Anal. Calcd for C₈H₉NO₂: C, 63.6; H, 5.95; N, 9.3. Found: C, 63.0; H, 5.9; N, 9.1.

Isopropylidene Cyclopentylidenemalonate (38).-- A mixture of cyclopentanone (8.4 g), isopropylidene malonate (14.4 g), piperidine (a few drops), and pyridine (5 ml) was kept at 40-50° for 12 hr. The mixture was cooled (-5°) until precipitation was complete, then filtered. The malonate **38**, (12.8 g, 61%) formed colorless needles from petroleum ether: nmr (CCl₄) δ 1.7 [s, 6, (CH₃)₂C], 1.6-2.1 (m, 4, cyclopentane H), and 3.0-3.4 $(m, 4, CH_2C =)$

Anal. Calcd for C11H14O4: C, 62.85; H, 6.7. Found: C, 63.2; H, 6.5.

1-Acetyl-4-(2-Keto-1-carbethoxycyclopentyl)-1,4-dihydroquinoline (47).—Acetyl chloride (2.3 g) was added dropwise to a solution of quinoline (11.6 g) and 2-carbethoxycyclopentanone (4.7 g) in dry benzene (150 ml). A precipitate of quinoline hydrochloride slowly formed; after 3 days at room temperature, the smell of acetyl chloride had disappeared. The quinoline hydrochloride was filtered off, and the precipitate was washed with ether. The combined filtrates were shaken with 2 N HCl (three 50-ml portions) and aqueous Na₂CO₃, dried, and evaporated. Crystallization of the residue from petroleum ether gave colorless cubes of the acetylquinoline 47: mp 138-140°; yield 3.9 g (40%); ir $\nu_{max}^{CCl_4}$ 1750, 1720, 1690, and 1655 cm⁻¹; nmr discussed in the text.

Anal. Calcd for $C_{19}H_{21}NO_4$: C, 69.7; H, 6.45; N, 4.3. Found: C, 70.0; H, 6.55; N, 4.2.

1-Acetyl-2-(2-keto-1-cyanocyclopentyl)-1,2-dihydroquinoline (48) was prepared as described for compound 47 using 2-cyanocyclopentanone; reaction was complete in 1 hr. The crude product in this case was a mixture of liquid and solid. The solid was removed and crystallized to give the acetyl-1,2-dihydroquinoline 48: mp 116-117°; yield 29%; ir $\nu_{max}^{CCl_4}$ 2245, 1752, 1642, and 1656 cm⁻¹; nmr discussed in the text.

Anal. Calcd for C17H18N2O2: C, 72.85; H, 5.75; N, 10.0. Found: C, 72.8; H, 5.55; N, 9.9. After removal of the solid, the filtrate was distilled, giving

some 2-cyanocyclopentanone and 1-acetoxy-2-cyanocyclopen-

tene, 49: bp 70-72° (0.1 mm); yield 35%; ir $\nu_{\text{max}}^{\text{film}}$ 2228, 1780, and 1660 cm⁻¹; nmr (CCl₄) δ 2.22 (s, 3, OCOCH₈), 1.8-2.2 (m, 2), and 2.3-2.8 (m, 4).

Anal. Calcd for $C_8H_9NO_2$: C, 63.55; H, 6.0; N, 9.25. Found: C, 63.8; H, 5.8; N, 9.6.

The enol acetates listed in Table II were similarly prepared from the appropriate acyl chlorides; no other dihydroquinolines were isolated.

Registry 3	No.— 2,	21372-65	-6; 2 (HCl), 1	21372-(36-7;
4, 21369-00-	6; 5 , 2	1369-01-7	; 5 (HC	l), 213	69-02- 8	3; 6 ,
21369-03-9;	7, 2859	-27-0; 8,	2859-28	-1; 9 , 1	21369-0)6-2;
11, 5100-57	- 2; 12 ,	21369-08	3 - 4; 13 ,	21369	9-09-5;	14,
21369-10-8;	15, 2	21369-11-9); 16,	21369	-12-0;	17,
21369-13-1;	18, 2	21369-14-2	2; 19,	21369	-15-3;	20,
21369-16-4;	21, 2	21369-17-8	5; 22,	21369	-18-6;	23,
21369-19-7;	25, 2	21369-20-0); 26,	21369	-21-1;	27,
21369-22-2;	28, 2	21389-70-8	3; 29 ,	21369	-23-3;	30,
21369-24-4;	31,	21615-81-	6; 35 ,	5660-	-83-3;	37,
21369-27-7;	38,	3968-30-7	; 40 ,	21369-	29-9;	42,
21369-30-2;	43, 2	21369-31-3	3; 44,	21369	-32-4;	45,
21369-33-5;	47, 2	21369-34-6	3; 48 ,	21369	-35-7;	49,
21369-36-8;	50 , 2	21369-37-9); 51,	21369	-38-0;	52,
21369-39-1;	53, 213	69-40-4;	quinald	inic aci	d N-oz	xide,
3297-64-1;	cyclope	entylidene	cyanoad	cetic a	cid, 21	369-
4 2-6 .		-	-			

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Oxygenation of Aromatic Compounds with Diisopropyl Peroxydicarbonate-Cupric Chloride¹

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The direct synthesis of aryl isopropyl carbonates from a wide variety of aromatic substrates has been accomplished with the diisopropyl peroxydicarbonate-aromatic-cupric chloride system in acetonitrile at 60°. The orientation and relative rate data lend further support to the hypothesis that substitution is effected by a radical entity possessing appreciable electrophilic character. A Hammett-Brown treatment yielded a ρ value of -2.3. Several reaction parameters were investigated, including photolytic conditions and variation in the amount of aromatic substrate.

