-xylenol and 1-phenylethyl 2,6-xylyl ether in the xylenolyses with variable concentrations of triethylamine are illustrated.

It is evident that the extrapolated results show that even in the absence of the base the phenolyses give *ortho* 1-phenylethylated phenols with partially *inverted* configuration, if the perturbation of hydrogen chloride was excluded. From these results we can conclude that the intrinsic steric course for the *ortho* alkylation of phenol with 1-phenylethyl chloride is predominantly *inverted.*

The Steric Course of the Formation of 1-Phenylethylphenols from 1-Phenylethyl Ethers of Various Phenols in the Acidic Phenol Solvents. In order to confirm the rate and the steric course of the acidic rearrangement of 1-phenylethyl group under the phenolysis condition, the rearrangement of optically active 1-phenylethyl ethers of phenol, *p*-cresol, *p*-chlorophenol, and 2,6-xylenol were carried out in the presence of hydrogen chloride in the respective phenolic solvents. The respective 1-phenylethyl ethers rearranged rapidly to the corresponding 1-phenylethylphenols (92—97% yield) in the respective phenol–benzene (1: 1 by wt.) solvents at the same temperature as the phenolyses were conducted. A summary of the stereochemical results is given in Table 4.

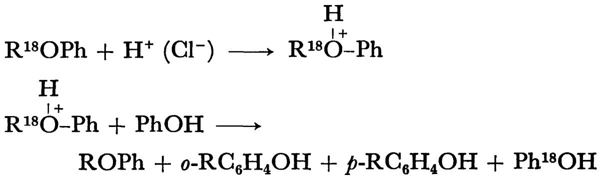
It is shown for each rearrangement that the 1-phenylethyl group rearranges to the *ortho* position with partial retention of the configuration whereas the *para* rearrangement proceeds with predominant inversion of configuration.

Besides the acidic intramolecular rearrangement of 1-phenylethyl phenyl ether, the rearrangement products, *i.e.*, *ortho*- and *para*-alkylated phenols may partly stem from the S_N1 phenolysis of reproduced 1-phenylethyl chloride due to the hydrogen chloride cleavage[5] of the 1-phenylethyl phenyl ether. This is a sort of intermolecular course for the rearrangement of 1-phenylethyl phenyl ethers in the acidic phenol solvent, and illustrated in the following scheme, using ^{18}O-labelled phenyl ether.

$$\mathrm{R^{18}OPh + HCl \longrightarrow RCl + Ph^{18}OH}$$
$$\mathrm{RCl + PhOH \longrightarrow}$$
$$\mathrm{ROPh} + o\text{-}\mathrm{RC_6H_4OH} + p\text{-}\mathrm{RC_6H_4OH}$$

In fact, it is known that this ether is cleaved by hydrogen chloride to give partially retained 1-phenylethyl chloride in toluene,[5c] 3-pentanone,[5c] isobutyl alcohol,[5b] benzene,[5b] acetone,[5b] and phenol–dioxane.[5d]

Furthermore, it is also conceivable as another course for the intermolecular rearrangement in the phenolic solvent that the protonated 1-phenylethyl phenyl ether might be phenolyzed, and give intermolecularly the alkylated phenols, as is shown in the following scheme.



$$\mathrm{R^{18}OPh + H^+ (Cl^-) \longrightarrow R^{18}\overset{H}{\overset{|+}{O}}\text{–}Ph}$$
$$\mathrm{R^{18}\overset{H}{\overset{|+}{O}}\text{–}Ph + PhOH \longrightarrow}$$
$$\mathrm{ROPh} + o\text{-}\mathrm{RC_6H_4OH} + p\text{-}\mathrm{RC_6H_4OH} + \mathrm{Ph^{18}OH}$$

In order to estimate the amounts of these intermolecular courses in the acidic rearrangement of 1-phenylethyl phenyl ether, ^{18}O-labelled 1-phenylethyl phenyl ether was subjected to the acidic rearrangement in the presence of *p*-toluenesulfonic acid in the phenol–benzene (1: 1 by wt) solvent at 25 °C. As illustrated in Table 5, it is evident that only 44.9% of *o*-1-phenylethylphenol and 25.7% of *p*-1-phenylethylphenol were intramolecularly produced from the labelled phenyl ether, but the rest of the alkylphenols was produced by the phenolysis of the oxonium ion of the phenyl ether or, less probably, by the phenolysis of 1-phenyl-

TABLE 4. THE PRODUCT COMPOSITIONS AND THE STERIC COURSES FOR THE ACIDIC REARRANGEMENTS OF 1-PHENYLETHYL PHENYL ETHERS (ROAr) IN THE PRESENCE OF HCl IN PHENOL(ArOH)–BENZENE (1: 1 by wt) SOLVENTS[a]