The direct introduction of oxygen into the aromatic nucleus has been effected by an electrophilic pathway resulting from heterolytic cleavage^{3a,4} or by radical attack via homolytic fission.^{5a} In the former category, Lewis acids are frequently employed as catalysts in conjunction with hydrogen peroxide,⁶ peroxy acids,⁷

(1) Aromtic Oxygenation. IX.

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diaroyl peroxides,⁸ and peroxydicarbonates,⁹ while hydroxylation with Fenton reagent¹⁰ and benzoyloxylation with benzoyl peroxide^{5a,11} are illustrations of the radical type. Also, the production of benzoate esters in the aromatic-benzoyl peroxide-iodine system has been described by Perret and Perrot.¹²

Recently, reports^{13,14} from this laboratory showed that aromatic oxygenation could be realized in high yield with diisopropyl peroxydicarbonate and small amounts of cupric chloride. The stoichiometry of the

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reaction is presented in eq 1, and the proposed mechanism is shown in eq 2–5.

$$(i-\operatorname{PrOCO}_2)_2 + \operatorname{ArH} \xrightarrow{\operatorname{Oucl}_2} \operatorname{ArOCO}_2\operatorname{Pr} \cdot i + \operatorname{CO}_2 + i - \operatorname{PrOH} (1)$$

$$(i-\operatorname{PrOCO}_2)_2 \longrightarrow 2 \ i-\operatorname{PrOCO}_2$$

i-PrOCO₂· + ArH + CuCl₂ -

$$ArOCO_2Pr-i + HCl + CuCl$$
 (3)

(2)

$$(i - \text{PrOCO}_2)_2 + \text{CuCl} \longrightarrow i - \text{PrOCO}_2 + \text{CuClOCO}_2 \text{Pr-}i$$
 (4)
I

$$I + HCl \longrightarrow CuCl_2 + CO_2 + i - PrOH$$
(5)

Two possiblities have been advanced for the aromatic substitution process (eq 3): oxidation of the isopropoxycarboxy radical with subsequent electrophilic attack (eq 6), or homolytic aromatic substitution by

$$i \operatorname{PrOCO}_{2^{\bullet}} \longrightarrow i \operatorname{PrOCO}_{2^{+}} \xrightarrow{\mathbb{C}_{6}H_{6}}$$

 $i \operatorname{PrOCO}_{2^{-}} \xrightarrow{\mathbb{C}_{6}H_{6}} i \operatorname{PrOCO}_{2}\mathbb{C}_{6}H_{5}$ (6)

the oxy radical entailing oxidation of a radical σ complex by cupric chloride (eq 7). Various lines of evidence

$$i$$
-PrOCO₂· $\xrightarrow{C_6H_6}$ i -PrOCO₂· $\underbrace{\bigcirc}$ $\underbrace{CuCl_2}$

$$i$$
-PrOCO₂C₆H₅ + HCl + CuCl (7)

indicate that the former pathway is unlikely.^{14,15} The preceding studies with a limited number of aromatic reactants revealed that the peroxydicarbonate-cupric chloride combination affords a simple, one-step method for preparation of the oxygenated aromatic derivative in high yield, and with less interference from competing side reactions in comparison with prior procedures involving peroxides.

It is the purpose of this paper to present results pertaining to the scope and utility of this novel process, and also to provide additional information bearing on the theoretical aspects. Studies were made with a variety of aromatic substrates, and the significance of the orientations and relative rates is treated. Investigation of some additional reaction parameters was also carried out.

Results and Discussion

In general, the reactions were performed in acetonitrile solvent at 60° with aromatic reactant-diisopropyl peroxydicarbonate (IPP)-cupric chloride in a 17.3:1: 0.3 molar ratio. Results from the aromatic substrates, representing various degrees of reactivity in the benzene series, are presented in Table I. The oxygenated products were obtained as the aryl isopropyl carbonate esters which were identified by elemental analysis and comparison with authentic materials. Near-quantitative yields were realized with mesitylene and *m*-xylene, with a steady decrease in proceeding from alkyl- to the halobenzenes, and terminating in little or no oxygenation with the more strongly deactivated types. These findings lend further credence to the thesis that nuclear attack is being effected by a radical possessing pronounced electrophilic character.