Ar–O–(1-Phenylethyl)		HCl[b]	Product			
			o-Alkylated phenol		*p*-Alkylated phenol	
Ar	α_D[c] M	M	Yield %	$[\alpha]_D$[d] Net steric course, α%	Yield %	$[\alpha]_D$[d] Net steric course, α%
Phenyl[e]	+3.25° (±0.05°) 0.050	0.050	54.8	−0.925° (±0.025°) 47.9 Ret.	39.7	−0.520° (±0.026°) 73.0 Inv.
Phenyl[f]	−6.41° (±0.02°) 0.0968	0.0234	23.4	+2.85° (±0.32°) 74.5 Ret.	75.8	+1.21° (±0.09°) 85.8 Inv.
p-Cresyl[g]	+0.378° (±0.006°) 0.050	0.051	93.5	+0.036° (±0.003°) 10.1 Ret.		—
p-Chlorophenyl[g]	−4.56° (±0.05°) 0.050	0.051	92.2	−0.448° (±0.022°) 4.93 Ret.		—
2,6-Xylyl[h]	−2.86° (±0.01°) 0.050	0.052		—	96.5	−0.012° (±0.002°) 2.86 Inv.

a) The maximum rotations for the relevant optically active compounds in this table are shown in Table 2. b) Determined by titration. c) The rotations for a neat sample at 24—32°C in a 1 dm tube. d) The rotations for a benzene solution (*c* 4.8—73.6) at 22—30 °C. e) At 50 °C for 2 hr. f) At 40 °C for 5 hr (in PhOH–MeCN (1: 1 by wt)). g) At 100 °C for 5 hr. h) At 100 °C for 20 hr.

TABLE 5. ^{18}O CONTENT OF ALKYLPHENOLS PRODUCED BY THE REARRANGEMENT OF 1-PHENYLETHYL PHENYL ETHER-^{18}O IN A PHENOL–BENZENE (1 : 1 by wt) SOLVENT IN THE PRESENCE OF *p*-TOLUENESULFONIC ACID AT 25 °C AT 49% CONVERSION a)

Material	Yield %	^{18}O atom% excess a)	Retention % of ^{18}O atom% excess
ROPh (0.100M)	—	0.863	—
o-RC_6H_4OH	31.3	0.387	44.9
p-RC_6H_4OH	17.7	0.222	25.7

a) TsOH=3.96×10^{-3}M; H_2O=7.8×10^{-3}M; oxygen-18 contents were determined by the method of Rittenberg and Ponticorvo (Ref. 8).

ethyl *p*-toluenesulfonate, produced by the acidic cleavage of the phenyl ether with *p*-toluenesulfonic acid.

In conclusion, in view of these findings mentioned above, the formation of the *ortho*-alkylates with *retained* configuration in the phenolysis without an added base is attributed not to the direct retentive alkylation of the phenols, but to the rapid rearrangement of the 1-phenylethyl ethers with net *retention* of configuration, caused by the hydrogen chloride liberated in the S_N1 phenolysis of 1-phenylethyl chloride in the respective phenolic solvents.

Experimental6)

Materials. *S*-(−)-1-Phenylethyl chloride was prepared by the reaction of *S*-(−)-1-phenylethanol with thionyl chloride in a manner previously described.1) Sodium *p*-substituted phenoxide was prepared by refluxing the toluene solution of *p*-substituted phenol with sodium metal. All the other reagents employed were of an analytical reagent grade and were fractionated just prior to use.

Synthesis of 1-Phenylethyl Phenyl Ether-^{18}O. According to the method of Stevens and Bentel,7) phenol-^{18}O (4.46 g; containing some ether) was prepared by a diazotization of aniline (2.8 g, 0.030 mol) with sodium nitrite (2.1 g, 0.030 mol) in $H_2{}^{18}O$ (^{18}O 3 atom% excess; 15 ml). 1-Phenylethyl phenyl ether-^{18}O (0.66 g; ^{18}O 0.863 atom% excess) was synthesized by refluxing an acetone solution (60 ml) of phenol-^{18}O (4.46 g; containing some ether), 1-phenylethyl chloride (3.3 g, 0.020 mol), and potassium carbonate (4.1 g, 0.030 mol) after the method described by Hart and Eleuterio.9) The ^{18}O content was determined by the method of Rittenberg and Ponticorvo.8)

Rate Measurement. The previous procedure1) was followed. Aliquots (1 ml) were removed at intervals from a reaction mixture (15 ml) placed in a constant-temperature bath. The increase of acid concentrations was followed by titration with standard sodium acetate in acetic acid, using crystal violet as an indicator. In each case, a first-order linear relationship was obtained to *ca.* 20% conversion. Infinity titers were calculated from the weight of the chloride used. These results are summarized in Table 1.