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This hypothesis is also consistent with the isomer distributions, (ortho + para) > meta, and $\alpha > \beta$. For example, the orientation with toluene is, for the most part, a compromise of the values reported for homolytic phenylation (ortho/meta/para, 67:19:14)¹⁶ and electrophilic chlorination (ortho/meta/para, 60:1:40).¹⁷ Oxygenation of naphthalene exhibits a pronounced degree of selectivity $(\alpha/\beta, 92:8)$, greater than is found in free-radical phenylation $(\alpha/\beta, 82:18)$,^{5b} or hydroxylation $(\alpha/\beta, 80:20)$.^{5c} The observed ratio, in fact, more closely resembles that found in electrophilic sulfonation at low temperatures $(\alpha/\beta, 96:4)$.¹⁸ Similarly, *m*-xylene yields a relatively large proportion of the 2,6 product in oxygenation, whereas phenylation reportedly affords only the 2,4 isomer.¹⁹ It should be recognized that the arylation work was done before the availability of modern analytical techniques. On the other hand, the 2,4/2,6 ratio for nitration²⁰ and chlorination²¹ is 86:14 and 77:23, respectively. Also, oxygenation (ortho/meta/para, 47:4:49) of biphenyl approximates nitration with nitric acid (ortho/para, 53:47)^{3b} more closely in orientation than phenylation (ortho/meta/ para, 48:23:29).²² Of course, differences in the steric factor associated with the attacking entity should be taken into account in interpretation of the various data.

In analysis of the isomer distributions for the activated aromatic reagents, although one sees definite evidence of electrophilicity associated with the oxygenating entity, there is no clear-cut indication of radical character. Fortunately, however, information for the deactivated substrates from our own work and prior studies^{16,17,23,24a,b} plays a complementary role in illustrating the dual nature of the attacking species. The homolytic reactions (phenylation, oxygenation, and cyclohexylation) of benzotrifluoride exhibit a meta/ (ortho + para) ratio of approximately 1, whereas the ratio increases to 4 in electrophilic chlorination. In like fashion, acetophenone yields a relatively low amount of *meta* isomer in oxygenation (*ortho/meta/para*, 50:33:17) in comparison with nitration (ortho/meta, \sim 30:68).^{24c} Attempted phenylation did not meet with success. A similar appreciable difference is evident from comparison of oxygenation, phenylation, and cyclohexylation with nitration and chlorination of fluorobenzene. The trend is maintained with benzonitrile and methyl benzoate, although we were unable

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		······································	Products, %b		
Aromatic substrate ^c	Yield. %	Orientation. (%)	opropyl carbonates	Mp or bp ^{d,e} (mm), °C	Other ^f
Toluene	85	ortho (57)	21333-52-8	81-84 (2.5)	69
	00	meta (15)	21333-53-9	94-97(11)	v
		para (28)	21333-54-0	94 (1.5)	
<i>p</i> -Xylene	78	2.5	21333-55-1	94-95(2)	114
<i>m</i> -Xylene	~100	2.4(65)	21333-56-2	93-94(2)	3
	100	2.6(33)	21333-57-3	90-91(1.4)	Ŭ
		3.5(2)	-1000 01 0		
Mesitylene	98		21333-58-4	86-89(0.6)	71
Cumene	68	ortho (48)	21333-59-5	89-91 (1)	2*
		meta (16)	21333-60-8	96-98(1)	-
		para (36)	21371-66-4	101-104(1)	
Biphenvl	86	ortho (47)	21333-61-9	123-125(1)	
L V		meta (4)	21333-62-0	142 - 144(1)	
		para (49)	21333-63-1	97-99	
Naphthalene	89	α (92)	21333-64-2	130-131 (1)	
•		β (8)	21333-65-3	63-65	
Fluorobenzene	30	ortho (33)	21333-66-4	105 - 107(4)	
		meta (22)	21333-67-5	85-89 (15)	
		para (45)	21333-68-6	41-45	
Chlorobenzene	29	ortho (54)	21333-69-7	120-121(3)	
		meta (13)	21333-70-0	91-97 (1)	
		para (33)	5335-19-3	117 - 119(4)	
Acetophenone	27	ortho (50)	21333-71-1	115-117 (1)	2^l
•		meta (33)	21333-72-2	123-125 (1)	
		para(17)	21333-73-3	44-46	
Phenyl isopropyl		• • •			
carbonate	17	ortho (47)	7504-92-5	127 - 131(1)	
		meta (16)	7504-71-4	140-143(1)	
		para (37)	21333-75-5	140-142	
Benzotrifluoride	2	ortho (47)	21333-76-6	65-67 (1)	1 **
		meta (51)	21333-77-7	67-68 (1)	
		para(2)	21333-78-8	75-76 (1)	

		TABLE 1		
Oxygenation of A	AROMATIC COMPOUNDS	WITH DIISOPROPYL	PEROXYDICARBONATE-CUPRIC	Chloride ^a

^a Aromatic-peroxide-CuCl₂, 13.6-21.6:1:0.3, 60°, 2 hr, acetonitrile solvent; see general procedure. ^b See Experimental Section for yield basis. ^c Methyl benzoate, benzonitrile, and nitrobenzene did not react. ^d Synthetic samples. ^e Elemental analyses were within $\pm 0.3\%$ of the calculated values. ^d Aromatic materials. ^e Benzyl chloride, 5%, bibenzyl and benzaldehyde, 1% each. ^h Two unknown products, 9 and 2%. ⁱ Two unknown products, 1 and 2%. ⁱ Two unknown products, 5 and 2%. ^kt-Cumyl chloride. ^l Phenacyl chloride. ^m Unknown.

to bring about the oxygenation of these species. As the deactivation decreases, as in the case of chlorobenzene, classification of the oxygenating species becomes more uncertain.