Product Isolation (General Procedure). The vessel, containing a reaction mixture, was placed in a constant-temperature bath; at the desired time the reaction was quenched by cooling and dilution with ether. The mixture was successively washed with 10% aq. NaOH and 10% aq. NaCl, dried with $MgSO_4$, and concentrated. The concentrate was subjected to preparative thin-layer chromatography on silica gel. The detailed procedures are described in representative cases which follow.

1-Phenylethyl Chloride Phenolysis in p-*Cresol in the Presence of Sodium* p-*Cresoxide.* A mixture of 1-phenylethyl chloride (1.500 ml, 0.01136 mol; $\alpha_D^{27.2}$ −34.50±0.05° (neat, 1 dm)) and *p*-cresol (220 ml) containing sodium *p*-cresoxide (0.0541 M: determined by titration) was kept at 100.0±0.1 °C for 5 hr. After the working-up mentioned above, 1-phenylethyl *p*-cresyl ether (0.9601 g, 39.8% yield; bp 160—165 °C/4 mmHg; $\alpha_D^{32.0}$ −0.201±0.013° (neat, 1 dm)) and *o*-(1-phenylethyl)-*p*-cresol (0.3350 g, 13.9% yield; bp 170—175 °C/4 mmHg; $[\alpha]_D^{34.0}$ +1.12±0.074° (*c* 2.016, benzene)) were obtained.

1-Phenylethyl Chloride Phenolysis in p-*Cresol in the Absence of an Added Base.* A mixture of 1-phenylethyl chloride (0.6410 g, 0.00456 mol; $\alpha_D^{27.2}$ −34.5° (neat, 1 dm)) and *p*-cresol (90 ml) was maintained at 100 °C for 5 hr and worked up as mentioned above: *o*-(1-phenylethyl)-*p*-cresol (0.8442 g, 87.3% yield; bp 170—175 °C/4 mmHg; $[\alpha]_D^{32.6}$ +0.118±0.010° (*c* 9.31, benzene)) and 1-phenylethyl *p*-cresyl ether (24.2 mg, 2.50% yield; bp 155—160 °C/4 mmHg; $[\alpha]_D^{34.0}$ +0.431±0.330° (*c* 0.232, benzene)) were obtained.

The Acidic Rearrangement of 1-Phenylethyl p-*Cresyl Ether in* p-*Cresol–Benzene (1: 1 by wt).* A mixture of 1-phenylethyl *p*-cresyl ether (1.0651 g, 0.00502 mol; $\alpha_D^{32.0}$ +1.890±0.030° (neat, 1 dm)) and *p*-cresol–benzene (1: 1 by wt.; 100 ml) containing anhydrous hydrogen chloride (0.0505 M) was kept at 100 °C for 5 hr. After the working-up mentioned above, *o*-(1-phenylethyl)-*p*-cresol (0.9971 g, 93.5% yield; bp 170—177 °C/4 mmHg; $[\alpha]_D^{29.8}$ +0.182±0.051° (*c* 18.5, benzene)) was obtained.

The Acidic Rearrangement of 1-Phenylethyl Phenyl Ether-^{18}O in Phenol–Benzene (1: 1 by wt). A mixture of 1-phenylethyl phenyl ether-^{18}O (0.2911 g; 0.00147 mol; ^{18}O 0.863 atom% excess) and phenol–benzene (1: 1 by wt.; 14.5 ml) containing anhydrous *p*-toluenesulfonic acid (0.00396 M) was kept at 25 °C for 10 min (49% conversion by glc) and worked up in a manner mentioned above. *o*-(1-Phenylethyl)phenol (0.9115 g, 31.3% yield; ^{18}O 0.387 atom% excess) and *p*-(1-phenylethyl)phenol (0.0515 g, 17.7% yield; ^{18}O 0.222 atom% excess) were obtained.

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6) A Hitachi Model 023-6001 gas chromatographic instrument, with a thermocouple detector, a Hitachi Model 215 spectrophotometer, a Hitachi Model R-24 60 MHz NMR instrument, and an Atlas Model CH-4 mass spectrometer were used for analytical works. Optical rotations were measured with a JASCO Model DIP–SL polarimeter.

Each product was identified by the fact that the IR and NMR spectra and the retention time of glc (Apiezon Grease L on Neopak 1A 3 mm$^\phi$ × 2 m column, at 200°) were the same as those of an authentic sample.

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