Other aspects of the orientation picture should be considered. Several possible interpretations of the high ortho/para ratio for acetophenone and benzotrifluoride come to mind. With acetophenone, coordination effects (cyclic or linear), similar to those reported by various investigators,²⁵ may be operative, possibly in conjunction with enhanced *para* deactivation,²⁶ to give the high *ortho/para* ratio in oxygenation (structure 1).



Chlorobenzene provided a greater ortho/para ratio in oxygenation than did fluorobenzene, the situation

generally observed in electrophilic substitution.^{3c} The relatively large amount of *meta* isomer from fluorobenzene (*cf.* chlorobenzene) can be construed as evidence for a secondary relay of the resonance effect, acting to offset the strong inductive influence of the substituent.^{3d}

Although the α hydrogen in cumene is generally more susceptible to radical abstraction than that of toluene,²⁷ only 2% *t*-cumyl chloride was detected, whereas toluene yielded benzyl chloride in 5% yield. Furthermore, bicumyl was not detected in the cumene reaction mixture. These data might be construed as evidence for operation of a steric factor. It should also be noted that alkoxycarboxy radicals are not highly prone (less so than alkoxy radicals) to participate in hydrogentransfer ractions.¹⁴

Relative Rates.—In an effort to characterize the attacking species more fully, relative rate studies were carried out with a number of aromatic compounds in the standard oxygenation system (Table II). The substrates employed (fluoro- and chlorobenzene, biphenyl, and phenyl isopropyl carbonate) displayed rates of 0.3 to 11 times that of benzene. Reasonably good agreement was realized at various ratios of the two

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	Relative H	RATE DATA FO	OR OXYGENATION WIT	н					
DIISOPROPYL PEROXYDICARBONATE-CUPRIC CHLORIDE ⁴									
Ar'H	ArH	Ar'H/ ArH M	[Ar'OCO2Pr-i]/ [ArOCO2Pr-i] ^b	kAr'H/ kArH	Average rel rate				
Fluorobenzene	Benzene	1.90	0.592	0.311	0.311 ± 0.002				
Chlorobenzene	Benzene	2.20	0.969	0.440					
					0.459 ± 0.019				
Chlorobenzene	Benzene	4.38	2.10	0.478					
Biphenyl	Benzene	1.00	11.86	11.86					
					11.45 ± 0.40				
Biphenyl	Benzene	0.50	5.50	11.00					
Phenyl isopropyl									
carbonate	Chlorobenzene	1.00	0.740	0.74	0.74 ± 0.20				

TABLE II

 $\begin{array}{ccc} \text{Phenyl isopropyl} \\ \text{carbonate} & \text{Chlorobenzene} & 1.00 & 0.740 & 0.74^c & 0.74 \pm 0.20 \\ \end{tabular} & \text{Total aromatic-peroxide-CuCl}_2, 30-81:1:0.3, 60^\circ, 2 \text{ hr, acetonitrile solvent; see experimental procedure. } because is the average of two or more runs in close agreement. } \end{tabular} & \en$

TABLE III
Relative Reactivities (k) and Partial Rate Factors (f)
FOR HOMOLYTIC AROMATIC SUBSTITUTION

Oxygenation ^a								-Cyclohe	Cyclohexylation ^c			
Aromatic	k^{d}	fortho	Imeta	Ipara	k^{d}	for tho	<i>fmeta</i>	k _{para}	kď	fortho	Imeta	Ípara
C ₆ H ₅ OCH ₃	24.9*	47.1	0.60	53.8	1.7/	3.6	0.93	1.3'	2.3	4.6	1.9	0.69
C ₆ H ₅ CH ₃	3.8	6.4	1.7	6.3	1.2	2.5	0.71	1.0	0.76	0.73	0.98	1.1
C_6H_5F	0.31	0.31	0.21	0.84	1.0	1.7	0.95	0.86	1.9	3.6	2.0	0.47
C_6H_5Cl	0.46	0.74	0.18	0.91	1.1	1.6	1.0	1.2	3.5	5.6	3.5	2.5

^a Reaction temperature, 60°, acetonitrile solvent. ^b D. H. Hey, S. Orman, and G. H. Williams, J. Chem. Soc., 565 (1961), except where noted. ^c Reference 23a. ^d Relative to benzene. ^e Reference 15. ^f T. Inukai, K. Kobayashi, and O. Simamura, Bull. Chem. Soc. Jap., 35, 1576 (1962).

competitors, indicating the validity of the treatment. Although the data for phenyl isopropyl carbonate/ benzene could not be obtained directly, the product of $k_{\text{phenyl isopropyl carbonate}/k_{\text{chlorobenzene}} \times k_{\text{chlorobenzene}}/k_{\text{benzene}}$ was found to be 0.32. Hence, the competition experiments rationalize the absence of di- or polyoxygenated material which are commonly produced with other systems, such as Fenton reagent. The relative rates, which are in accord with earlier studies,^{13,15,28} point up the electrophilic character of the attacking radical.

 $k_{\text{chlorobenzene}} \times k_{\text{chlorobenzene}}/k_{\text{benzene}}$; see Experimental Section.

Having obtained the relative reactivities (k) of fluorobenzene and chlorobenzene and using the values reported¹⁵ for toluene and anisole, we then calculated (Table III) the partial rate factors (f) employing the data in Table I. The corresponding figures for cyclohexylation and phenylation are included for comparison. Whereas the spread for k in phenylation occupies a narrow range since the phenyl radical is relatively insensitive to the nature of the substituent, the figures^{23a} for cyclohexylation, involving a nucleophilic radical, vary by a factor of approximately 5. On the other hand, the values for oxygenation vary by a factor of 50, and, quite significantly, generally in a direction opposite that of the cyclohexyl radical. Thus, for these homolytic aromatic substitution reactions, the order of decreasing electrophilicity is oxygenation >phenylation > cyclohexvlation.

The partial rate factors for *meta* and *para* oxygenation may be correlated with the available σ^+ -substituent parameters²⁹ according to the Hammett-Brown relationship, as illustrated in Figure 1. The straight line which best fits these points has a slope of -2.27 with a deviation of 0.03. The *p*-fluoro and *m*-methoxy data

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Figure 1.—Hammett-Brown correlation for aromatic oxygenation with diisopropyl peroxydicarbonate-cupric chloride.

present the greatest difficulties for a more ideal accommodation. Certain other homolytic reactions, such as the formation of substituted benzylic radicals by abstraction of hydrogen by chlorine⁸⁰ and bromine atoms⁸¹ and trichloromethyl radicals³² give better

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			VARIATION IN A	IOLAR RATIO ^a			
ArH,	CuCl2,	Time,	Temp,	~~~ <u>~</u>		carbonates — —	
М	М	hr	°C	Yield, % ^b	Orientation		
			Naphtl	nalene			
20	0.4	2	60	89			
20	0.3	2	60	90			
10	1	22	25	86			
1	1	22	25	52			
1	0.3	22	25	48			
1	0¢	22	25	6			
1	1	4.5	25	54			
1	0.3	4.5	25	42			
			Biphe	enyl			
					ortho	meta	para
20	0.3	2	60	86	47	4	49
1	1	22	25	26	52	4	44
1	0°	22	25	0			
			Tolu	ene			
20	0.3	2	60	85^d	57	15	28
1	1	22	25	15	64	13	23
1	0.3	22	25	11°	64	13	23
1	0°	22	25	0			

TABLE IV							
VARIATION I	NМ	OLAR	RATIO				

^a Diisopropyl peroxydicarbonate, 1 mol; see general procedure. ^b See Experimental Section for yield basis. ^c Control reaction. ^d Benzyl chloride, 5%; benzaldehyde, 1%. ^e Benzyl chloride, 4%; benzaldehyde, 2%.

Hammett correlations with σ^+ values. Howard and Ingold,³³ in discussing the difference between σ and σ^+ in radical reactions, suggest that radicals with an appreciable electron affinity would be expected to follow σ^+ rather than σ values. It is equally significant that a negative ρ value is observed, similar to those for the trichloromethyl³² (-1.46) and hydroxyl³⁴ (-0.41, σ values) radicals, and in contrast to the figures for phenylation (+0.05, σ values)³⁵ and cyclohexylation (+1.1, σ values).^{23a}

Reaction Variables .-- During the course of prior investigations of the oxygenation system a number of reaction variables, such as, alteration in the catalyst/ peroxide and the toluene/peroxide ratios, the effect of additives, and changes in the temperature and solvent, were examined.¹⁴ In continuation, the effect of variation in reaction time was investigated. The yields and orientation in the toluene reactions did not vary appreciably for the 1-4-hr reaction span. However, the chlorobenzene and acetophenone reactions showed a significant variation in yield, and minor, unexplained fluctuations in the isomer distributions. Whereas incomplete reaction resulted from short reaction times, the decrease in yield for the longer periods may be due to the loss of product esters through subsequent interaction with species present in the system.

Earlier work revealed that a large excess of toluene was required for the optimum yield of tolyl isopropyl carbonates.¹⁴ This constitutes a handicap in the case of relatively inaccessible aromatic substrates. Bose³⁶ recently found that anisole could be oxygenated in resonable yield using stoichiometric amounts of the aromatic starting material (anisole-IPP-CuCl₂, 1:1:1, M), lower temperatures, and extended reaction times.

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(35) R. Ito, T. Migita, N. Morikawa, and O. Simamura, Tetrahedron, 21,

We decided to pursue this lead with several aromatic hydrocarbons of graduated activities (naphthalene, biphenyl, and toluene) (Table IV). A study of several variables revealed that the naphthalene reaction proceeded in reasonable yields (42-54%) at 25° with a 1:1 ratio of hydrocarbon/peroxide in the presence of cupric chloride. The isomer distribution remained unchanged. The adverse effect of thermal decarboxylation of the isopropoxycarboxy radicals is minimized by operating at lower temperatures. Under identical reaction conditions at 25° with the decreased level of aromatic substrate, the yield order was, naphthalene >biphenyl > toluene. Thus, substitution can occur to an acceptable degree with stoichiometric amounts of the aromatic component, but only when it possesses appreciable activity.

Photolytic conditions were also employed with the aim of (1) obtaining further mechanistic insight, (2) utilizing both fragments of the peroxide for oxygenation, and (3) checking a pertinent literature report.²³ The results with both diisopropyl peroxydicarbonate and benzoyl peroxide in the presence of toluene are recorded in Table V. With radiation supplied by a GE H100-A14 mercury vapor lamp, the peroxydicarbonate runs were made at 4° to avoid the competing thermal reaction, and the benzoyl peroxide reactions were at 23°. Selection of reaction times was based upon information from related studies.²⁸

In the presence of cupric chloride, toluene afforded a 26% yield of tolyl isopropyl carbonates with an orientation similar to that observed in the thermal reactions (ortho/meta/para, 65:12:23). In a control reaction with cupric chloride in the dark, no appreciable decomposition of the peroxide occurred. In the absence of oxidant, products were obtained which can be rationalized¹⁴ on the basis of decarboxylation of the isopropoxycarboxy radical followed by abstraction of side-chain hydrogen. In the toluene-cupric chloride system, benzoyl peroxide gave tolyl benzoates in 27% yield with an isomer distribution of *ortho/meta/para* of 58:15:27 which compares favorably with the data

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⁽³⁶⁾ A. K. Bose, personal communication; we wish to thank Professor Bose for making available his unpublished results.

	TABLE V	
PHOTOLYTIC	OTVGENATION	OF TOLUENE

			Time,	Temp,	Peroxide	Products	%					
Peroxide	Oxidant	Solvent	hr	°C	decomp, %	Aryl ester	Other					
IPP	None	$CH_{3}CN$	10	4	20	1	a					
IPP	None	CH₃CN	32	4	48	1						
\mathbf{IPP}	$CuCl_2$	CH₃CN	10	4	50	26	2^b					
$(BzO)_2$	CuCl_2	CH₃CN	52	23	52	27	2°					
$(BzO)_2$	CuCl_2	None ^d	52	23	46	0						
$(BzO)_2$	O_2	None	52	23	50	18	8°					
^a Benzaldehy	yde, 2% ; bibenzyl,	3%; benzyl isopr	opyl carbonate,	1%; unknown,	1%. • Benzyl	chloride. ^c Phenyl	benzoate-					

^a Benzaldehyde, 2%; bibenzyl, 3%; benzyl isopropyl carbonate, 1%; unknown, 1%. ^o Benzyl chloride. ^c Phenyl benzoate-^d Heterogeneous.

previously recorded³⁷ for thermal conditions (*ortho*/ *meta/para*, 56:18:26). When cupric chloride was replaced by oxygen (neat conditions), the yield decreased as expected for the less effective oxidant, but no significant change in orientation was noted (*ortho*/ *meta/para*, 55:13:32). Phenyl benzoate is believed to arise from a cage effect.²⁸

Hence, oxygenation can be effected under photolytic conditions which further substantiates a homolytic reaction pathway.¹⁴ However, this method was found to be not so efficient or convenient as the thermal process. Several attempts were made to increase the yield by employing lamps of greater intensity and of other wavelengths without success.

In 1967, Nakata, Tokumaru, and Simamura²⁸ reported the photolytic benzoyloxylation of aromatic substrates in fair to good yield in the presence of oxygen. They proposed reversible attack on the aromatic nucleus by the benzoyloxy radical, followed by rearomatization of the cyclohexadienyl radical. However, these workers recorded an isomer distribution of ortho/meta/para of 47:35:18 for toluene, which disagrees with our findings. It should be noted that the light sources in the two studies were not identical.

Experimental Section³⁸

Materials.—Fluorobenzene was distilled through a 3-ft spinning-band column before use. All other aromatic reactants and acetonitrile, of high purity according to glpc, were used directly. Cupric chloride, about 90% pure (Fisher), was used without further purification. We are grateful to the Pittsburgh Plate Glass Co. for generous samples of diisopropyl peroxydicarbonate.

Aromatic Oxygenation. Standard Procedure. 1. At 60° .— The standard procedure is described elsewhere.¹⁴ In general, a solution of diisopropyl peroxydicarbonate (0.5 M) in acetonitrile was added to the aromatic-acetonitrile-cupric chloride solution; in some instances, however, a 0.5 M peroxide solution in the aromatic reactant was added to the catalyst-solvent solution. With toluene, this variation in the method of peroxide addition produced no noticeable change in yield or orientation. With naphthalene and biphenyl, quenching with hydrochloric acid-ice caused precipitation of the residual aromatic component. In these cases, a small quantity of benzene was added to dissolve the precipitate, and the washings were then performed as usual. The final solution was diluted in a volumetric flask (100 or 250 ml) and dried over sodium sulfate.

Variation in reaction times gave the following results with chlorobenzene and acetophenone (R in RC_6H_6 —time, hour; yield, %; ortho/metal/para ratio): Cl—1, 2, 4; 19, 29, 20; 59:12:29, 54:13:33, 60:11:29; COCH₃—1, 2, 4; 17, 27, 21; 55:30:15, 50:33:17, 56:26:18.

2. At Room Temperature.—Cupric chloride (3-10 mmol) was weighed quickly and dissolved in acetonitrile (130-250 ml)

with heat and stirring. Occasionally, additional solvent was introduced to obtain a homogeneous solution. The aromatic reactant (0.01-0.03 mol) was added, and the solution was cooled to room temperature. The peroxide solution (0.05 M) in acetonitrile (10-60 ml) was pipetted into the stirred solution, and the flask was lightly stoppered. At the end of reaction the standard work-up procedure was followed.

Iodometric analysis was carried out in some experiments to determine the completeness of peroxide decomposition. Unless otherwise noted, product yields are based on the stoichiometry of 1 mol/mol of peroxide and comprise the average of two or more runs which were in satisfactory agreement. These same procedures were followed in the control runs without catalyst.

Photolytic Reactions. 1. Diisopropyl Peroxydicarbonate. Cupric chloride (0.4 g, 0.003 mol) was weighed quickly and dissolved in acetonitrile (200 ml) with heating and stirring. After addition of toluene (17.3 g, 20 ml, 0.188 mol), the solution was placed in a 300-ml Pyrex reaction vessel equipped with a con-denser and a water-jacketed immersion well. By packing the vessel in ice in a dewar flask and by circulating ice water through the jacketed well, the solution was cooled to 4°. Diisopropyl peroxydicarbonate (20 ml, 0.5 M, 0.01 mol) was then added in one portion, and a GE H100-A14 mercury vapor lamp was inserted in the immersion well. In some cases the reaction was followed by gas evolution and/or iodometry. After the allotted reaction time, the lamp was removed and the solution quenched with hydrochloric acid (75 ml) and ice (200 g). Following the separation of layers, the organic portion was washed twice with saturated sodium carbonate solution (100 ml each time) and water (100 ml). The resultant reaction mixture was dried over sodium sulfate.

2. Benzoyl Peroxide.—Cupric chloride (0.4 g, 0.003 mol) was weighed quickly and dissolved in acetonitrile (200 ml) with heat and stirring. After toluene (17.3 g, 20 ml, 0.188 mol) was added, the solution was placed in the Pyrex reaction vessel described in 1. A solution of benzoyl peroxide (2.42 g, 0.01 mol) in 30 ml of acetonitrile was then added to the reaction mixture. In the reactions without solvent, the peroxide was dissolved in the aromatic substrate and placed in a Pyrex reaction vessel equipped with a condenser, thermometer, and gas frit for the introduction of oxygen.

Upon completion of the reaction, those experiments carried out in acetonitrile were treated as in the peroxydicarbonate reactions, while the mixtures from the neat systems were concentrated to approximately 50 ml by evaporation of the solvent under reduced pressure. The residual solution was then diluted to a known volume in a volumetric flask, and the product analysis was performed as in the thermal reactions of naphthalene and biphenyl.

Competitive Oxygenation.—Cupric chloride (1.5-3 mmol) was dissolved in acetonitrile (130 ml), the aromatic reactants were added, and the resultant solution was brought to 60° under a nitrogen stream as in the general procedure.¹⁴ Disopropyl peroxydicarbonate (5-10 mmol total) in acetonitrile (0.5 M) was then added in one portion. The molar ratio of total aromaticperoxide-catalyst was 30-81:1:0.3 with a reaction time of 2 hr following peroxide addition. After quenching and work-up, the carbonate esters were analyzed by glpc. Duplicate runs were performed in each competition. Numerous attempts were made to verify the phenyl isopropyl carbonate-chlorobenzene relative rate by varying the molar ratio of the competitors without success.

Product Identification.—A portion of the organic solution after work-up was concentrated by removal of most of the aromatic substrate under reduced pressure. The various products

⁽³⁷⁾ M. E. Kurz and P. Kovacic, J. Org. Chem., 33, 1950 (1968).

⁽³⁸⁾ Elemental analyses were performed by Galbraith Laboratories Knoxville, Tenn. Boiling points and melting points are uncorrected.

were then separated and collected by glpc. Comparison with authentic materials (infrared spectrum and glpc retention time) was used for the characterization of the isopropyl carbonate esters, benzyl chloride, and benzaldehyde. t-Cumyl chloride and phenacyl chloride, which could not be collected, were identified on the basis of glpc retention time with an aliquot from the original reaction mixture.

Authentic Materials .- The products, with certain exceptions, were commercially available. p-Hydroxybenzotrifluoride was prepared from diazotized p-aminobenzotrifluoride.^{39,40} The carbonate esters, synthesized from the phenolic compounds by adaptation of a literature procedure,⁴¹ were identified on the basis of the infrared spectrum (μ) (strong C=O absorption, 5.6-5.75; strong C=O absorption, 7.8-8.2; and the aromatic substitution pattern, 12-14.5) and elemental analysis. The remaining carbonate esters are reported elsewhere.13-15

Analytical Procedures. A. Gas Chromatography.-An Aerograph Hy-Fi 600C gas chromatograph and a homemade unit were used: copper column; block temperature, 250°; injector temperature, 280°; bridge current, 195 mA; sample size, 5-30 μ l, with the appropriate attenuations for the homemade unit; and block temperature, 200°; hydrogen flow, 20-25 ml/min; sample size, $0.5-1.0 \ \mu$ l, with the appropriate attentuations for the Hy-Fi unit. The indicated columns were used: (1) 10 ft by 0.25 in, 20% silicone fluid (SF-96) on acid-washed Chromosorb P (30-60 mesh), He flow, 75 ml/min; (2) 6 ft by 0.25 in, 15% silicone grease (SE-52) on acid-washed Chromosorb P (30-60 mesh), He flow, 60 ml/min; (3) 10 ft by 0.13 in, 5% Carbowax 6000 on Chromosorb W (60-80 mesh), N₂ flow, 20 ml/min; (4) 10 ft by 0.13 in, 10% Apiezon L on Chromosorb P (60-80 mesh), N₂ flow, 20 ml/min.

B. For Peroxides .-- An iodometric method was taken from the literature.42

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C. For Product Yields.-The yields of the carbonate esters and aromatic by-products were determined by glpc according to the method of internal standards (1,2,4-trichlorobenzene or phenyl isopropyl carbonate in most cases, the exceptions being o-dichlorobenzene for benzotrifluoride, bibenzyl for naphthalene, 4-bromobiphenyl for biphenyl, diphenyl ether for acetophenone, triisopropylbenzene for cumene, and p-cumyl isopropyl carbonate for phenyl isopropyl carbonate). Glpc column 1 at 145-170° was used for most of the analyses, except with the naphthalene, biphenyl, and phenyl isopropyl carbonate reactions (column 2). The reaction mixtures after work-up were analyzed directly by 1:1 addition of the marker solution in the appropriate aromatic component. In the case of naphthalene and biphenyl, a 25-ml sample was withdrawn from the diluted solution and concentrated to approximately 5 ml. After the marker was weighed into the solution, the yield was ascertained. The molar ratio of products was determined by comparing the respective area ratios with plots of area vs. mole ratios for known mixtures of the products. In several instances, two or more analyses were made on the same reaction mixture with excellent reproducibility.

D. For Isomer Distributions.—In most cases, glpc column 1 served in providing the isomer distributions. Column 3 was used for the toluene and benzotrifluoride reactions, while column 4 gave the orientation for the chloro- and fluorobenzene systems. Analyses were performed as described for the product yields with plots of peak area vs. concentration ratio.

E. For Competitive Oxygenations.-Glpc column 1 was used predominantly, whereas column 2 was employed for the biphenyl and phenyl isopropyl carbonate relative rates, and column 4 for the fluorobenzene vs. benzene runs.

Registry No.-Diisopropyl peroxydicarbonate, 105-64-6; cupric chloride, 7447-39-4.

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The Fate of Oxygen-18 in Oxygenation of p-Xylene with Benzovl Peroxide-carbonyl-¹⁸O and Copper Chloride¹

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Benzoyl peroxide, labeled with oxygen-18 in the carbonyl oxygens, was allowed to react with p-xylene in the presence of Cu(II) and Cu(I) chlorides in acetonitrile. The resultant *p*-xylenyl benzoate, on treatment with hydrazine, yielded 2,5-dimethylphenol and benzoyl hydrazide, each of which contained essentially 50% of the original oxygen-18 on the basis of mass spectral analysis. We conclude that oxygenation entails attack by a benzoyloxy radical containing equivalent oxygens through scrambling.

Recent reports³⁻⁶ from this laboratory have presented a method for aromatic oxygenation by means of certain types of peroxides and cupric chloride in acetonitrile. It was postulated that the mechanism involves an oxygen radical possessing electrophilic character. Although some features of the substitution process have been delineated, further information was desired concerning the precise nature of the attacking species, particularly since appreciable variations in

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orientation were observed with alteration in the metal salt or solvent for the free radical system.³⁻⁵ Therefore, isotopic studies were undertaken with labeled peroxide. Owing to the ease of $obtaining^{7-10}$ benzoyl peroxide with the carbonyl-18O tag, and since oxygenation has been accomplished with benzoyl peroxidecupric chloride,¹¹ this peroxide was selected rather than the more thoroughly studied diisopropyl peroxydicarbonate.

Generally, two methods of analysis are available for determination of oxygen-18 in organic compounds,

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